SWEET POTATO: A REVIEW OF ITS PAST, PRESENT, AND FUTURE ROLE IN HUMAN NUTRITION

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The overall objective of this chapter is to review the past, present, and future role of the sweet potato (*Ipomoea batatas* [L.] Lam) in human nutrition. Specifically, the chapter describes the role of the sweet potato in human diets; outlines the biochemical and nutritional composition of the sweet potato with emphasis on its β-carotene and anthocyanin contents; highlights sweet potato utilization, and its potential as value-added products in human food systems; and demonstrates the potential of the sweet potato in the African context. Early records have indicated that the sweet potato is a staple food source for many indigenous populations in Central and South Americas, Ryukyu Island, Africa, the Caribbean, the Maori people, Hawaiians, and Papua New Guineans. Protein contents of sweet potato leaves and roots range from 4.0% to 27.0% and 1.0% to 9.0%, respectively. The sweet potato could be considered as an excellent novel source of natural health-promoting compounds, such as β-carotene and anthocyanins, for the functional food market.

Also, the high concentration of anthocyanin and β-carotene in sweet potato, combined with the high stability of the color extract make it a promising and healthier alternative to synthetic coloring agents in food systems. Starch and flour processing from sweet potato can create new economic and employment activities for farmers and rural households, and can add nutritional value to food systems. Repositioning sweet potato production and its potential for value-added products will contribute substantially to utilizing its benefits and many uses in human food systems. Multidisciplinary, integrated research and development activities aimed at improving production, storage, postharvest and processing technologies, and quality of the sweet potato and its potential value-added products are critical issues, which should be addressed globally.

I. INTRODUCTION

Currently, in some developed countries, overnutrition rather than undernutrition presents a major public health challenge. However, from a global perspective, undernutrition, food insecurity issues, droughts, and limited agricultural technologies are major problems. In developing countries, many farmers are highly dependent on root and tuber crops, as contributing, if not principal, sources of food, nutrition, and cash income (Scott *et al.*, 2000). From this standpoint, there is need to critically reevaluate versatile, locally available, hardy root and tuber crops with wide ecological adaptability for their usefulness in human nutrition. The sweet potato (*Ipomoea batatas* [L.] Lam) is one such crop because it is high yielding and drought tolerant, with wide adaptability to various climates and farming systems (Diop, 1998; Jiang *et al.*, 2004). Furthermore, a single sweet potato plant may produce 40–50 roots ranging in length from a few to 30 cm, and weighing between 100 and 1000 g, and the roots, leaves, and shoots are all edible (CIAD *et al.*, 1996). It has been emphasized that the sweet potato roots and leaves (greens or tips) can support more people per unit hectare than any other food (Woolfe, 1992). The leaves of the sweet potato are dark green and are expected to have nutritive values comparable to common dark green leafy vegetables (Ishida *et al.*, 2000).

Regular consumption (100 g or half-cup daily) of yellow- or orange-fleshed sweet potato roots having about 3 mg/100 g β-carotene on a fresh weight basis provide the recommended daily amount of vitamin A for children less than 5 years old (Tsou and Hong, 1992). Jalal *et al.* (1998) reported that incorporation of orange-fleshed sweet potato into meals eaten by 3- to 6-year olds improved vitamin A status. Weight for weight, some orange-fleshed sweet potato cultivars (cv.) contains 20–30 times more β-carotene than Golden Rice

(Ye *et al.*, 2000). Also, sweet potato is a typical food security crop because it can be harvested little by little over several months. It is because of these unique features and nutritional value of the sweet potato that the National Aeronautics and Space Administration (NASA) has selected it as a candidate crop to be grown and incorporated into the menus for astronauts on space missions. The sweet potato has immense potential and has a major role to play in human nutrition, food security, and poverty alleviation in developing countries.

Sweet potato is a creeping dicotyledonus plant with the following scientific classification (Kingdom: Plantae; Division: Magnoliophyta; Class: Magnoliopsida; Order: Solanales; Family: Convolvulaceae; Genus: *Ipomoea*, and Species: *batatas*). The sweet potato, its leaves and roots are shown in Figure 1. Common names for the root include: sweet potato (English); batata, boniato, camote (Spanish); kumar (Peru); kumara (Polynesian); and cilera abana, "protector of the children" (eastern Africa); *kara-imo*, "Chinese potato" (southern Kyushu, Japan); Ubhatata (South Africa); and *satsuma-imo*, "Japanese potato" (most of the other parts of Japan). The sweet potato is said to have originated in the New World; however, the exact origin has not been well defined. Austin (1988) proposed the origin of the sweet potato as being between the Yucatán Peninsula of Mexico and the Orinoco River in Venezuela. In 1514, nine sweet potato cv. were identified in Honduras. Currently, hundreds of cv. are grown throughout the world and are unique to countries or smaller regions within countries. All cv. are more or less sweet flavored. In developed countries, limited numbers of sweet potato cv. are grown. In the United States, producers tend to grow only one or two major cv. for regional and national markets, but may grow several cv. in small amounts for local markets. The two cv., which account for most of the current US acreage, are "Jewel" and "Beauregard."

There is a need to differentiate between the sweet potato and yam because of some confusion that exists regarding them in the United States. Sweet potatoes and yams are both angiosperms (flowering plants), however, they are botanically different. Sweet potatoes, often called "yams" in the United States, are dicotyledons (having two embryonic seed leaves) and are from the Convolvulaceae or morning glory family. On the other hand, yams are monocotyledons (one embryonic seed leaf) and are from the Dioscoreaceae or yam family. Also, the edible storage organ of the sweet potato is a true root, and for the yam it is a tuber. A tuber is a thickened part of the stem or rhizome (Kays *et al.*, 1992). The root system of the yam is a rhizome, which is a thickened stem that grows horizontally underground. The appearance and shape of the sweet potato and yam are also different. For example, the sweet potato is usually smaller, short, and blocky with tapered ends, while yams are usually long and cylindrical with some toes. β-Carotene content is usually high in orange-fleshed sweet potatoes

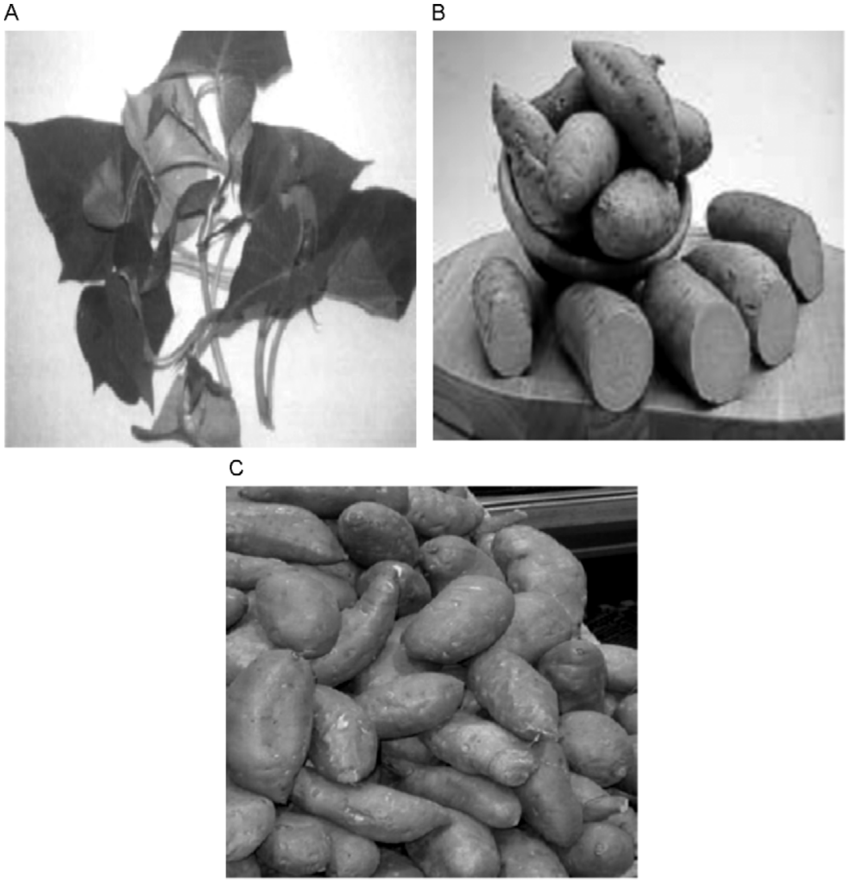

FIG. 1 Sweet potato leaves and roots. (A) Sweet potato leaves. (B) Orange-fleshed sweet potato roots. (C) White-fleshed sweet potato roots (http//encyclopedia.laborlawtalk.com).

but low in yams. The growing season is 90–150 and 180–360 days for the sweet potato and yam, respectively (http://www.loc.gov/rr/scitech/mysteries/sweet-potato.html). This chapter focuses on the sweet potato and not yams. The overall objective of this chapter is to review the past, present, and future role of the sweet potato in human nutrition. Specifically, the paper will:

- Describe the role of the sweet potato in human diets
- Outline the biochemical and nutritional composition of the sweet potato with emphasis on its β-carotene and anthocyanin contents

- Highlight sweet potato utilization and its potential for incorporation into value-added products for use in human food systems
- Use case studies to demonstrate the potential of the sweet potato in the African context

II. SWEET POTATO IN HUMAN DIETS

The records left by early Europeans indicated that sweet potato provided a staple food source for many indigenous populations in southern Central America and South America (Sauer, 1950). Piperno and Holst (1998) reported that starch grain analysis revealed sweet potato as a staple food source for inhabitants in coastal Peruvian sites. The sweet potato or kumara was one of the most important crops in the diets of the Maori people, early New Zealand settlers of Polynesian descent, and was already an important staple food in Hawaii in 1778 (Huang *et al*., 1999). Commercial cultivation of sweet potato began in Hawaii in 1849, and since then many cv. have been introduced (Valenzuela *et al*., 1994). The sweet potato remains an important staple food in the diets of the Maori people, Papua New Guineans, and Hawaiians (Cambie and Ferguson, 2003; Huang *et al*., 1999; Sawer, 2001). Sweet potato, which is the commonest traditional root crop in Papua New Guinea, is consumed daily by 66% and 33% of the rural and urban population, respectively (Sawer, 2001). The Satamu sweet potato provides the largest part of the energy intake and contributes to self-sufficiency in Okinawa in the Ryukyu Island (Sho, 2001). Sweet potato is also an important staple in countries such as the Solomon Islands, Tonga, and New Caledonia (Hijmans *et al*., 2002). In parts of West, Central, and East Africa, sweet potato is an important source of calories and is consumed by people of all age groups (Hagenimana *et al*., 1998a). For example, in Nigeria, the traditional utilization of sweet potatoes includes: (1) boiled and eaten with stew; (2) boiled and pounded with either boiled or fermented cassava as "*foofoo*" or boiled or pounded yam; (3) dried and milled for sweetening of gruel or *ogi* porridge; and (4) sliced into chips, dried, and fried in vegetable oil or boiled with beans or vegetables. Koreans value sweet potato leaves as a very nutritious and tasty vegetable. The leaves are usually cooked together with other ingredients in various Korean dishes or can be dried and stored for later use as a boiled or fried vegetable (www.agnet.org/library/article/pt2001034.html).

The sweet potato is also an important starch source in China, Vietnam, Korea and Taiwan, and the Philippines (Collado *et al*., 1999; Marter and Timmins, 1992). Although sweet potato may contribute essential nutrients, it is usually consumed for its sensory properties, as a substitute or supplement to corn, rice, or wheat or as the main ingredient of traditional, but infrequently consumed dishes in many developing countries (Shewry, 2003; Van Den and del Rosario, 1984).

