The potential contribution of bread buns fortified with β-carotene–rich sweet potato in Central Mozambique

Jan W. Low and Paul J. van Jaarsveld

Abstract

Background. *Orange-fleshed sweet potato is an efficacious source of vitamin A. Substituting wheat flour with orange-fleshed sweet potato in processed products could reduce foreign exchange outlays, create new markets for producers, and result in increased vitamin A consumption among consumers provided there is adequate retention of β-carotene during processing.*

Objective. *To explore whether substituting 38% of wheat flour (by weight) in bread buns ("golden bread") with boiled and mashed orange-fleshed sweet potato from fresh roots or rehydrated chips would produce economically viable β-carotene–rich products acceptable to Mozambican rural consumers.*

Methods. *Modified local recipes maximized sweet potato content within the limits of consumer acceptability. Sensitivity analysis determined parameters underlying economic viability. Two samples each of buns from five varieties of orange-fleshed sweet potato were analyzed for β-carotene content. Processed products with at least 15 μg/g product of trans-β-carotene were considered good sources of vitamin A.*

Results. *Golden bread made from fresh roots of medium-intensity orange-fleshed sweet potato varieties met the good source criterion, but bread from lighter-intensity sweet potato varieties did not. Bread from rehydrated dried chips was not economically viable. Consumers strongly preferred golden bread over pure wheat flour bread because of its heavier texture and attractive appearance. The ratio of the price of wheat flour to that of raw sweet potato root varied from 3.1 to 3.5 among the bakers, whose increase in profit margins ranged from 54% to 92%.*

Conclusions. *Golden bread is a good source of β-carotene and is economically viable when the price ratio of wheat flour to raw orange-fleshed sweet potato root is at least 1.5. Widespread adoption during sweet potato harvesting periods is feasible; year-round availability requires storage.*

Key words: Bread, β-carotene, orange-fleshed sweet potato, vitamin A content

Introduction

Sweet potato is one of the most widely grown root crops in sub-Saharan Africa, occupying around 3.2 million hectares with an annual estimated production of 13.4 million tons of roots in 2005. It is expanding faster than any other major food crop in southern Africa [1]. Sweet potato generates large amounts of food per unit area per unit time during relatively short rainy periods, tolerates occasional dry spells, and produces greater yields even on less fertile soils than crops such as maize [2]. In countries with two rainy seasons where sweet potato is a primary staple (Rwanda, Burundi, and Uganda), sweet potato is available 11 months a year. In most other sub-Saharan African countries, sweet potato is a secondary staple, with one dominant growing season. Sweet potato is available in these countries from 4 to 8 months a year, depending on whether households can access lowland areas with sufficient moisture to sustain a dry season crop and the maturity period of available varieties. The most common form of storage is in-ground, with farmers harvesting sweet potato piecemeal as needed. However, storing dried

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chips is practiced in areas with prolonged dry seasons, and storage of fresh roots for 1 to 5 months in protected pits is feasible, but uncommon.

An *ex ante* impact assessment indicated that orange-fleshed sweet potato could make a major contribution to alleviating vitamin A malnutrition in sub-Saharan Africa [3]. Replacing the white-fleshed varieties grown by farmers with high-β-carotene varieties that meet local preferences could benefit an estimated 50 million children under 6 years of age, who are currently at risk for diseases associated with vitamin A deficiency. Eleven sub-Saharan African countries are now members of the Vitamin A for Africa (VITAA) platform to promote the breeding and promotion of locally adapted, conventionally bred, β-carotene–rich orange-fleshed sweet potato varieties [4]. For example, various cultivars of orange-fleshed sweet potato are used in home garden projects in South Africa. Some of these are the dark-orange-fleshed variety Resisto, containing 13,200 to 19,400 μg of β-carotene per 100 g fresh weight [5]; Excel, containing 7,780 μg of β-carotene per 100 g fresh weight; and Jewel, containing 9,840 μg of β-carotene per 100 g fresh weight [6].

The efficacy of boiled and mashed β-carotene–rich orange-fleshed sweet potato (Resisto variety, 1,031 μg of retinol activity equivalents [RAE] per day) compared with boiled and mashed white-fleshed sweet potato (Bosbok variety, 0 μg RAE per day) has been demonstrated in South African primary school children [7]. Diets enriched with plant sources of β-carotene, the primary source being orange-fleshed sweet potato, increased serum retinol concentrations in Indonesian children marginally deficient in vitamin A [8]. In both studies, the sweet potato was very well accepted by the children.