In 1999, sweet potato accounted for approximately 20% of the total world production of root and tuber crops (FAO, 1999). Asia is the largest sweet potato-producing region in the world, with an annual production of 125 million tonnes. China produces roughly 65% of the world's sweet potato, making it the leading supplier of sweet potatoes in the world (Hijmans *et al*., 2002). Latin America and North America produce about 1.9 million and 600,000 tonnes annually, respectively. In the United States, North Carolina and Louisiana each grow 40% of the total sweet potatoes, while California, Alabama, and Texas grow the bulk of the remainder (Burden, 2005). The only European country that produces considerable quantities of sweet potato is Portugal, at 23,000 tonnes annually (FAO, 1999). There are considerable concentrations of sweet potato in the Caribbean region; Indonesia; New Guinea, Papua New Guinea; and Vietnam (Hijmans *et al*., 2002). Production of sweet potato in Africa amounts to 6% of world production (Karyeija *et al*., 1998). The largest sweet potato growers in Africa are: Uganda, the third largest producer in the world (2.2 million metric tonnes); Rwanda (1.1 million metric tonnes); Kenya and Burundi (0.7 million metric tonnes each); Tanzania (0.4 million metric tonnes); and Ethiopia (0.2 million tonnes) (Diop, 1998; Karyeija *et al*., 1998; http://www.harvestplus.org/sweetpotato.html). The other African countries with annual sweet potato production ($\times 10^3$) exceeding 100,000 tonnes are shown in Figure 2. However, over the last four decades, global sweet potato production has remained static, and demand for the crop is greatly decreased, possibly because of diversified eating habits and little knowledge about its nutritional and functional properties among other things (Kays, 2005; Yamakawa and Yoshimoto, 2002).

III. BIOCHEMICAL AND NUTRITIONAL COMPOSITION OF THE SWEET POTATO

The sweet potato has immense potential to help prevent and reduce food insecurity and mal-, under-, and overnutrition in developing and developed countries because of its nutritional composition and unique agronomic features. However, paucity of information regarding the nutritional composition of the sweet potato greatly limits its exploitation. Improved awareness of the nutritional quality, utilization, and future economic importance of the crop has important implications for human food systems, nationally and internationally (Scott *et al*., 2000). The sweet potato contains many nutrients including protein, carbohydrates, minerals (calcium, iron, and potassium), carotenoids, dietary fiber, vitamins (especially C, folate, and B_6), very little fat, and sodium. As described in the following sections, the nutrient composition of the sweet potato varies greatly according to genetic and environmental factors.

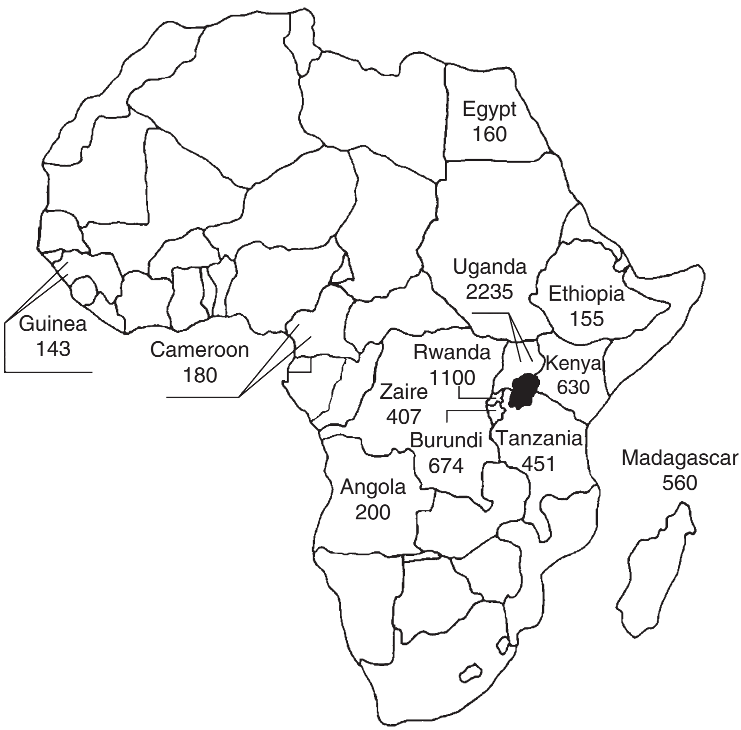

FIG. 2 The 12 African countries with an annual sweet potato production ($\times 10^3$) exceeding 100,000 tonnes. Note the main production area concentrated around Lake Victoria (in black). Modified from Karyeija *et al.* (2000) and FAO (1995).

A. PROTEIN: SWEET POTATO LEAVES

In Africa and Japan, the leaves of the sweet potato are eaten, and the protein content has been reported to be as high as 27% protein on dry weight basis (dwb; Diop, 1998). Tewe *et al.* (2003) reported that the protein content of sweet potato leaves was 18.4%, while fiber content was between 3.3% and 6.0%. Ishida *et al.* (2000) studied two kinds of sweet potatoes and reported that the leaves contained high amounts of protein (3.8 and 3.7 g/100 g), total dietary fiber (5.9 and 6.9 g/100 g), and ash (1.9 and 1.5 g/100 g). Ishiguro *et al.* (2004) described a newly developed sweet potato cv. (*Suioh*) for utilization as vegetable greens. The nutritional composition of the greens is shown in Table I. The total polyphenol content and radical-scavenging properties of the *Suioh* were reported to be much higher than that of spinach, broccoli, cabbage, and lettuce (Ishiguro *et al.*, 2004). Also, sweet

TABLE I
NUTRITIONAL CONTENT OF SUIOH SWEET POTATO GREENS

Nutrient	Percentage (dwb)
Iron (mg/100 g)	2.6–26.4
Calcium (g/100 g)	1.2
Vitamin E (mg/100 g)	15.8
Total carotenoid (mg/100 g)	34.7

Source: Ishiguro *et al.* (2004).

potato tea made from *Suioh* greens was more acceptable to sensory judges than other teas (Ishiguro *et al.*, 2004). Pace *et al.* (1996) described the nutritional content of sweet potato greens as 4.0–6.0% protein, 8.0–12.0% carbohydrate, 60-mg/100 g calcium, and 80-mg/100 g phosphorus. Tewe *et al.* (2003) also reported that in some parts in Nigeria, sweet potato leaves were acceptable as soup ingredients in terms of flavor, appearance, palatability, softness, and acceptability. Islam (2006) reported that sweet potato leaves contain at least 15 biologically active anthocyanins, which are beneficial to human health and may also be useful as natural food colorants.

B. PROTEIN: SWEET POTATO ROOTS

The crude protein content of sweet potato (Kjeldahl nitrogen $\times$ 6.25) generally ranges from 1.3% to $>$10% dwb (Bradbury *et al.*, 1985; Purcell *et al.*, 1978). However, substantial variation has been shown to exist. Ishida *et al.* (2000) reported 2.1% and 1.3% protein for *Koganesengan* and *Beniazuma* sweet potato cv., respectively. Diop (1998) reported 1.0–2.4% protein in sweet potato while Bovell-Benjamin *et al.* (2001) and Dansby and Bovell-Benjamin (2003a) reported protein contents ranging from 1.2 $\pm$ 0.05% to 1.8% (fresh weight) for hydroponically grown sweet potatoes. Oboh *et al.* (1989) analyzed 49 varieties of sweet potato sold in Nigerian markets and reported protein contents between 1.4% and 9.4%. The protein contents of sweet potato roots from 16 cv. grown in Sri Lanka ranged from 3.0% to 7.2% on dwb (Ravindran *et al.*, 1995). Cambie and Ferguson (2003) reported 1.7% protein content for sweet potato while Gichuhi *et al.* (2004) reported 4.5%, 4.7%, and 9.0% protein (dwb) for cv. J6/66, Beauregard (commercial), and TU-82-155. Bovell-Benjamin *et al.* (2004) observed a wide variation in the protein content of three cv. of sweet potato with TU-82-155 containing almost twice as much protein (8.7 $\pm$ 0.1%) on dwb as J6/66 (4.4 $\pm$ 0.03%) and Beauregard (4.7 $\pm$ 0.5%).

Sporamins A and B, the major storage proteins in sweet potato, which account for more than 80% of the total protein, are also of importance (Gichuhi *et al.*, 2004; Scott and Symes, 1996). It has been reported that sporamins A and B, which are proteinase inhibitors, may have some anticarcinogenic properties (Maeshinia *et al.*, 1985). Although the biological significance is still unclear, Hou and Lin (1997) reported that sporamins have antioxidant activity, acting as dehydroascorbate reductase and monodehydroascorbate reductase, which are associated with intermolecular thiol/disulfide exchange.

Although regarded as a low-protein food in the United States, sweet potato serves as an important protein source to a large segment of the world's population (Walter *et al.*, 1984; Woolfe, 1992). For example, the highlanders of Papua, New Guinea rely on sweet potatoes as a major source of protein and for 60–90% of their energy requirements (Clark and Moyer, 1988).

C. β-CAROTENE

Globally, sweet potato has a significant role to play in the fight against vitamin A deficiency (VAD). VAD is of public health significance in developing countries, causing temporary and permanent eye impairments and increased mortality, especially among children, pregnant, and lactating women. It has been shown that more than 230 million of the world's children have inadequate vitamin A intake, with 13 million of them being affected by night blindness (Schweigert *et al.*, 2003; Stephenson *et al.*, 2000; Underwood and Arthur, 1996). Children in South Asia, eastern, western, central, and southern Africa have the highest prevalence of VAD (Mason *et al.*, 2001). VAD is caused by habitual inadequate intake of bioavailable carotenoids (provitamin A) or vitamin A to meet physiological needs (Van Jaarsveld *et al.*, 2005). Plant foods do not contain vitamin A, however, they contain precursors or provitamin A (β-carotene and other carotenoids), which the human body converts to vitamin A. One approach to controlling VAD is improving dietary quality and quantity through diversification. Dietary diversification includes the production of β-carotene-rich crops such as orange-fleshed sweet potato for human consumption (Van Jaarsveld *et al.*, 2005).

More than eight decades ago, Steenbock (1919) reported that sweet potato eliminated the symptoms of VAD in rats. Later, Ezell and Wilcox (1948) stressed the importance of sweet potato as a source of β-carotene. Haskell *et al.* (2004) concluded that daily consumption of cooked, pureed green leafy vegetables or sweet potatoes impacts positively on vitamin A stores in populations at risk for VAD. In Kenya, orange-fleshed sweet potatoes have been recognized as the least expensive year-round source of provitamin A (Low *et al.*, 1997). Hagenimana *et al.* (1999) reported that consumption of orange-fleshed sweet potato increased the dietary vitamin A intake in Kenyan children and women. Another study indicated that consumption of orange-fleshed sweet potato could contribute substantially to reducing VAD in sub-Saharan Africa (Low *et al*., 2001). The consumption of diets containing primarily orange-fleshed sweet potatoes as a source of β-carotene significantly increased serum retinol (vitamin A status) levels of Indonesian children with marginal VAD (Jalal *et al*., 1998). Van Jaarsveld *et al*. (2005) also concluded that increased consumption of orange-fleshed sweet potato could be a feasible food-based strategy for controlling VAD in children in developing countries.

Sweet potato varieties exist in many colors of skin and flesh, ranging from almost pure white through cream, yellow, orange, or pink, to a very to deep purple, although white and yellow-orange flesh are the most common (Onwueme, 1978). For example, white- to cream-colored flesh sweet potatoes are common in the South Pacific, Africa, the Caribbean, and most other developing countries. In contrast, sweet potatoes commonly consumed in the United States and other developed countries, normally have yellow to orange flesh (Bradbury and Holloway, 1988). The commercial sweet potato varieties in Hawaii have white, cream, yellow to orange, and purple color flesh. The flesh colors and β-carotene content in sweet potato roots vary widely because they are affected by genetic variety, maturity, growing conditions, postharvest storage, season, and which part of the vegetable is consumed (Hart and Scott, 1995; Hulshof *et al*., 1999). The intensity of the yellow or orange flesh color of the sweet potato is directly correlated to the carotenoid content (Ameny and Wilson, 1997). Sweet potato is an excellent source of carotenoid because its major carotenoid is all *trans*-β-carotene, which exhibits highest provitamin A activity among the carotenoids.

Carotenoids, which can be red, yellow, or orange, are a diverse group of structurally related isoprenoids biosynthesized mainly by plants that have the capacity to trap lipid peroxyl radicals and singlet oxygen species (Ben-Amotz and Fishler, 1998). Provitamin A carotenoids are those which can be cleaved to yield retinaldehyde. β-Carotene, the primary carotenoid in sweet potato, is cleaved in the intestinal mucosa by carotene dioxygenase, yielding retinaldehyde, which is reduced to retinol (vitamin A). The total amount of vitamin A in foods is expressed as microgram retinol equivalents (Bender, 2002). Nutritionally, 6 μg of dietary β-carotene is equivalent to 1 μg of retinol (Bender, 2002). Provitamin A from orange-fleshed sweet potato appears to be more bioavailable than that from dark green leafy vegetables (de Pee *et al*., 1998; Jalal *et al*., 1998).

Ben-Amotz and Fishler (1998) reported relatively high β-carotene content in sweet potato (Table II). Hagenimana *et al*. (1998a) reported varying β-carotene for orange, cream, and white flesh sweet potato roots, respectively, while Holland *et al*. (1991) reported β-carotene values for orange-fleshed sweet potatoes (Table II). Huang *et al*. (1999) reported β-carotene contents for 18 commercial varieties of sweet potato roots grown in Hawaii.

TABLE II
β-CAROTENE CONTENTS OF SWEET POTATO REPORTED BY DIFFERENT RESEARCHERS

References	β-Carotene content (μg/100 g) unless otherwise indicated	Sweet potato type
Holland *et al.*, 1991	1800–16,000	Orange-fleshed sweet potatoes on fresh weight basis
Simonne *et al.*, 1993	100–19,000	dwb
Bhaskarachary *et al.*, 1995	1000	Yellow-fleshed variety “kiran”
Hulshof *et al.*, 1999	5.0 ± 1.0 to 58.0 ± 70.0	Indonesian sweet potato varieties
Ben-Amotz and Fishler, 1998	79.8	dwb
Hagenimana *et al.*, 1998a	2130 ± 109 to 7983 ± 339 158 ± 39 to 1071.3 ± 101 19.6	Orange flesh, cream flesh, white flesh
Huang *et al.*, 1999	6700–13,100 <0.1–0.6	Orange flesh, yellow, white, and purple flesh
Sungpuag *et al.*, 1999	7.9 ± 0.2 4.5 ± 0.3	Raw, yellow-flesh cooked, yellow-flesh
Dansby and Bovell-Benjamin, 2003a	1566 ± 306	Raw, orange-flesh, hydroponic, fresh weight
Namutebi *et al.*, 2004	6800–12,500	Orange-flesh
Bendech *et al.*, 2005	1911–2348	Orange-flesh grown in Burkino Faso

The β-carotene content of raw orange-fleshed hydroponically grown sweet potato was reported by Dansby and Bovell-Benjamin (2003a). Simonne *et al.* (1993) reported the β-carotene content in blanched sweet potato roots from different cv. (Table II). Bendech *et al.* (2005) reported mean β-carotene contents for orange-fleshed sweet potatoes grown in Burkino Faso as shown in Table II. Namutebi *et al.* (2004) and Sungpuag *et al.* (1999) detailed high β-carotene concentrations for orange-fleshed, and raw and cooked yellow sweet potato varieties (Table II). Traditional Indian sweet potato cv. are white fleshed and contain no carotenes, however, a new yellow-fleshed variety, “kiran” showed significant amounts of β-carotene, and mean β-carotene content for six samples was 1087 ± 0.14 μg/100 g (Bhaskarachary *et al.*, 1995).

Cancer is not a rare disease in most developing countries. For example, in women, cancer cumulative mortality from cancer in developing countries is actually higher than in developed countries (Parkin *et al.*, 2005). Several epidemiological studies have shown associations between carotenoids such as β-carotene, and decreased risk for cancer, heart disease, and age-related macula degeneration (Kohlmeier and Hastings, 1995; Niizu and Rodriguez-Amaya, 2005; Olson, 1996; Russell, 1998; van Poppel and Goldbohm, 1995). Using a case-control study, Pandey and Shukla (2002) evaluated the possible role of diet in gallbladder carcinogenesis. The authors reported that a significant reduction in odds ratio (OR 0.33; 95% CI 0.13–0.83) was seen with the consumption of sweet potato, radish, and green chili. On the basis of its β-carotene content, there is a potential role for sweet potato in cancer prevention and risk reduction.

D. MINERAL CONTENTS

It has been argued that the mineral content of agricultural products varies with geographic location. Makki *et al.* (1986) reported that in two Egyptian sweet potato cv., the mineral in highest concentration was calcium followed by magnesium, iron, copper, zinc, and manganese. However, older data reported by Ekpenyong (1984) from FAO (1972) cited phosphorous as the mineral in highest concentration for sweet potatoes. The data indicated 56-, 36-, 0.9-, 2.0-, and 387-mg/100 g for phosphorus, calcium, iron, zinc, and manganese, respectively. Olaofe and Sanni (1988) reported potassium (3617 mg/100 g) as the most abundant mineral in sweet potato roots followed by magnesium (580 mg/100 g) and calcium (112 mg/100 g). Manganese, iron, copper, and zinc were present in low amounts of 8.8, 14.0, 1–5.0, and 3.0 mg/100 g, respectively. A more extensive discussion of mineral occurrence in sweet potato is contained in Woolfe (1992).

E. DIETARY FIBER

The importance of dietary fiber in noncommunicable disease prevention has been extensively discussed elsewhere (Guillon and Champ, 2000; Schneeman, 1998). Dietary fiber contains all the polysaccharides and lignin of the diet that are not digested by human enzymes (Brody, 1994). Dietary fibers include: resistant starches; cellulose; hemicellulose; β-glucans; pectins, nonstarch polysaccharides and lignin (Brody, 1994). For populations that consume sweet potato as a staple food, its dietary fiber contribution could be critical. Huang *et al.* (1999) reported that the total dietary fiber content of orange-fleshed sweet potato cv. ranged from 2.0 to 3.2 g/100 g fresh weight, which is higher than the 0.7 g/100 g listed in the United States Department of Agriculture (USDA) database. Four purple-fleshed sweet potatoes had dietary fibers ranging from 2.3 to 3.9 g/100 g, while yellow/white-fleshed sweet potato cv. had values between 2.3 and 3.3 g/100 g (Huang *et al.*, 1999). Crude dietary fiber ranged from 3.8% to 5.9% in 49 varieties of sweet potatoes analyzed by Oboh *et al.* (1989). Two Egyptian sweet potato cv., "*Abees*" and "*Giza 69*" studied by Makki *et al.* (1986) had crude dietary fiber contents of 5.6% and 5.7%, respectively, dwb. Total dietary fiber content of two kinds of sweet potato roots were reported as 3.4 and 2.3 g/100 g by Ishida *et al.* (2000).

However, in agreement with Tsou and Hong (1992), it should be noted that crude dietary fiber which consists of cellulose and lignin does not adequately express the role of sweet potato as a dietary fiber provider in human nutrition. Research is being conducted to provide consumers with a sweet potato, which is low in cellulose and lignin but high in other components of dietary fiber (Tsou and Hong, 1992).

F. ANTHOCYANINS

Until the mid-1800s, the only external sources of colorants used in food systems were natural (Gilbert, 2005). Over the next 50 years, synthetic organic dyes became the most common type of food coloring (Gilbert, 2005). However, during the last decade, the demand for food colorants from natural sources has increased because of legislative and consumer pressure to reduce the use of synthetic additives in foods (Giusti and Wrolstad, 2003). Evidence of this trend is reflected in food industry's replacement of synthetic dyes such as FD&C red 40 and the banned FD&C red 2 with natural plant colorants (Fabre *et al.*, 1993). Additionally, most natural colorants are bioactive, and they add status to food products marketed as "natural" and "organic."

Anthocyanins are a large group of water-soluble pigments responsible for the attractive orange, red, purple, and blue colors of fruits and vegetables (Plata *et al.*, 2003). Anthocyanins extracted from plants are commonly used in soft drinks, jams, confectioneries, and bakery products as a natural colorant (Plata *et al.*, 2003). Deep purple sweet potato flour (SPF) and paste are also used as coloring materials for bread, snacks, and noodles (KNAES, 1995). Cevallos-Casals and Cisneros-Zevallos (2002) reported Peruvian, purple sweet potato colorant as having much higher color retention and more stability than commercial red grape colorant. Additionally, there is an increasing demand for carotenoids, such as β-carotene, as food colorants because of their natural origin, lack of toxicity, and flexibility of providing both lipo- and hydrosoluble colorants (Ben-Amotz and Fishler, 1998; Cinar, 2005).

Consumption of the sweet potato has always been associated with good health and enhanced human nutrition. However, limited research has addressed the role of sweet potato in human nutrition and health. In human life, cell damage from oxygen free radicals (OFRs) is ubiquitous. OFRs are known to have carcinogenic potential (Dreher and Junod, 1996). Dietary or natural antioxidants such as carotenoids are said to be protective against the effects of OFRs. Antioxidants exert their effect on OFRs by neutralizing them (Scheibmeir *et al.*, 2005).

It has been reported that white, yellow, orange, and purple-fleshed sweet potato cv. have antioxidative and radical-scavenging activities, with the purple

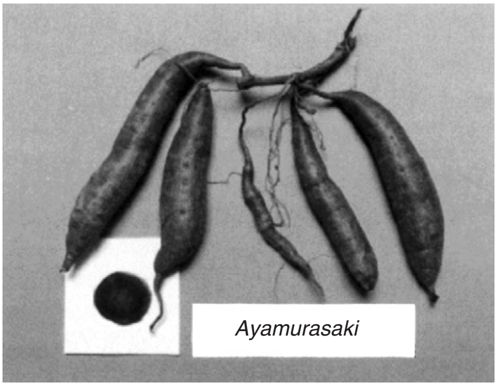

FIG. 3 *Ayamurasaki* sweet potato with high-antioxidative and radical scavenging activities (Cevallos-Casals and Cisneros-Zevallos, 2002; Furuta *et al.*, 1998).

ones such as cv. *Ayamurasaki* (Figure 3) having the highest activity (Cevallos-Casals and Cisneros-Zevallos, 2002; Furuta *et al.*, 1998). Antioxidant activity of purple sweet potato was observed to be 3.2 times higher than that of a blueberry variety (Cevallos-Casals and Cisneros-Zevallos, 2002). Interestingly, the antioxidant activity in sweet potato skin was found to be almost three times higher than in the rest of the tissue. Animal studies have shown that when purple sweet potato juice from cv. *Ayamurasaki* was fed to rats it reduced liver injury induced by carbon tetrachloride (Suda *et al.*, 1998). Persons consuming cv. *Ayamurasaki* juice daily for 44 days effectively decreased the blood serum levels of λ-guinidine triphosphate (GTP), glutamin-oxaloactive transaminase (GOT), and glutamin-pyruvic transaminase (GPT) (indicators of liver injury) (Suda *et al.*, 1998). Suda *et al.* (2003) reported that purple-fleshed sweet potato is a good source of anthocyanin.

Some foods contain mutagens, which are associated with carcinogenesis. Purple-fleshed sweet potato roots were reported to have high antimutagenic activity (Yoshimoto *et al.*, 1999). Various studies have reported the relationship between consumption of anthocyanin-rich foods and improved health. Health benefits associated with anthocyanin extracts include chemopreventive activities such as antimutagenicity and antioxidative potential (Table III). It has also been shown that a glycolipid (ganglioside) found in sweet potato juice reduces the multiplication of cultured human cells in cancers of the womb neck and melanoma (Shimozono *et al.*, 1996). Sweet potato juice has been associated with antihypertensive and antidiabetic properties (Kusano and Abe, 2000; Matsui *et al.*, 2001; Suda *et al.*, 1998). Further, the anthocyanins, chlorogenic acid, and other polyphenolic compounds in sweet potato have the capability to inhibit carcinogens generated during food processing and cooking.