A 2-year, integrated, orange-fleshed sweet potato–based agriculture–nutrition project with a market development component, known as the Towards Sustainable Nutrition Improvement (TSNI) Project, was implemented in Zambézia Province, Central Mozambique, from December 2002 through January 2005 [9]. The vitamin A deficiency problem is severe in Mozambique, with an estimated prevalence of 71% among children 6 to 59 months of age [10]. The study area in Southern Zambézia Province is characterized by sandy soils, undependable rainfall, poor public services, low levels of formal education, and limited market opportunities for agricultural products. Sixty-four percent of study children under 5 years of age were stunted at baseline and 61% of their mothers had no formal education [11]. The results indicate that integrated promotion of orange-fleshed sweet potato can contribute to increases in vitamin A intake and serum retinol concentrations among young children in rural Mozambique and similar areas in sub-Saharan Africa [9, 11]. The market development component was included to accelerate and ensure adoption of orange-fleshed sweet potato through active creation of demand for fresh sweet potato roots and the establishment of linkages between sweet potato producers and traders. The framework hypothesized that if an economically viable orange-fleshed sweet potato–based processed product could be developed, it would likewise contribute toward ensuring sustained adoption of sweet potato by creating new market outlets for root producers and enhancing cash incomes of sweet potato growers and manufacturers of processed product. Diversification of the use of orange-fleshed sweet potato could also result in increased consumption of vitamin A by both producers and non-producing consumers, provided the product did not suffer significant losses of β-carotene in processing. Carotenoids are likely to be significantly reduced when exposed to heat for a considerable period of time [12].

The present work focuses on the pilot experience concerning the development of golden bread, the processed product identified as the most economically viable opportunity to incorporate orange-fleshed sweet potato as a significant ingredient in resource-poor rural areas of Central Mozambique. The objectives are to describe the process used to identify viable candidates for development of a processed orange-fleshed sweet potato product for poor consumers, utilizing rural markets; report the development of the product and its acceptability to consumers; determine the β-carotene content of the product, derived from both dried chips and fresh roots of five different varieties of sweet potato; establish whether the product can be considered a good source of vitamin A; assess the profitability of the product and its sensitivity to changes in the relative prices of sweet potato and the ingredient for which it is substituting; and discuss its potential for widespread adoption.

Materials and methods

Research setting and project partners

This pilot study was a small component of a 2-year intervention research project undertaken in three drought-prone districts of Zambézia Province in central Mozambique. The project partners were Michigan State University, the Nutrition Division of the Mozambique Ministry of Health, World Vision Mozambique, the National Institute for Agronomic Investigation, the Southern African Root Crops Research Network (SARRNET), and Helen Keller International. The study protocol was reviewed and approved by the ethics review committees of the Micronutrient Initiative of Canada, Michigan State University and the National Bioethics Committee for Health of Mozambique.

Product identification and development and determination of profitability

A survey instrument was prepared to assess the costs and revenues generated from producing a batch of a processed product made by local processors and record the actual recipe used. This survey was administered by project extension personnel in Quelimane, Licuari, and Lualua markets for all processed products available for sale in June and July 2004. Net returns to labor were determined by subtracting the total variable costs from the total revenue for a typical single batch produced and sold by the interviewed individual.

Local recipes were modified by substituting boiled and mashed orange-fleshed sweet potato for wheat flour, maximizing the amount of sweet potato included that local consumers found acceptable in terms of taste and appearance. The recipe developed for golden bread replaced 38% of wheat flour by weight with boiled and mashed sweet potato. The net returns to labor calculations for golden bread were based on quantities and unit sizes actually produced by local bakers when they substituted sweet potato in their standard pure wheat flour recipe to produce 250 buns averaging about 60 g per bun. Sensitivity analysis was performed with Microsoft EXCEL to determine how profits would vary as the price of wheat flour varied with respect to the price of fresh sweet potato root, with all other factors held constant.