TABLE III
POSSIBLE HEALTH BENEFITS ASSOCIATED WITH ANTHOCYANINS

Possible health benefit	References
Chemopreventive activities (e.g., antimutagenicity)	Karaivanova *et al*., 1990; Morazzoni and Magistretti, 1986
Vasoprotective and anti-inflammatory properties	Lietti *et al*., 1976
Enhancement of sight acuteness	Politzer, 1997; Timberlake and Henry, 1988
Antidiabetic, controlling diabetes, and antineoplastic agents	Kamei *et al*., 1995; Matsui *et al*., 2002, 2004; Scharrer and Ober, 1981
Hepatoprotective	Mitcheva *et al*., 1993
Vasotonic agents	Colantuoni *et al*., 1991
Radiation-protective agents	Akhmadieva *et al*., 1993; Minkova *et al*., 1990
Antioxidant capacity	Islam *et al*., 2002, 2003; Prior *et al*., 1998; Rice-Evans and Miller, 1996; Tamura and Yamagami, 1994; Wang *et al*., 1997
Antihypertension	Suda *et al*., 1998; Yoshimoto, 2001
Fibrocystic disease of the breast	Leonardi, 1993

Sweet potato also contains the coumarins scopoletin (3, $R{=}H$), aesculetin (3, $R{=}OH$), and umbelliferone (3, $R{=}OMe$) compounds, which have anticoagulation properties and are postulated to inhibit HIV replication (Weiss and Finkelmann, 2000). The sweet potato could be considered as an excellent novel source of natural health-promoting compounds, such as anthocyanins, for the functional food market. Ultimately, this could increase utilization and demand for the crop by consumers, and the food industry.

In sum, the commonly consumed white to cream-colored-flesh sweet potatoes in the South Pacific, Africa, the Caribbean, and most other developing countries contain less β-carotene than the orange-fleshed sweet potato. Orange-fleshed sweet potato is one of the most promising plant sources of β-carotene (Hagenimana and Low, 2000). However, it should be noted that although orange-fleshed sweet potato roots contain abundant amounts of β-carotene, the content decreases over time with processing (van Hal, 2000). Sungpuag *et al*. (1999) also demonstrated that boiling yellow-fleshed sweet potato resulted in further loss (43%) of β-carotene. Increased consumption of fresh orange-fleshed sweet potato roots and sweet potato-based processed foods in developing countries could contribute substantially toward improving vitamin A nutrition and enhancing food security. Sweet potato contains β-carotene and other dietary carotenoids, which have anticancer properties. The high concentration of anthocyanin and β-carotene in sweet potato combined with the high stability of the color extract make it a promising and healthier alternative to synthetic coloring agents in food systems.

IV. SWEET POTATO UTILIZATION AS VALUE-ADDED PRODUCTS IN HUMAN FOOD SYSTEMS

Over the last 40 years, utilization of the sweet potato has shifted from being a "subsistence," "food security," or "famine relief" crop in some developing countries. Although traditional uses are still important in many countries, new uses are emerging, especially in China and parts of sub-Saharan Africa. Average annual per capita consumption of fresh roots for 1994–1996 was estimated at: 73, 18, 9, 7, 5, and 2 kg in Oceania, Asia, Africa, Japan, Latin America, and United States, respectively (FAO, 1997). In contrast to potato, per capita sweet potato consumption in Canada, Europe, and Australia is extremely limited and often confined to immigrant populations. In the developing world, sweet potato consumption varies by countries, regions, season of year, and income. For example, in Africa annual per capita sweet potato consumption in Rwanda is estimated at 160 kg; Burundi, 102 kg; and Uganda 85 kg. In northeast Uganda (one of the poorest parts of that country), sweet potato becomes a seasonal staple during the dry season when most other foodstuffs are in short supply. Currently, US per capita consumption is roughly 9.5 kg down from a recorded high of 30.6 kg in 1949.

Several years ago, Carver (1918) recognized and demonstrated the importance of processing the sweet potato into value-added products by encouraging economically deprived farmers in the southern United States to grow and process it. Approximately 100 new products were processed from the sweet potato in Carver's era, including flour, starch, sugar bread, mock coconut, tapioca, and vinegar (Carver, 1918). Additionally, SPF has been fermented to make products such as soy sauce and alcohol, or if immediately cooked, could be further processed into wine, vinegar, and "Nata de coco." "Nata de coco" is a popular dessert or "on-the-go" food in the Philippines, and adjacent Asian countries, and is becoming very popular in Japan. It is a chewy, translucent, ready-to-eat mixture of coconut, sweet potato, and fruit, which resembles the American canned "fruit cocktail."

Today, long after Carver's era, most of the global sweet potato production is marketed as cleaned, but otherwise unprocessed roots (Burden, 2005). Unprocessed sweet potato roots have a short shelf life compared to carrots, white potatoes, and so on, and they are difficult to store. In developing countries, where limited transport infrastructure exists, processing the sweet potato into value-added products provides an alternative to the difficulties associated with storage and transport of the raw roots (Dansby and Bovell-Benjamin, 2003a). Furthermore, vegetable industry data suggest that 15% of all vegetables marketed in the United States are now in more consumer-friendly, convenient forms (Burden, 2005). If the sweet potato is to gain increased market visibility and play a more important role in human nutrition, some of the total production must be converted into more consumer-friendly, convenient forms such as: (1) ‘‘minimally processed’’(ready-to-use—peeled and packaged or peeled, cut, and packaged); (2) ‘‘intermediate processed’’ (bulk ingredients such as flour and starch for use in other products, and so on); and (3) ‘‘preprocessed’’ (ready-to-eat products). The following sections discuss some potentially feasible value-added products from the sweet potato.

V. SWEET POTATO STARCH UTILIZATION IN HUMAN FOOD SYSTEMS

In developing countries, sweet potato offers much potential for income generation through small-scale processing because they are efficient producers of carbohydrate. Carbohydrates could be converted into stable intermediate bulk ingredients (starch and flour) that are suitable for diverse markets in the food industry (Wheatley *et al*., 1996). Bulk ingredients from the sweet potato can be incorporated into the menus for astronauts and human food systems by further processing them into convenient, ready-to-use products. For example, sweet potato starch (SPS) can be enzymatically processed into different products such as glucose syrup, which have a wide range of applications in the food and pharmaceutical industries (Sarikaya *et al*., 2000). Starch is very versatile with a number of uses in most major industries, but in developing countries, it is used predominantly to make processed foods. Worldwide, the biggest user of starch is the sweetener industry. In the food industry, starch is used to impart ‘‘functional’’ properties to processed foods such as thickening, binding, and filling. Starch is also used in canned soups, instant desserts, ice creams, noodles, processed meats, sauces, and bakery products. It can be processed into sweeteners and syrups, and in the manufacture of monosodium glutamate, a taste enhancer (Fuglie and Oates, 2002; Zhang and Oates, 1999). About 5% of total SPS production is used for making distilled spirit ‘‘shochu’’ in Japan as well as lactic acid, butanol, acetone, vinegar, and yeast (Woolfe, 1992). SPS has been successfully used to thicken chocolate pudding at Tuskegee University (Hoffman and Bovell-Benjamin, 2001). Major users of starch in nonfood industries include the textile, paper, plywood, and adhesive industries and pharmaceuticals.

Starch is a naturally occurring biopolymer in which glucose is polymerized into amylose, an essentially linear polysaccharide, and amylopectin, a highly branched polysaccharide. Starch occurs in plant tissues in the form of discreet granules whose size, shape, and form are unique to each botanical species (Woolfe, 1992). Sweet potato roots contain approximately 80–90%

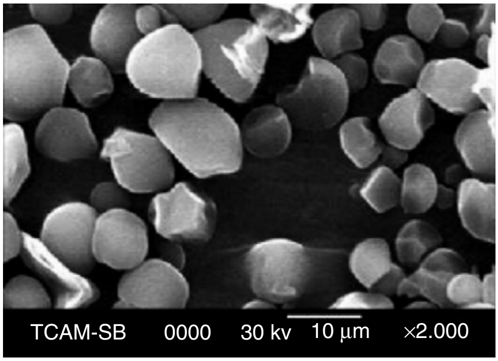

FIG. 4 Scanning electron micrographs of sweet potato starch granules (Miller *et al.*, 2003).

carbohydrate, mainly starch, making it a good raw material for the starch industry (Garcia and Walter, 1998; Lu and Sheng, 1990; Miller *et al.*, 2003). Brabet *et al.* (1998) evaluated 106 sweet potato clones and reported an average total starch content of 61.5% dwb. Miller *et al.* (2003) reported 81% starch content on dwb in SPS. According to Woolfe (1992), sweet potato starches occur in oval-, round-, or polygonal-shaped granules, and mean granule size ranges from 12.3 to 21.5 µm. Bovell-Benjamin *et al.* (2004) isolated SPS and reported granule sizes in the range of 9.0–34.2, 2.6–15.8, and 5.3–21.8 µm for J6/66, Beauregard, and TU-82-155 cv., respectively (Figure 4). These findings were consistent with those of Mandamba *et al.* (1975) and Chen *et al.* (2003) who reported the same phenomenon for the granule size of three Chinese sweet potato cv. Kays (1992) also reported a range from 1 to 30 µm for SPS granules. Starch processing from sweet potato can create new economic and employment activities for farmers and rural households and can add nutritional value to food systems.

Conversion of sweet potato to starch should be especially attractive to developing countries because it can help to lessen the need for imported materials, which reduces import bills (Garcia and Walter, 1998). For example, sweet potato accounted for 26% of starch production in Asia, and the global SPS production of 4.15 million metric tonnes in the early 1990s came from Asia (Ostertag, 1993). SPS is widely used in a variety of food and industrial applications in Asia (Tian *et al.*, 1991). An industry based on SPS extraction has been developed in several regions in China (Li *et al.*, 1991) and may account for more than two million tonnes annually, but the statistics are not quite precise (Wheatley and Bofu, 2000). The starch is utilized primarily for the production of traditional noodles, although some factories use it for production of derived products such as maltose. For noodles, starch quality is an important factor, and starch from sweet potato is preferred over starch from other crops such as corn and cassava (Fuglie and Oates, 1990). Vietnam exports about 840 tonnes of sweet potato annually to China for production of maltose and glucose syrups, which are used in the manufacture of baby foods in some developed countries. Recently, SPS has emerged as a commercially important value-added product in the Philippines with the institution of three starch plants in the last 9–10 years (Collado *et al*., 1999). CIAD *et al.* (1996) assessed the potential demand for SPS in both food and nonfood industries in China, and industry estimated starch demand at over 200,000 million tonnes versus 100,000 million tonnes of maize starch actually supplied to the industrial sector. This situation reflects a great potential for SPS in human food systems, although some uncertainties have been reported.

Researchers have reported that starches from different sweet potato cv. exhibit a variety of nutritive, physical and sensory properties, such as higher starch content and more extractable starch (Madhusudhan *et al*., 1996). Maximizing starch yield from the sweet potato requires varieties with high dry matter and starch contents; however, these genetic characteristics can be manipulated. Ideally, for most food products SPS should have a smooth texture, which is consistently soft and flexible at low temperature and must be able to retain its thickening power at high temperature (Garcia and Walter, 1998). In SPS production, quality of the fresh root and the amount of extractable starch are important because of their influence on final product quality and effects on process efficiency. The key issue in SPS production is product quality, especially the chemical (ash, protein, fiber, and so on) and functional properties of the starch itself. Wheatley and Bofu (2000) reported that SPS has low viscosity values on pasting when compared with potato starch, and it may not be sufficiently white in color. However, Miller *et al.* (2003) reported L^* color values of SPS, which are comparable to those of cornstarch. Excessive moisture content, as high as 15%, has been reported for SPS, but Miller *et al.* (2003) and Bovell-Benjamin *et al*. (2004) reported a 4.4 ± 0.2%, 5.0 ± 0.2%, and 6.0 ± 0.3% moisture contents for starch extracted from three sweet potato cv. (J6/66, TU-82-155, and Beauregard, respectively). Garcia and Walter (1998) extracted starch from seven sweet potato cv. and reported moisture levels extending from 9.8% to 15.3%. The limited chemical properties (impurities) reported could be addressed through process improvements such as more effective separation, additional purification steps, and more efficient drying.