In each of three rural villages with active local markets, 8 to 10 people were trained by extension personnel to make golden bread, orange-fleshed sweet potato–based doughnuts, and sweet potato juice. Half of those trained already made and sold either doughnuts or bread; the other half belonged to farmers' groups enrolled in the project who expressed interest in processed product development. Those choosing to produce and sell sweet potato products were provided with promotional signs, extension agent assistance to link them to sweet potato farmers producing roots, and credit to purchase a portable oven made from an oil drum (250-L capacity) if they did not already own a local oven.

Consumer assessments

Consumer tasting panels were conducted among untrained market shoppers during 3 days in Licuari market. A brief statement describing the purpose of the study and participant confidentiality was read to each shopper, and oral consent obtained before proceeding. A total of 95 participants were recruited by offering three bread buns for sale at the price of two buns. There were three different buns at each of six assessment tables, one local and two orange-fleshed sweet potato-based buns. An enumerator obtained information on basic socioeconomic characteristics of each participant, information concerning consumption patterns, and ranking information concerning key characteristics (texture, color, form, appearance, and taste) of the bread tasted.

In February 2005, a rapid assessment of consumer acceptance of golden bread was conducted in two markets where it had been sold in 2004, Lualua and Licuari. Of the 112 shoppers randomly selected for interview, 58% (37 men and 18 women) had heard of golden bread. Among these, 47 (42% of the total sample) had purchased golden bread and were interviewed in greater depth with the use of a structured questionnaire.

Sweet potato material

Sweet potato (*Ipomoea batatas* Lam.) varieties were obtained from research plots in Lualua District of Zambézia Province by agronomists working for the TSNI Project in 2004. The specific batches of Resisto (440001), Persistente (MgCL01), Gabagaba (440215), TIB4 (440060), and LO-323 (440185) used in this study were harvested after a growing season of 20 weeks. Because the common name for the same variety differs among countries, the identification numbers assigned to the variety in the International Potato Center (CIP) germplasm bank are provided in parentheses after the common name used in Central Mozambique. Persistente is a local landrace from Mozambique and has no CIP identification code.

Preparation of bread buns and sampling

The recipe used to prepare the sweet potato-based buns sent for analysis was the same as that used by local bakers, except that the sliced sweet potato chips were dried in an electric drier instead of under the shade of a tree. For each of the five varieties, five medium-size roots (about 240 g each) were sliced into 1- to 3-mm-thick chips and dried in an electric vegetable drier for 8 hours at 60°C, and five medium-size roots (about 225 g each) were boiled intact for 25 minutes, peeled, and mashed with a fork. Then two batches of 44 buns of golden bread were prepared for each variety using 950 g of boiled and mashed sweet potato derived from the fresh roots and using 950 g of mashed sweet potato derived from rehydrating 360 g of dried chips by soaking them in water for 20 minutes and then boiling them for 30 to 40 minutes until they were soft enough to be mashed.

The mashed sweet potato was added to a mixture of 1.5 kg of wheat flour, 15 g of dried yeast, 2 g of improver (a product sold especially for making bread), and 1 teaspoon of salt. After the sweet potato had been incorporated into the wheat flour mixture, 500 mL of water was added and the mixture was well kneaded for 8 minutes. Then an additional 500 mL of water was added little by little while kneading was continued until the mass did not stick to the preparer's hands. The mixture was divided into 44 buns, covered, and left to rise for 25 minutes in direct sunlight. The buns were baked in an oil-drum oven over charcoal for 12 to 15 minutes.

In total there were 10 separate variety–preparation categories. Five bread buns randomly selected from 44 units in one baked batch each of fresh and dried chips for each variety were sampled, put into Ziploc plastic freezer bags, and placed within plastic containers with a lid. The average amount of boiled and mashed sweet potato added to buns was 21.7 ± 2.3 g. The average weight of the baked buns was 58.6 ± 4.0 g. These were sent in a Styrofoam box containing ice packs by courier service to the laboratory of the Nutritional Intervention Research Unit, Cape Town, South Africa, and stored at −20°C for 4 weeks until analysis of the β-carotene content.

The five frozen bread buns from each sample were thawed at room temperature overnight and prepared for extraction the next day. The buns were quartered, and two opposite sections from each bun were combined, cut into smaller pieces, and homogenized with the use of a hand-held whisk (Braun type 4169). Four grams were taken for analysis.