For example, in China, Timmins and Marter (1992) added "sour liquid" from a traditional fermentation process (liquid fermentate from peas or beans) at the separation stage to remove impurities, which produce off-colors in the SPS (Figure 5). The process of starch isolation from the sweet potato using a modified technology with more efficient drying is shown in Figure 5. The functional properties of SPS can be manipulated by processing (milling, sifting) as well as by cv. selection and chemical or enzymatic modifications. The seasonal nature of the sweet potato harvest limits the processing period,

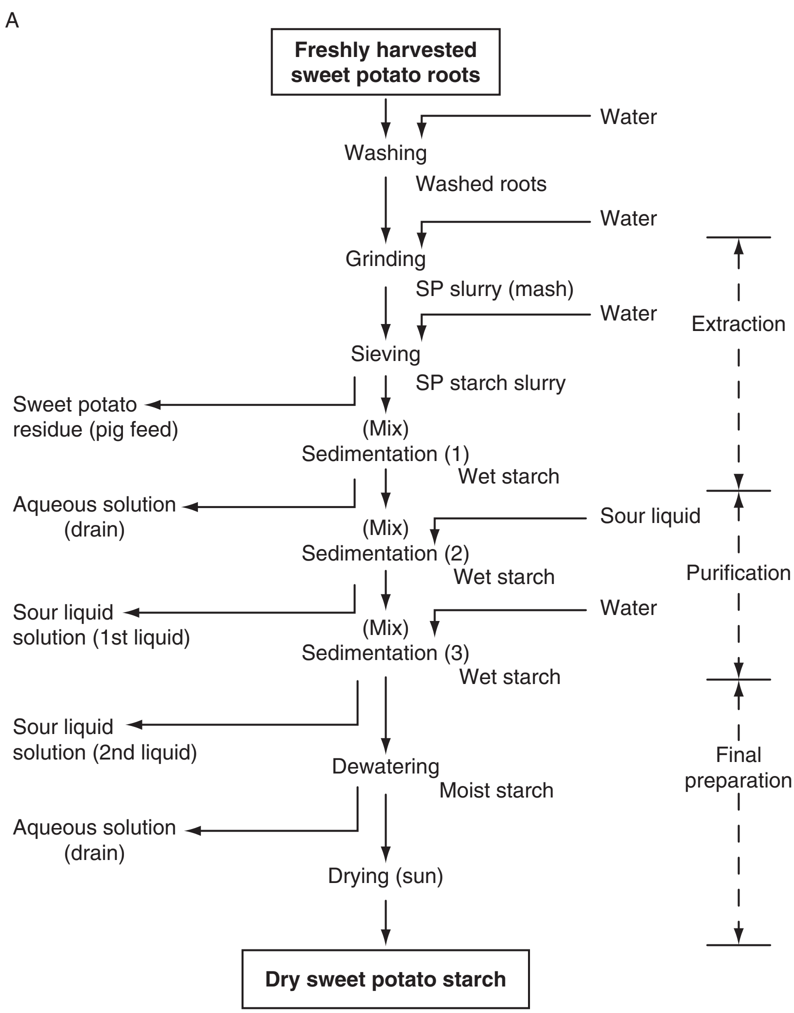

FIG. 5 (*continued*)

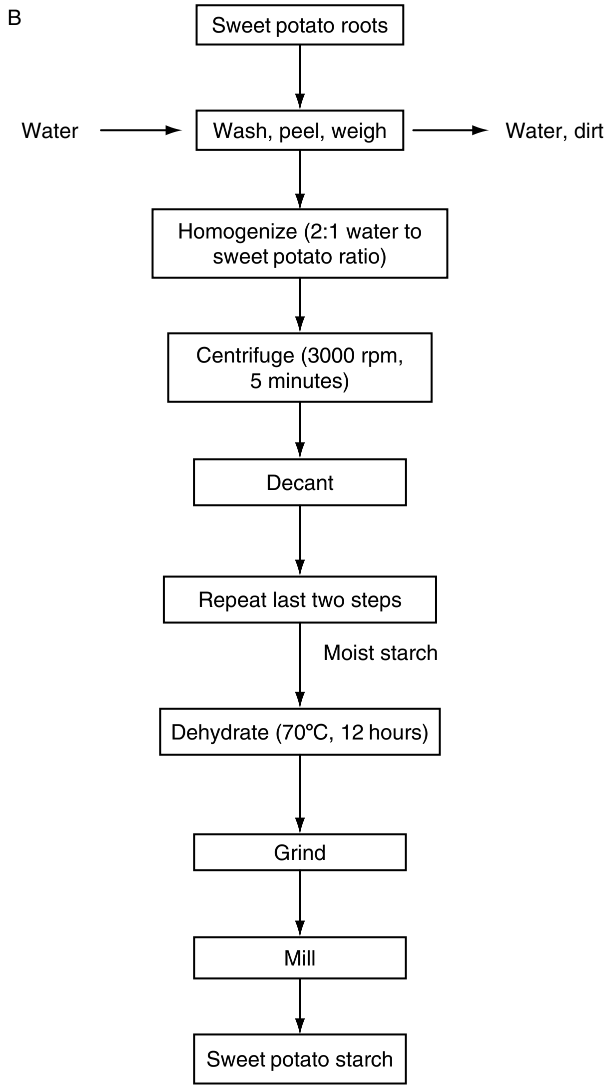

FIG. 5 Procedures for sweet potato starch production. (A) Sweet potato starch production by the sour-liquid method (Timmins and Marter, 1992). (B) Sweet potato starch isolation (Miller *et al.*, 2003).

and such constraints help to make large-scale investment in production of SPS uneconomic. However, small- and medium-scale enterprises may not suffer from this drawback. The summaries of the following studies demonstrate the potential usefulness of SPS in human food systems in space and on Earth.

A. BULK INGREDIENTS FROM THREE CV. OF SWEET POTATOES: COMPOSITION AND PROPERTIES (BOVELL-BENJAMIN *ET AL.*, 2004)

The study processed three sweet potato cv. into starch and evaluated the suitability of the starch for use as a bulk ingredient on space flights and on Earth. Starch was isolated from TU-82-155, Beauregard, and J6/66 cv. as shown in Figure 5B, and X-ray diffraction (XRD) was used to determine starch crystallinity level. The protein, ash, moisture, carbohydrate, and fat contents of starch from the three different cv. were similar (Table IV). Figure 6 shows the XRD patterns of the three sweet potato starches, as well as that for TU-82-155 hydroponically grown sweet potato. The Beauregard, J6/66, and the hydroponic sweet potato starches had similar XRD patterns. However, the field grown TU-82-155 exhibited only one XRD peak, indicating that the sample was almost entirely amorphous. According to Morris *et al.* (2005), the strong 3.8- to 5.8-Å spacings are consistent with the presence of crystallites characterized by a hexagonal array of sixfold amylase double helices, whose central channel is occupied by another double helix. This structure, which is typical of cereal starch crystallites, was also recognized in SPS. These results suggest that it is possible to relate the functional properties of the SPS to the XRD patterns, and hence predict their potential use in human food systems.

B. EFFECTS OF PROCESSING TECHNOLOGY ON SPS YIELD AND QUALITY (JIANJUN, 2004)

The effect of processing technologies that affect the quality and extraction rate of SPS was examined by orthogonal design. An orthogonal test was made with nine trials which included three combinations of technologies on milling method, separating fineness, and precipitation method of starch extraction from "Xushu 18" sweet potato cv. Two sets of technology to enhance starch quality and extraction rate were identified. Recommendations to improve

TABLE IV
PROXIMATE COMPOSITION STARCH PROCESSED FROM THREE SWEET POTATO CV.

Cultivar	Moisture (%)	Carbohydrate (%)	Protein (%)	Ash (%)	Fat (%)
J6/66	4.4 ± 0.2	93.6	1.3 ± 0.0	0.6 ± 0.01	0.1 ± 0.1
TU-82-155	5.0 ± 0.2	92.8	1.2 ± 0.0	0.7 ± 0.04	0.3 ± 0.2
Beauregard	6.0 ± 0.3	92.1	1.1 ± 0.1	0.6 ± 0.01	0.2 ± 0.1

Source: Bovell-Benjamin *et al.* (2004).

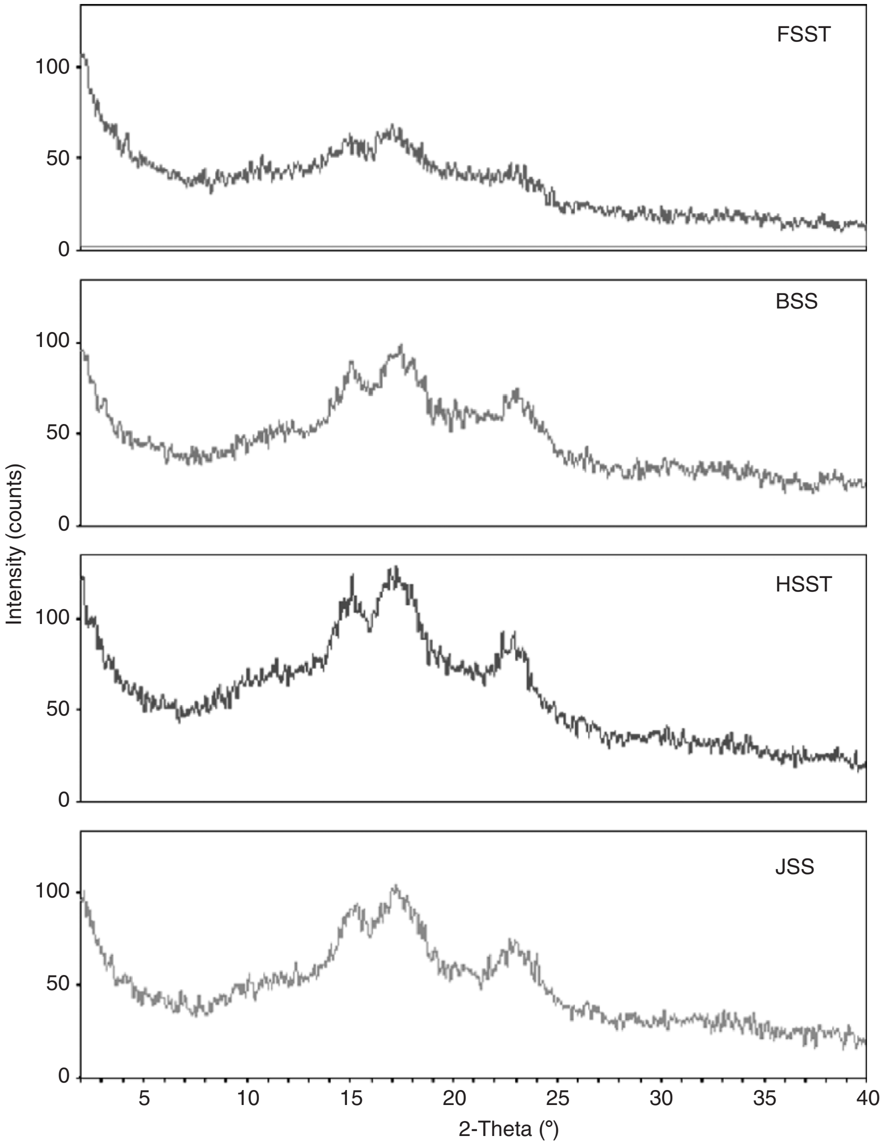

FIG. 6 X-ray intensity curves for starch from three sweet potato cv. FSST, starch from TU-82-155 cv. (field grown); BSS, starch from Beauregard cv.; HSST, starch from TU-82-155 cv. (hydroponic); JSS, starch from J6/66 cv. (Greene, 2003).

starch quality were the combination of saw tooth milling at 1000 rpm, separation using 120-size mesh, and precipitation with sour liquid. A combination of hammer mill in 4200 rpm, separation using 120-size mesh, and natural precipitation was recommended to improve extraction rate.