β-Carotene analysis

Analyses were carried out in duplicate according to a validated method developed for β-carotene–rich orange-fleshed sweet potato [5]. This involved the purification of a β-carotene standard (synthetic, crystalline, Type II, product C-4582) from Sigma Chemical Co. and quantitative analysis by high-performance liquid chromatography (HPLC). The purity of the final purified standard solution was verified by HPLC (91%), and the concentration of the standard solution was corrected accordingly. A standard curve with five different concentrations, ranging from 0.79 to 9.51 μg/mL and bracketing the concentration present in the samples, was constructed in triplicate. The curve passed through the origin and had a coefficient of correlation of 0.999.

β-Carotene extracts were prepared as described previously [5], with minor modifications to the extraction solvents and analytical columns, as described below. The samples were extracted twice with 30 mL of tetrahydrofuran:methanol (1:1 vol/vol) for about 1 minute with a Polytron homogenizer (Kinematica, type PT 10-35) and filtered into a 250-mL round-bottom flask. The extracts were partitioned to petroleum ether [13], collected into a 50-mL volumetric flask, and made up to volume. An aliquot of 3 mL was brought to dryness under a stream of nitrogen in a water bath at a maximum temperature of 35°C. The residue was redissolved in 1 mL of HPLC-grade acetone and filtered through a 0.22-μm PTFE syringe filter into a sample vial, and 10 μL was automatically injected into the HPLC equipment. Quantification was performed by external standardization.

The chromatographic system (Thermo Separation Products) was the same as described previously [5], except that a 10-μL sample loop and a different column and mobile phase were applied for the standard curve and samples. Chromatography was performed with a monomeric C_{18} column (Waters Spherisorb ODS 2, 3 μm, 4.6 × 150 mm). The mobile phase consisted of acetonitrile (containing 0.05% triethylamine):methanol:ethyl acetate (80:10:10), with a flow rate of 0.7 mL/min. The detector wavelength was set at 450 nm for the detection of β-carotene. Integration of the chromatograms was performed by the DELTA Chromatography Data System for windows software, version 5.5 (Data worX Pty.).

Results and discussion

Product identification and development

The results from the rapid appraisal of net return to labor for nine existing processed products in local markets are shown in **table 1**. Most products are produced by a single individual who makes a batch and sells it before making the next batch. The majority of the products have wheat flour as an ingredient. Imported wheat flour in Zambézia is transported from the port of Beira in Sofala Province, more than 500 km away. The major constraint faced by product makers is the low purchasing power of consumers. No unit price exceeded 1,000 Meticais (MT) (1,000 MT = US$0.04), and the sellers stated that it would be difficult to sell any product above that price. Net returns to labor per unit sold for seven products were small (US$0.007). Bread and fried doughnuts had the highest net returns per unit sold (US$0.016 and US$0.015, respectively).

In rural areas, bread is not produced in the home but is purchased in local markets. An expenditure survey among 28% of all 741 study households in 2003, all in rural areas, found that 63% had purchased bread during the previous month. Bread is considered a treat on market days, and small-scale baking in rural markets is common when access to wheat flour exists. Doughnut production for rural markets is more limited than that of bread, because doughnut production requires access to oil as well as wheat flour. Hence, the present work focused on bread making as the most likely option for an economically viable sweet potato-based product most likely to be sustained in rural markets.

The bread recipe was modified from the recipe currently being used by a local baker in Lualua market, with substitution of different amounts of boiled and

TABLE 1. Examples of estimated net returns to labor (profit) from batches of processed products sold in markets in Zambézia during June and July 2004[a]

Product	Major ingredients	Units per batch (MT)	Unit selling price (MT)	Revenue (MT)	Total cost (MT)	Net return to labor (MT)	Net return per unit sold	
							MT	US$
Bread buns	Wheat flour, yeast, improver	2,880	1,000	2,880,000	2,414,000	466,000	162	0.007
Bread buns (market: Lualua)	Wheat flour, yeast, improver	250	1,000	250,000	223,274	26,726	107	0.004
Bread buns (market: Licuari)	Wheat flour, yeast, improver	121	1,000	121,000	75,722	45,278	274	0.016
Twisted Berlin bun	Wheat flour, sugar, yeast	270	1,000	270,000	249,817	20,183	75	0.003
Coconut sugar bar	Coconut, sugar	600	500	300,000	245,000	55,000	92	0.004
Biscuit	Wheat flour, sugar, yeast	150	1,000	150,000	138,700	10,300	69	0.003
Fried doughnut	Wheat flour, sugar, oil	70	500–1,000	58,310	22,350	25,060	258	0.015
Juice from powder (240-mL cups)	Powder	164	500	82,000	68,000	14,000	85	0.004
Bajia (fried cowpea)	Wheat flour, cowpea, oil	212	500	106,000	83,777	223	111	0.005

a. Market location is Quelimane unless specified otherwise. Average exchange rate in 2004: 24,000 Meticais (MT) = US$1.