C. PHYSICOCHEMICAL AND VISCOMETRIC PROPERTIES OF AN SPS SYRUP (MILLER *ET AL.*, 2003)

This study processed syrup from SPS and determined its physicochemical [refractive index (RI) and color] and viscometric properties during storage at 21 ± 3 and 4°C. SPS was isolated from field-grown Hillbilly sweet potato cv. (Figure 5B). The SPS was rehydrated, heated to 102°C, treated with α-amylase at 90°C for 5 hours, cooled, and further treated with glucoamylase at 62.5°C for 12 hours (Figure 7). The solutions were filtered, evaporated, and cooled. RI, color, and viscometric properties were measured. The RI of the sweet potato syrup was significantly higher ($p < 0.01$) than that reported in the literature (1.42 ± 0.02 vs 0.66). The mean L^*, a^*, and b^* values of the syrups were 68.8 ± 0.6, 0.7 ± 0.1, and 18.7 ± 0.6, respectively.

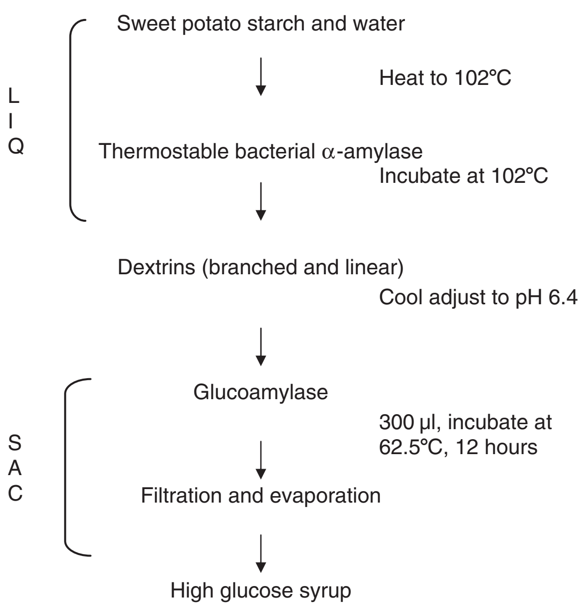

FIG. 7 Overview of enzymatic hydrolysis of sweet potato starch into glucose syrup. LIQ = Liquefaction, SAC = Saccharification (Bovell-Benjamin *et al.*, 2005).

The mean viscosity of the sweet potato syrup was 1.98 Pa·s at room temperature and 0.95 Pa·s at 4°C. The viscosity for the sweet potato syrup gradually increased as storage time increased. With syrups stored at both temperatures, increased shear stress decreased their viscosities. However, when a commercial corn syrup was tested under the same conditions, there was no decrease in viscosity as shear stress increased. Overall, the SPS syrup had RI, color, and viscosity comparable to that of the commercial corn syrup.

D. EFFECTS OF pH AND CONCENTRATION TIMES ON SELECTED FUNCTIONAL PROPERTIES OF A SWEET POTATO SYRUP (YOUSIF-IBRAHIM *ET AL.*, 2003)

The overall objective of this study was to optimize previously developed sweet potato syrup. Specifically, the study determined the effect of varying pH and time at the liquefaction and concentration stages, respectively, on the moisture, RI, color, and yield of an SPS (Figure 10). SPS was used to process three syrups in which the protocol remained constant, except for the pH and concentration times. At the liquefaction stage, the pH was adjusted to 6.4, 7.0, and 8.0 for Syrup A (SPSA), Syrup B (SPSB), and Syrup C (SPSC), respectively. At the concentration stage, the syrups were exposed to 35, 40, and 43 minutes of heat. The moisture content of the syrups concentrated for 35 minutes was significantly ($p < 0.05$) different, with the SPSC having the highest moisture. Similarly, the moisture content for the SPSC heated for 40 minutes was highest, but lowest when heated for >43 minutes. The mean refractive indices were similar for the syrups, ranging from 1.4 to 1.5. As the concentration time increased, the L^* value decreased for the syrups, with SPSA being lightest in color at all concentration times. At all concentration times, the total syrup yield from 60-g SPS was highest for SPSC. The syrup with pH 8.0, and 40 minutes, at the liquefaction and concentration stages, respectively, had the most desirable RI, color, and overall yield.

E. INFLUENCE OF α-AMYLASE ON THE PHYSICAL PROPERTIES AND CONSUMER ACCEPTABILITY OF SPS SYRUP (BOVELL-BENJAMIN *ET AL.*, 2005)

Technology was developed on a laboratory scale for the production of SPS syrup, and the effect of varying levels of α-amylase on syrup quality, storage stability, and consumer acceptance were evaluated. Three levels of thermostable bacterial α-amylases (1.5, 3.0, and 4.5 ml) were used for conversion of SPS into glucose syrup. The 1.5-ml α-amylase-treated SPS was dropped from the experiment because there was no hydrolysis. The enzymatic conversion of SPS into glucose was significantly higher ($p < 0.05$) for the 4.5-ml α-amylase-treated compared to the 1.5 and 3.0 ml levels. The RI was 1.5 and 1.4 for the 4.5 and 3.0 ml α-amylase-treated syrups, respectively, while moisture content (16.7 vs 12.5) and °Brix (65.0 vs 57.0) were higher for the 4.5 ml α-amylase-treated syrup. Syrups were stored at room (RSPSS) and refrigerated (RESPSS) temperatures. During storage, the L^* color value for RESPSS was significantly higher ($p < 0.05$) than that of RSPSS. Similarly, the °Brix was 64.1 ± 1.1 and 66.0 ± 1.7 for the RSPSS and RESPSS, respectively. The RSPSS was stable for 12 weeks. The sweet potato starch syrup (SPSS) and two commercial syrups (maple and ginger) were evaluated by 112 children between the ages of 12 and 13 years on a nine-point hedonic scale with plain waffle as a "carrier." For the younger children, there were no significant differences in liking between the SPSS (6.1) and maple syrup (5.8). However, the mean preference for the ginger syrup was significantly less ($p < 0.001$). Overall, the SPSS had acceptable physical and consumer properties, indicating the need for further research to convert it into a commercially viable product.

F. SENSORY AND CONSUMER EVALUATION OF SPS SYRUP (MILLER *ET AL.*, 2003)

This study evaluated selected sensory attributes of SPS using a modified magnitude estimation (ME) procedure, and determined consumer acceptance using a nine-point hedonic scale. A syrup made from hydroponic sweet potato starch (HSPS) was tested against two commercial control (ginger and corn) syrups. For the ME, 11 undergraduate students on Tuskegee University campus were trained as judges to do ME scaling. The judges were trained in ratio scaling by contrasting a reference line with relative lengths of experimental lines in random order in proportion to the fixed modulus of 15 (Giovanni and Pangborn, 1983). The three syrups were evaluated in triplicate with the modulus anchored at "30." Five attributes, namely, mouthfeel, pourability, aroma, sweetness, and color were evaluated. The samples were evaluated relative to the modulus, for example, if a sample was twice as sweet as the modulus, it would be assigned the value of "60." For the consumer testing, 43 untrained judges evaluated the syrups for color, sweetness, aroma, viscosity, and overall preference.

The pourability of the HSPS and corn syrups was significantly ($p < 0.05$) higher than the ginger syrup, which is a more desirable feature for consumers. The ME judges scored the HSPS as having a more desirable color than both commercial syrups. Ratings for the HSPS and ginger syrups were similar for the aroma attribute, but significantly higher for the corn syrup. The ginger and corn syrups were equally sweet, but the HSPS was significantly ($p < 0.05$) less sweet. Consumers liked the color HSPS and corn syrups moderately (7.0 score on the hedonic scale), and this is promising because a 7.0 indicates that it is highly likely the particular attribute will be acceptable to consumers. The viscosity of the HSPS was also liked slightly and equally well as the commercial ginger syrup. However, the sweetness and aroma attributes were disliked slightly. Further optimization of the HSPS syrup such as isomerization into fructose syrup could help to improve the sweetness and aroma attributes.

VI. ADVANCES IN SPF PRODUCTION AND UTILIZATION FOR HUMAN FOOD SYSTEMS

Peters and Wheatley (1997) conducted an in-depth diagnostic assessment of the feasibility of establishing a household-level SPF processing industry in East Java. Their results identified SPF as a promising product to increase rural income with potential markets in bakery, noodle, and various snacks. This finding is also relevant to other developing countries such as Kenya, Uganda, and Nigeria where the potential for small-scale SPF production was identified as an alternative for traditional flours (Hagenimana and Owori, 1996; Hagenimana *et al*., 1995; Omosa, 1994). SPF could be marketed as a low-cost alternative to imported wheat flour, thus reducing bakery costs and foreign exchange bills. For example, Peters and Wheatley (1997) postulated that for a 5% substitution rate, the potential savings from wheat import reductions for Indonesia would be US$40,000,000 based on 1995 import volume and value. SPF can also serve as a source of carbohydrate, β-carotene, minerals; can add natural sweetness, color and flavor to processed products; and can prevent food allergies in some instances (van Hal, 2000).

Food allergies have become a public health issue in many countries including the United States (Maleki, 2001). Cereals containing gluten are ranked among the eight most common causes of food allergy (Taylor and Hefle, 2001). It is estimated that up to 5% of the population has serious allergies to some foods, including the gluten in wheat (Mannie, 1999). Celiac disease affects the small intestines due to sensitivity to gluten present in certain cereals including wheat, wheat starch, rye, barley, triticale, and probably oats, and the only effective treatment is strict adherence to a 100% gluten-free diet for life (Caperuto *et al*., 2000). SPF can serve as an alternative for individuals diagnosed with celiac disease or with allergies to the gluten in wheat.

Perhaps, more importantly, van Hal (2000) estimated that SPF could contribute 0–100%, 20%, 20–40%, 17%, and 10% of the daily nutrient needs [based on the recommended daily allowances (RDA)] for β-carotene, thiamin, iron, vitamin C, and protein, respectively. SPF can also be used directly or as a raw material for processing into other products. A variety of products such as doughnuts, biscuits, muffins, cookies, fried sweet potato cakes, extruded sweet potato chips, ice creams, porridge, brownies, pies, breakfast foods, and weaning foods have been made from SPF (Fuglie and Hermann, 2004; Greene, 2003). In India, dried sweet potatoes grounded into flour are used to supplement flours in bakery products, chapatis, and puddings, while in the Philippines, dried sweet potato chips are pounded into flour for use in gruel (Nair *et al*., 1987). The steps involved in processing sweet potato into flour are shown in Figure 8.

The ratio of the weight of the flour to the weight of the fresh sweet potato roots expressed as a percentage is termed the yield or conversion rate. Limited information regarding flour yields from sweet potato is available, but it is known that flour yield is dependent on factors such as sweet potato cv., technologies used, and the dry matter of the final flour. Dawkins and Lu (1991) reported a 13–18% yield in flour prepared from steam blanched, microwave blanched, and unblanched sweet potatoes. A flour yield ranging from 17% to 38% for different sweet potato cv. was also reported by Gakonyo (1993a). Two Philippine sweet potato cv. Georgia Red and Ilocos Sur were reported to yield 12 and 37 kg, respectively, of flour from 100-g fresh roots (Van Den, 1984). Dansby and Bovell-Benjamin (2003a) calculated the mass balance for flour made from hydroponic sweet potato and reported a yield of 15%. Average sweet potato root:flour conversion rates ranging from 23% to 27% were reported by Peters *et al*. (2005). Suismono (1995) reported 24% fresh root:flour conversion rate, while Martin (1984) reported a 17–38% range. Peters and Wheatley (1997) calculated the data from two on-farm trials, and the fresh

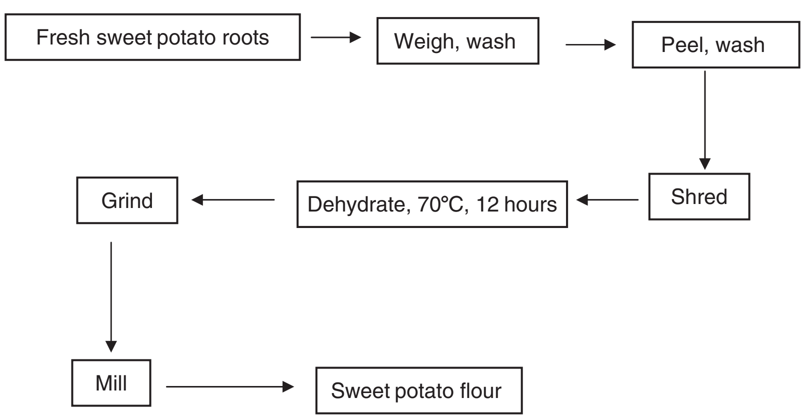

FIG. 8 Production of sweet potato flour (Dansby and Bovell-Benjamin, 2003a).

root:flour conversion rates were approximately 20%. Overall, the reported literature indicates that fresh sweet potato root:flour conversion rate ranges from 13% to 38%. Variations in yield could be affected by factors such as drying times, cv., processing methods, and calculations.