mashed sweet potato for wheat flour as much as product quality permitted. The final product, golden bread, substitutes approximately 38% of wheat flour by weight with boiled and mashed sweet potato. The only other modification of the baker's recipe was to reduce the number of risings of the dough from two to one. With golden bread, the buns are formed immediately after all ingredients have been combined and they are covered with a cloth and left to rise in direct sunlight. Introducing the boiling and mashing process of the sweet potato roots increased the labor involved in bread preparation, but because the number of risings was reduced, the total amount of time needed to prepare a batch of buns did not significantly change.

β-Carotene content

The results shown in **table 2** indicate that over 75% of the total β-carotene in all samples is in the *trans* form, which has more provitamin A activity than the *cis* isomers [14]. As a rule of thumb, processed products with at least 15 µg/g product of *trans*-β-carotene can be considered good sources of vitamin A. Buns made from fresh, boiled and mashed roots from three varieties with medium-intensity orange flesh color (Resisto, Persistente, and Gabagaba) met this criterion. Buns from two varieties with lighter-intensity orange flesh color (< 35 µg/g β-carotene in fresh root) (TIB4 and LO-323) did not, nor did any of the buns made from rehydrated dried chips except those made from Resisto chips.

The potential contribution of any product to improved nutrient intakes depends on the age and sex of those consuming it, since recommended intakes differ between major categories. The US Food and Drug administration guidelines for nutrient content claims recommend that a product can be considered a good source of vitamin A if it contains 10% to 19% of the daily value per reference amount, and an excellent source if it contains 20% or more of the daily value per reference amount [15]. The reference amounts are typical serving sizes for a given product. Using the recommended dietary allowances (RDAs) for vitamin A [16] as a proxy for daily values, **table 3** shows the percent contribution of vitamin A (in micrograms of RAE) that a small (60 g) and a medium-sized (110 g) bun of golden bread made with Resisto would provide to children of different ages, women at different reproductive stages, and men. On the basis of these guidelines, a 110-g golden bread bun is an excellent source of vitamin A for children and non-pregnant women and a good source for all other adults. Small buns (60 g) are an excellent source of vitamin A only for children 1 to 3 years of age and a good source for older children and non-lactating women.

TABLE 2. Total and *trans*-β-carotene content of golden bread buns made from five orange-fleshed sweet potato varieties

	β-Carotene content[b]		β-Carotene and vitamin A content[b]	
Variety[a]	Total β-carotene (μg/g bun)	*Trans*-β-carotene (μg/g bun)	*Trans*-β-carotene (μg/60 g bun)	Vitamin A (μg RAE/60 g bun)[c]
Medium intensity				
Resisto (fresh)	19	15	890	74
Resisto (chips)	19	15	888	74
Persistente (fresh)	20	15	879	73
Persistente (chips)	18	14	808	67
Gabagaba (fresh)	21	16	969	81
Gabagaba (chips)	18	13	774	65
Lighter intensity				
TIB4 (fresh)	13	9	549	46
TIB4 (chips)	10	7	413	34
LO-323 (fresh)	12	9	540	45
LO-323 (chips)	10	7	444	37

a. Orange-fleshed sweet potato varieties were used to prepare bread buns from fresh, boiled roots (fresh) or rehydrated, boiled 1- to 3-mm-thick dried chips (chips).
b. Mean of duplicate analyses.
c. 12 μg of *trans*-β-carotene = 1 μg of retinol = 1 μg of retinol activity equivalents (RAE) [16].

Acceptability to consumers

During the 2004 orange-fleshed sweet potato season, between 150 and 200 buns of golden bread, prepared daily 4 to 5 days per week, were sold over a 4-month period (August to November) in three rural markets. Buns were sold irregularly from November 2005 to January 2006 because of limited supplies of sweet potato root. Bread makers reported that consumers readily bought the buns made within 1.5 days of baking and expressed interest in storing fresh roots in protected pits in the future to reduce time spent in procuring roots.

TABLE 3. Total and *trans*-β-carotene content of small and medium-sized golden bread buns made from fresh orange-fleshed sweet potato variety Resisto and contribution to vitamin A intake according to age and sex

Variable	60-g bun	110-g bun
Total β-carotene (μg)	1,132	2,078
Trans-β-carotene (μg)	890	1,631
Vitamin A value (μg RAE[a])	74	136
% contribution to vitamin A dietary reference intake[b]		
Children 1–3 yr	25	45
Children 4–8 yr	19	34
Children 9–13 yr	12	23
Non-pregnant women ≥14 yr	11	20
Pregnant women	10	18
Lactating women	6	10
Men ≥14 yr	8	15

a. 12 μg of *trans*-β-carotene = 1 μg of retinol = 1 μg of retinol activity equivalents (RAE) [16].
b. Vitamin A dietary reference intakes (μg RAE/day): children 1–3 yr, 300; children 4–8 yr, 400; children 9–13 yr, 600; non-pregnant women ≥14 yr, 700; pregnant women, 770; lactating women, 1300; men ≥14 yr, 900.

Two days of consumer taste tests comparing golden bread and pure white wheat flour bread were conducted in Licuari Market. The results of these tests showed a strong preference for golden bread over white wheat flour bread because of its heavier texture (i.e., it “fills the stomach”), superior taste, and attractive golden appearance. Round golden bread buns were preferred over those with elongated shapes. Golden bread made from fresh boiled and mashed roots was preferred in terms of taste and appearance to golden bread made from rehydrated dried sweet potato chips [17].

Of 112 consumers randomly approached in two markets in February 2006, 47 (42%) had purchased golden bread. Consumers who had purchased golden bread found the color (98%) and taste (85%) of the golden bread superior to that of the white bread. Seventy-eight percent preferred heavier-textured breads such as golden bread to lighter breads. Ninety-two percent preferred golden bread to white bread. Half of golden bread purchasers said that they would buy golden bread daily if it was available, although only a quarter of the sample currently purchased white bread daily. Differences in desired frequency of purchases were due in part to recognition of the presence of vitamins and the heavier texture of golden bread.

Profitability for rural bakers

Table 4 compares the net return to labor (profit) for a

TABLE 4. Comparison of costs and profits for one batch of pure wheat flour buns and one batch of orange-fleshed sweet potato golden bread buns at Lualua Market in 2004

Component of Cost	Quantity of Unit of Measure: Wheat flour bun	Quantity of Unit of Measure: Golden bread bun	Unit of measure	Total no. of grams: Wheat flour bun	Total no. of grams: Golden bread bun	Total value (MT)[a]: Wheat flour bun	Total value (MT)[a]: Golden bread bun
Wheat flour	20	12	Plastic jug (750 mL)	15,700	9,420	186,830	112,098
Yeast	2	12	Matchbox (level)	30	181	3,024	18,144
Improver (sold to bakers)	1	6	Matchbox (level)	17	25	1,670	2,496
Salt	1	2	Tablespoon (level)	13	26	1,000	1,486
Boiled and mashed orange-fleshed sweet potato[b]		18	Plastic cup (300 mL)	0	5,742		21,016
Daily market fee	1	1	Daily payment			2,000	2,000
Wood	1	1	Stack (0.5 m^3)			5,000	5,000
Charcoal	0.25	0.20	Sack (90 kg maize size)			3,750	3,000
Personal transport[c]	0.25	0.20	Return trip			15,000	12,000
Transport of wheat flour sack[c,d]	0.25	0.20	Return trip			5,000	4,000
Summary of Costs, Revenues, and Net Returns						Wheat flour bun	Golden bread bun
Total number of buns						250	264
Total revenue (MT)[a]						250,000	264,000
Total cost (MT)						223,274	181,240
Net return to labor (MT)						26,726	82,760

a. Average exchange rate in 2004: 24,000 Meticais (MT) = US$1.
b. Orange-fleshed sweet potato, 30 fresh roots of 225 g average weight.
c. Return trip between Lualua and Quelimane.
d. Wheat flour and bakers' improver were only available in Quelimane for purchase; for wheat flour bun, one sack lasts 4 days; for golden bread bun, one sack lasts 5 days.