It is important to understand the functional, physical, and chemical characteristics of SPF if its suitability for use in value-added products has to be determined. Previous researchers have noted a lack of information on SPF quality. For example, Hagenimana and Owori (1996) mentioned that SPF is very convenient for utilization by the food industry, but its quality and shelf life are not documented. The quality characteristics of SPF include high starch content, white color, low acidity, crude fiber, and ash contents (Antarlina, 1990). The moisture content of SPF is especially important because high moisture can speedup chemical or microbial deterioration (van Hal, 2000). According to Woolfe (1992) and Collado and Corke (1999), the moisture content of SPF ranges from 4.4% to 13.2%. Reddy and Basappa (1997) prepared SPF using different peeling methods: hand, lye, mechanical abrasive, no peeling, and no peeling and cooking. Final SPF had moisture contents between 9.3% and 12.6%. The sensory, nutritional, and microbiological quality of SPF processed from nonsoaked and soaked slices using minimum amounts of water were compared by Owori and Hagenimana (2000). The moisture contents of SPF soaked for 0, 30, 60, and 90 minutes are shown in Table V. Fuglie and Hermann (2004) and

TABLE V
MOISTURE, CARBOHYDRATE, PROTEIN, AND β-CAROTENE CONTENTS OF SWEET POTATO FLOUR

References	Moisture (%)	Carbohydrate	Protein (%)	β-Carotene (μg/100 g)
Woolfe, 1992			1.0–14.2	60–39,848
Collado *et al.*, 1997			1.0–14.2	
Reddy and Basappa, 1997	9.3–12.6			
Dansby and Bovell-Benjamin, 2003a	2.6 ± 0.02 3.3 ± 0.1 2.9 ± 0.02 4.2 ± 0.1	89.1 ± 1.3 91.3 ± 1.9	0.9 ± 0.1 1.2 ± 0.1	16,800
Owori and Hagenimana, 2000	9.3 9.4 10.3		4.2 6.4	27,580 g/kg
Fuglie and Hermann, 2004	7.1	61.0	5.6	
Yadav *et al.*, 2005	73.0 ± 0.6 73.8 ± 0.7 73.6 ± 0.7		6.3–6.6 g/100 g	

Dansby and Bovell-Benjamin (2003a) also evaluated the moisture contents of SPF processed from conventionally and hydroponically grown sweet potatoes (Table V). The hydroponic SPF had lower mean initial moisture than those reported by Woolfe (1992) and Collado and Corke (1999). However, the final moisture content is dependent on the drying method and time.

The bulk of SPF is carbohydrate between 85% and 95% dwb, but this varies according to cv. Several researchers have reported the total carbohydrate content of SPF as ranging from 86.1% to 94.8% dwb (Gurkin-Ulm, 1988; Maneepun *et al*., 1992; Woolfe, 1992). Dansby and Bovell-Benjamin (2003a) reported carbohydrate values for hydroponic SPF stored for 5 months at room and refrigerated temperatures (Table V). Yadav *et al*. (2005) determined the effect of drying methods (native, drum dried, and hot air-dried) on the functional properties of SPF from red- and white-skinned sweet potato. Fuglie and Hermann (2004) documented carbohydrate content for a complex instant SPF as shown in Table V.

The protein content of SPF is usually low, ranging from 1.0% to 14.2% (Collado *et al*., 1997; Woolfe, 1992). Owori and Hagenimana (2000), Dansby and Bovell-Benjamin (2003a), Yadav *et al*. (2005), and Fuglie and Hermann (2004) reported protein values for SPF (Table V). The β-carotene content of SPF processed from hydroponically grown sweet potato reported by Dansby and Bovell-Benjamin (2003a) was within the range of that reported by Woolfe (1992) for field-grown sweet potatoes (Table V). Total dietary fiber of SPF was reported to range between 11.0 ± 0.1% and 17.6 ± 0.3% by Dansby and Bovell-Benjamin (2003a) and Yadav *et al*. (2005), respectively. Dietary fiber content of SPF is between 0.4% and 13.8% (van Hal, 2000). Fuglie and Hermann (2004) reported 2% crude dietary fiber in SPF. SPF has higher amounts of β-carotene than wheat products and is an effective way of increasing dietary carotenoid intake. Although SPF is identified as one of the most promising sweet potato products, its quality and storage stability need to be further researched.

Dansby and Bovell-Benjamin (2003a) evaluated the proximate composition and color of processed hydroponic SPF during storage. The researchers concluded that the storage temperatures and time (4 or 21 ± 4°C for 5 months) did not significantly affect the proximate composition and color of the SPF. However, although no discoloration or browning of the SPF was observed, the flour stored at 21 ± 4°C lost more of the orange/yellow color than that stored at refrigerated temperature. Orbase and Autos (1996) found that there was no discoloration in flour from four sweet potato cv. stored for 6 months in polyethylene, cotton, and polyethylene/cotton packaging. No deterioration was observed in flour stored for 5–7 months in polyethylene and polypropylene bags (Woolfe, 1992). Similarly, Gurkin-Ulm (1988) reported that the proximate composition and dietary fiber of SPF stored for 1.5 month were not affected by storage time, temperature, or atmosphere. In general, the SPF retains most of the nutritional composition of fresh sweet potato roots, and many advances have been made in the technology of SPF production, its storage stability and nutrition, making the flour a highly feasible, commercial value-added product.

Many studies have reported the feasibility of using SPF as an alternative to wheat especially in bakery products. Woolfe (1992) reported that at SPF substitution levels above 20%, bread became unacceptable in terms of loaf volume, flavor, and texture. In Peru, commercial bakeries are producing widely accepted bread supplemented with 15% and 30% sweeet potato (Huaman, 1992). The technology has advanced, and substitution levels as high as 65% SPF have resulted in bread with acceptable loaf volumes, flavor and texture. For example, breads supplemented with 50%, 55%, 60%, and 65% SPF had acceptable texture and loaf volumes (Greene *et al.*, 2003). Marklinder *et al.* (1996) considered barley sourdough bread that yielded volumes >450 ml as acceptable, and 990-ml loaf volume for standard wheat bread as acceptable. The studies reported below illustrate the advances in utilization of SPF.

A. BREADMAKING PROPERTIES OF SPF (GREENE *ET AL.*, 2003)

There is limited research regarding the processing of sweet potato bread. The objectives of this research were to: (1) determine the chemical properties (moisture, loaf volume, and texture) of bread supplemented with different levels of SPF, and (2) evaluate the structural properties of bread supplemented with different levels of SPF using scanning electron microscopy (SEM) and differential scanning calorimetry (DSC). Whole-wheat bread formulations were supplemented with 50%, 55%, 60%, and 65% SPF. The maximum percentage strain required to cut the breads into two pieces was used to indicate texture (firmness). The Jeol 5800 SEM and DSC 2010 were used to determine the morphological structure and enthalpies of the breads, respectively. The moisture contents of sweet potato bread ranged from 36.8 $\pm$ 0.7% to 40.4 $\pm$ 0.7%. The bread supplemented with 50% SPF had the highest loaf volume, which was not significantly different from the other breads. Loaf volumes ranged from 825 ml (bread with 65% SPF) to 1450 ml (bread with 50% SPF). The loaf volume of the bread containing 65% SPF was acceptable and contrary to Woolfe's (1992) findings. All the sweet potato breads were less firm than the control (a 100% whole-wheat bread). The SEM showed that the 50% SPF bread had the most gelatinization of starch granules when compared with the others. The sweet potato breads had high enthalpies, possibly because of the presence of larger granules in the SPS. The chemical and structural properties of the sweet potato breads were similar. Overall, the sweet potato breads had similar loaf volume, texture, morphology, and enthalpies. The moisture content of the breads supplemented with 55% and 60% SPF were similar, but significantly different from those with 50% and 65% SPF. The SEM revealed that starch gelatinization was less in the breads supplemented with 55%, 60%, and 65% SPF. The DSC results indicated a high enthalpy in the bread with 50% SPF, which showed the most gelatinization. It can be concluded that sweet potato bread is a feasible option for incorporation into the diets of astronauts and consumers on Earth based on its chemical and structural properties.

B. MACROSCOPIC AND SENSORY EVALUATION OF BREAD SUPPLEMENTED WITH SPF (GREENE AND BOVELL-BENJAMIN, 2004)

The macroscopic and sensory properties of bread supplemented with 50%, 55%, 60%, and 65% SPF were evaluated. Trained judges evaluated 10 samples of freshly baked and 5 samples of day-old breads supplemented with 50%, 55%, 60%, 65% SPF, and two commercial controls (100% whole-wheat bread and potato bread). The proximate analysis showed that increasing percentages of SPF increased the β-carotene contents of the breads, while decreasing their protein contents. Twelve perceived sensory attributes, which could be used to differentiate the appearance (color, cell size, uniformity), texture (chewy, soft, gritty, denseness), and flavor (fresh bread smell, strong wheaty smell, strong sweet potato smell, wheaty taste, aftertaste) of breads supplemented with SPF were generated. The judges' perceptions for color and texture were in agreement with those from the instrumental measures used in the study. SPF could be used to substitute whole-wheat flour at 50%, 55%, 60%, and 65% levels in bread making.

C. DEVELOPMENT AND STORAGE STABILITY OF BREADS SUPPLEMENTED WITH SPF AND DOUGH ENHANCERS (HATHORN *ET AL.*, 2005)

Sweet potato and hard red spring wheat (HRSW) have been selected by the NASA to be grown in space. The objective of this study was to determine the storage stability of bread supplemented with SPF. Sweet potato and HRSW were processed into flour, and two dough enhancers, with and without SPS, were developed. Six breads, with two levels of SPF (50% and 65%) with and without dough enhancers were made. The breads were stored at room temperature (22 ± 2°C) for 7 days. Samples were randomly withdrawn every 24 hours, and the proximate composition, color, loaf volume, texture, and mold and yeast growth measured. Moisture contents ranged from 30% to 41% in all breads. The color of the breads lightened as storage time increased.

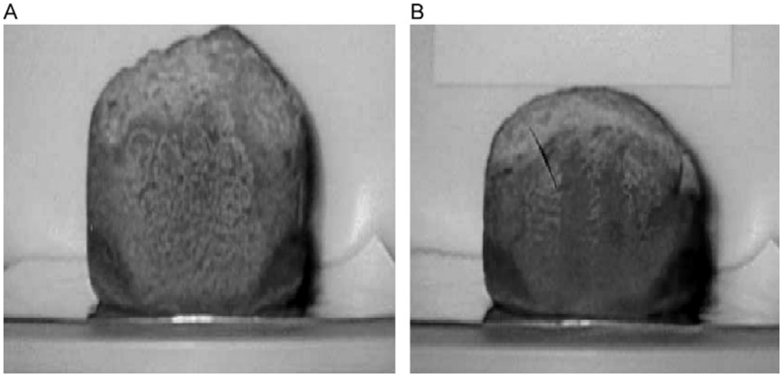

FIG. 9 (A and B) Loaf volumes of breads supplemented with 50% and 65% sweet potato flour, respectively.