Lualua baker from pure wheat flour buns and buns in which 5.7 kg of fresh, boiled and mashed sweet potato roots was substituted for 6.3 kg of wheat flour. The baker's profit increased by 92%, primarily due to the lower cost of utilizing locally available sweet potato compared with imported wheat flour. Rural bakers must purchase an entire 50 kg bag of flour in Quelimane. Using sweet-potato, the bag lasts for 5 batches instead of 4, reducing the total number of trips to Quelimane per month. Other bakers who had to purchase sweet potato at a higher price because of local market conditions still had increases in profit of around 50%. Bread makers are constrained by the price they can charge for a bun. Purchasing power is extremely limited in Zambézia, and buns costing more than 1,000 were unlikely to be sold in 2004. Thus, golden bread succeeded in increasing profits by lowering total costs.

In contrast, the profit from golden bread made from dried sweet potato chips was negative. Four kilograms of fresh roots are required to produce 1 kg of dried chips, and therefore the use of dried chips is not economically viable at the present time because of the greater revenue that can be gained from selling the fresh roots rather than selling bread made from chips. Significant increases in sweet potato production sufficient to drive average prices down would be required to make the use of dried sweet potato chips or flour economically viable.

Sensitivity analysis examining the profitability of golden bread buns made from boiled and mashed sweet potato according to the price ratio between wheat flour and sweet potato roots reveals that at a minimum, the price of wheat flour must be at least 1.5 times greater than the price of fresh sweet potato roots to justify substitution of sweet potato for wheat flour (**table 5**). The price ratio of wheat flour to raw sweet potato root varied from 3.1 to 3.5, corresponding to increases in profit among the rural bakers of 54% to 92%.

Potential for widespread adoption

Sub-Saharan Africa imported over 10.3 million tons of wheat and wheat flour in 2005, requiring more than US$1.8 billion in foreign exchange [18]. Nigeria, for instance, is attempting to reduce such outlays by legislation requiring all bread to contain 10% cassava flour. The promotion of golden bread would provide an opportunity for policy makers to concurrently create value-added markets for rural producers, combat vitamin A deficiency, and reduce foreign exchange outlay.

TABLE 5. Sensitivity analysis examining ratio of prices of wheat flour and orange-fleshed sweet potato root and its effect on net return to labor of golden bread buns compared with pure wheat flour buns[a]

Relative price			Net return to labor per batch				
Kg wheat flour/kg raw sweet potato root	Kg wheat flour/kg cooked sweet potato root	Total cost of wheat flour (MT)	Wheat flour bun (MT)	Golden bread bun (MT)	Golden bread bun (US$)	% increase in net return per golden bread bun	Net return to labor per golden bread bun (US$)
1.5	1.25	4,575	142,906	152,468	6.35	6.7	0.024
1.8	1.50	5,490	128,776	143,990	6.00	11.8	0.023
2.1	1.75	6,405	113,076	134,570	5.61	19.0	0.021
2.4	2.00	7,320	98,946	126,092	5.25	27.4	0.020
3.1	*2.50*	*9,150*	*70,686*	*109,136*	*4.55*	*54.4*	*0.017*
3.4	*2.75*	*10,065*	*56,556*	*100,658*	*4.19*	*78.0*	*0.016*
3.5	*2.84*	*10,402*	*50,276*	*96,890*	*4.04*	*92.7*	*0.015*
3.5	2.90	10,614	47,136	95,006	3.96	101.6	0.015
3.7	3.00	10,980	40,856	91,238	3.80	123.3	0.014
4.0	3.25	11,895	26,726	82,760	3.45	209.7	0.013
4.3	3.50	12,810	12,596	74,282	3.10	489.7	0.012

a. The range of values encountered during the study is presented in italic text. Golden bread buns are made in batches of 264, pure wheat flour buns in batches of 250. Average exchange rate in 2004: 24,000 Meticais (MT) = US$1.

In many parts of sub-Saharan Africa, price ratios favorable to golden bread are likely to exist outside port cities, since most wheat flour is imported. High internal transport costs favor substitution of wheat flour with locally available ingredients. The potential for widespread adoption among small- to medium-scale rural bakers is high if adequate supply chains exist to ensure consistent root supply. In areas where sweet potato production is seasonal, either the bread will have to be seasonally produced or investments will have to be made to improve fresh root storage or irrigation to enable year-round production. Storage trials of fresh roots in protected pits indicated that storing for up to 4 to 5 months is possible. Measurements of the β-carotene content of orange-fleshed sweet potato (Resisto variety) during room storage (of a harvested batch) and in-ground storage (left in the field) showed that after 12 weeks of room storage and 22 weeks of in-ground storage, the β-carotene content was still substantial but declining (170 and 154 µg/g fresh weight, respectively) (Van Jaarsveld PJ, unpublished data). Storage of fresh roots is uncommon and not currently practiced over long periods. However, the availability of orange-fleshed sweet potato can be extended over a much longer period if staggered planting of the crop is practised. Data are not available concerning losses of β-carotene over time for boiled and mashed sweet potato stored in freezers. On the other hand, the cost of a freezer and the availability of a constant supply of electricity may be constraints for resource-poor rural communities and small and medium-sized bakeries in urban centers. Further research on losses during fresh storage of different varieties is needed, but darker-intensity varieties are clearly preferable because losses do occur.

Rural bakers do not perceive dealing with the boiling and mashing process as an impediment to adoption. However, larger-scale urban bakers may require mashing and mixing equipment to handle larger quantities of roots. In theory, the use of dried sweet potato chips could extend the period during which golden bread can be baked if the chips could be economically ground into flour prior to use. The bakers disliked the laborious process required to mash the rehydrated boiled chips. Significant increases in orange-fleshed sweet potato production sufficient to drive average prices down would be required to make the use of dried sweet potato chips or flour economically viable, which is not the case at the present time. Moreover, only dried Resisto chips had sufficient β-carotene to be considered for use in this study. Given potential storage losses, orange-fleshed sweet potato varieties with flesh colors of darker intensity (for example varieties with at least 150 µg/g of β-carotene) than those currently in use would be required for dried chips to guarantee sufficient β-carotene content in the final product. If the use of dried chips from deeper-intensity varieties became economically viable, it would be easy to overcome seasonal fluctuations in supply. Moreover, dried chips stored at ambient temperature lost only 10% of carotenoid content after 11 months, showing a relative stability of carotenoids once tissue moisture content had been reduced below the critical level of normal metabolic processes [19]. Darker-intensity orange-fleshed sweet potato clones are in the breeding pipeline in Mozambique. If these materials prove to have higher yields than existing varieties, and better agronomic practices are concurrently adopted so that overall yields are increased by at least 40% (sufficient to drive the price of fresh roots down), one could envision dried chips or flour becoming an economically viable, provitamin A–rich option in the medium term.

Conclusions

Golden bread made by replacing 38% of wheat flour by weight with boiled and mashed fresh roots of orange-fleshed sweet potato of medium orange intensity in recipes used by rural bakers in Central Mozambique is an economically viable product that has enough β-carotene content to be regarded as a good source of vitamin A. Under present economic conditions in rural Mozambique, bread made from rehydrated sweet potato chips is not economically viable. Moreover, darker-intensity sweet potato varieties would be required to make golden bread with the desired β-carotene content from chips. Golden bread appears to satisfy consumer preferences in the area, and the challenge remains to create a sustainable supply chain of sweet potato roots for interested bakers. The potential exists to significantly expand the use of golden bread when the price ratio per kilogram of wheat flour to raw, fresh sweet potato roots is at least 1.5. Widespread adoption should be possible during sweet potato harvest season in a broad range of sub-Saharan African countries. Year-round production will be constrained by seasonality in sub-Saharan African countries where sweet potato is a secondary staple (4 to 8 months availability of fresh roots) compared with countries where it is a primary staple (year-round availability). Storage of fresh roots of the variety Resisto for 3 months and possibly longer with adequate β-carotene retention is possible, but further research on β-carotene loss during fresh storage of available varieties is needed. Within 5 to 10 years, improvements in sweet potato productivity and the availability of locally adapted, darker-intensity orange-fleshed sweet potato from clones now in the pipeline in several breeding programs may permit the use of dried chips or flour.

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