Loaf volumes were highest in breads containing 50% SPF and dough enhancers (Figure 9). Breads containing 65% SPF and no dough enhancer had the lowest loaf volume. Texture (firmness) was similar for all breads during the storage period. Yeast counts were low, but higher than mold counts throughout the storage. During storage, mold counts were <4 CFU/ml for all breads. On the seventh day, the breads deteriorated, and yeasts were too numerous to count. The findings indicate that sweet potato bread can be stored for 6 days at room temperature without deterioration in texture and adverse growth of yeasts and molds.

D. SENSORY CHARACTERIZATION OF A READY-TO-EAT SWEET POTATO BREAKFAST CEREAL BY DESCRIPTIVE ANALYSIS (DANSBY AND BOVELL-BENJAMIN, 2003b)

A trained panel evaluated the sensory attributes of extruded, sweet potato ready-to-eat breakfast cereals (RTEBC) using sensory descriptive analysis. Three cereal formulations with varying amounts of processed hydroponic SPF and/or wheat bran [100% SPF, 75%/25% SPF/whole-wheat bran (SPFWWB), and 100% whole-wheat bran (WWB)] were developed. Ten panelists evaluated the sensory attributes of the three RTEBC, and a commercial cereal, Fiber One® (the control). The intensity of 12 sensory attributes of the four RTEBC was rated. The appearance attributes evaluated were color, gloss, and sticklike; the flavor attributes were blandness, sweetness, sharp smell, cinnamon aftertaste; and the texture attributes were crunchiness, grittiness, hardness, chewiness, and dryness. Descriptive analysis revealed that the samples were significantly different for all attributes. Fiber One® had a significantly ($p < 0.05$) lighter brown color than the sweet potato RTEBC, but the 100%

SPF and SPFWWB were the crunchiest. The WWB was the sweetest cereal and significantly different to all the others. For the sweetness attribute, the SPFWWB and the Fiber One® were not significantly ($p < 0.05$) different, but the 100% SPF cereal was sweeter and significantly different from them. The sweet potato RTEBC was chewier than the control.

The underlying principle of descriptive analysis is the development of a descriptive language to be used for scoring the product. In this study, a descriptive language for sweet potato RTEBC was developed, and 12 terms could be used to describe and differentiate the appearance, texture, and flavor of sweet potato RTEBC. The data collected could be used to facilitate future training of similar panels and to enhance sensory communication regarding sweet potato RTEBC. Stone and Sidel (1993) and Pal *et al.* (1995) noted that descriptive analysis could contribute directly or indirectly to other activities such as cost reduction, determination of consumer reaction, quality maintenance, and evaluation in product development. Therefore, the data collected in this could be useful for further optimization of the sweet potato RTEBC and help to increase utilization of SPF. Finally, the data can be used in the design of follow-up consumer studies of the sweet potato RTEBC with the relevant population groups.

E. PHYSICAL PROPERTIES AND SIXTH GRADERS' ACCEPTANCE OF AN EXTRUDED READY-TO-EAT SWEET POTATO BREAKFAST CEREAL (DANSBY AND BOVELL-BENJAMIN, 2003c)

This study was a continuation of the authors' earlier investigations in a broader project to develop palatable, nutritious food ingredients and value-added products from the sweet potato. The nutritive, physical properties and sixth graders' acceptance of a newly developed RTEBC were determined. Extruded RTEBC were made from 100% and 75% SPF, 100% WWB, and extrusion cooking. The proximate composition, bulk density, expansion ratio, color, morphology, water absorption index, and water solubility index of the RTEBC were determined. Seventy-three sixth grade students evaluated three sweet potato RTEBC on a nine-point hedonic scale, with the nine structural levels ranging from 9 "supergood" through 5 "maybe good or bad" to 1 "superbad." The samples were: (1) 100% SPF cereal, (2) 75% SPF/25% WWB cereal, (3) 100% WWB cereal, and (4) Fiber One® (a commercial ready-to-eat breakfast cereal, made from wheat and corn bran was the control). Wheat bran was chosen as a control because the main ingredient in Fiber One® is wheat bran, and it is the commercial ready-to-eat breakfast cereal, which is similar in appearance to the sweet potato cereals.

The mean moisture content was similar for both sweet potato RTBC, but significantly higher for the 100% WWB. The crude ash content was significant ($p < 0.05$) for all the RTEBC, being highest in the 100% WWB and lowest in the

100% SPF. All the RTEBC had similar fat contents. As expected, carbohydrate and ascorbic acid contents were higher in the 100% SPF. The β-carotene content in the 100% SPF was significantly ($p < 0.05$) higher than that of the 100% WWB, which had negligible amounts (6495 μg/100 g compared with 280 μg/100 g). However, the dietary fiber in the 100% WWB was almost three times as high as that of the 100% SPF (29% vs 10%), not surprising because wheat is a richer source of dietary fiber than sweet potato. The vitamins thiamin and riboflavin contents were similar for the cereals. The bulk density and expansion ratio of extruded products describe the degree of puffing of the extrudates. The bulk densities and water absorption index were similar for the cereals. However, expansion ratio was highest in the 100% SPF cereal. The 100% WWB had the lightest color and most fibrous morphology. For the consumer testing, degree of liking (DOL) among the RTEBC differed significantly ($p < 0.05$). Fiber One® was liked significantly more than the other cereals. The 100% WWB was the least-liked cereal and was significantly different from all other cereals. The extruded RTEBC containing 100% SPF and 75%/25% SPFWWB received high ratings 6.7 ± 1.7 and 6.2 ± 1.7, respectively. In hedonic ratings, scores ≥ 5 reflect liking of the product by the consumers. The 100% WWB was unacceptable to the sixth graders which was not surprising because sensory descriptive analysis done earlier confirmed that it was the blandest, most gritty, most chewy cereal. Extruded RTEBC containing 100% SPF and 75% SPF are promising products to be included in human diets because they were well liked and acceptable to sixth graders. However, further work is continuing to decrease the chewiness of the sweet potato RTEBC and evaluate its stability during long-term storage studies.

F. PREPARATION OF SPF AND ITS FERMENTATION TO ETHANOL (REDDY AND BASAPPA, 1997)

The economic preparation of SPF and efficient conversion to ethanol were studied. SPF was prepared using abrasive peeling, hand peeling, lye peeling, and drum drying. The SPF was treated with pectinase, and then with culture filtrate (α-amylase and glucoamylase) of *Endomycopsis fibuligera.* The inoculated samples were fermented for 3 days. A winelike product with ethanol up to 8.6% (w/v), desirable aroma and color was processed.

G. GENETIC VARIATION IN COLOR OF SPF RELATED TO ITS USE IN WHEAT-BASED COMPOSITE FLOUR PRODUCTS (COLLADO *ET AL.*, 1997)

SPFs vary widely in color depending on genotype, and when used in wheat-based composite flours they will impart characteristic colors, which may be favorable or unfavorable for particular food products. SPF was prepared from

44 genotypes and analyzed for proximate composition and biochemical properties. The Hunter color L^*, a^*, b^* values of the dry SPF and their modified Pekar slicks (PS) with water and alkali were measured. Polyphenol oxidase activity, α-amylase activity, and total sugar were significantly correlated to L^* values of dry SPF and of their PS tests with water and alkali. The yellow pigment level was significantly correlated to the yellowness (b^*) of the dry flour and of the PS test with water, but less correlated to b^* of the PS test with alkaline. The results indicated a complex biochemical basis to SPF color, and no single biochemical factor examined was adequate to predict the color of a food product made from SPF. However, the PS color parameters were highly correlated with the color of dough sheets for white-salted and yellow-alkaline noodles made from wheat and sweet potato composite flour (75:25). Thus, the simple modified PS test could be used in screening of genotypes for color stability and suitability for a specific end-use. SPF genotypes conferred a wide range of colors on composite flour dough preparations. Some colors, particularly the range of greens and bright orange, may be useful in specialty product development.

H. QUALITY EVALUATION OF SPF PROCESSED IN DIFFERENT AGROECOLOGICAL SITES USING SMALL-SCALE PROCESSING TECHNOLOGIES (OWORI AND HAGENIMANA, 2000)

Owori and Hagenimana (2000) developed appropriate processes for small-scale production of SPF with the desired degree of odor, color, and nutritional and microbiological quality. It was reported that slicing and soaking the sweet potato roots for 1.5 hours prior to sun drying reduced the odor of the flour. For the color, as the soaking time increased, browning in the SPF decreased. There was a decrease in the total sugars, reducing sugars, starch, and proteins in flour processed from sweet potatoes soaked for 90 minutes. There were no differences in the microbial quality of SPFs made from soaked and nonsoaked sliced roots. The researchers concluded that soaking sliced sweet potato roots for 90 minutes prior to sun drying could be a suitable method for small-scale production of flour.

I. SPF-LIKE PRODUCTS

In Uganda, drying is the traditional way to preserve sweet potato. Women crush and sun dry chunks of the fresh root to prepare a coarse *inginyo*. For *amukeke* chips, the men slice up the roots into round, flat pieces, which the women then spread out to dry; both keep for 4–5 months (CIP, 1998). The *inginyo* or *amukeke* are ground into a coarse flour, which is rehydrated with water, boiled, mashed, and then eaten directly as a thick porridge known as *atapa*, starchy staple (CIP, 1998). The dried sweet potato is also boiled in sauces along with beans and vegetables. The recovery rate of fresh roots to *amukeke* dried chips is from 40% to 45%, and for every 45 kg of fresh sweet potato roots about 18 kg of dried chips (at 14% moisture) are produced. The nutritional composition of sweet potato chips has been reported as 5.2%, 0.1%, and 2.6% for crude protein, crude fiber, and ash, respectively (Tewe *et al.* 2003). Equally suitable as a human snack food, *amukeke* dried chips can be found in the marketplace, but command little consumer interest (CIP, 1998).

In Mali, West Africa, sweet potatoes are peeled, cut into small pieces, and sun-dried. The dehydrated sweet potatoes can be stored for several months. They are usually rehydrated and added to a sauce with other condiments and eaten with a stiff cereal porridge or rice (Scheuring *et al.*, 1996). Researchers have indicated that shade-dried sweet potato pieces still had high levels of β-carotene (Scheuring *et al.*, 1996). Sweet potato is processed into two local products called *Michembe* (the roots are withered, cut into slices, and dried) and *Matobolwa* (the roots are boiled, sliced, and dried) in Tanzania. These products can last for 5–8 months (Gichuki *et al.*, 2005). Other products that have been prepared in Tanzania include cakes, *chapatis, donates, kaimati*, and buns (Gichuki *et al.*, 2005).

VII. OTHER POTENTIAL SWEET POTATO PRODUCTS

Potential sweet potato products (some with limited commercialization) include sweet potato bread pudding, casserole, tart, muffins, scalloped sweet potato, and refrigerated sweet potato pieces (Figure 10). Other value-added, commercial SPF products sold in supermarkets in the United States include sweet potato pancake mixes and sweet potato chips. Some east coast restaurants in the United States, especially in New York and Florida now feature sweet potato fries (Adam, 2005). An extensive sweet potato recipe list including dishes from China, Ghana, Guyana, India, Japan, and the United States is available elsewhere (Hill *et al.*, 1992). The following section gives a more detailed description of selective potential sweet potato products.

A. CONSUMER ACCEPTANCE OF VEGETARIAN SWEET POTATO PRODUCTS INTENDED FOR SPACE MISSIONS (WILSON *ET AL.*, 1998)

The study determined consumer acceptability of products containing from 6% to 20% sweet potato on dwb. Vegetarian products made with sweet potato were developed for use in nutritious and palatable meals for future space explorers. Sensory (appearance/color, aroma, texture, flavor/taste, and overall acceptability) studies were conducted using panelists at NASA/Johnson Space Center, Houston, Texas. All the products were vegetarian with the exception of a

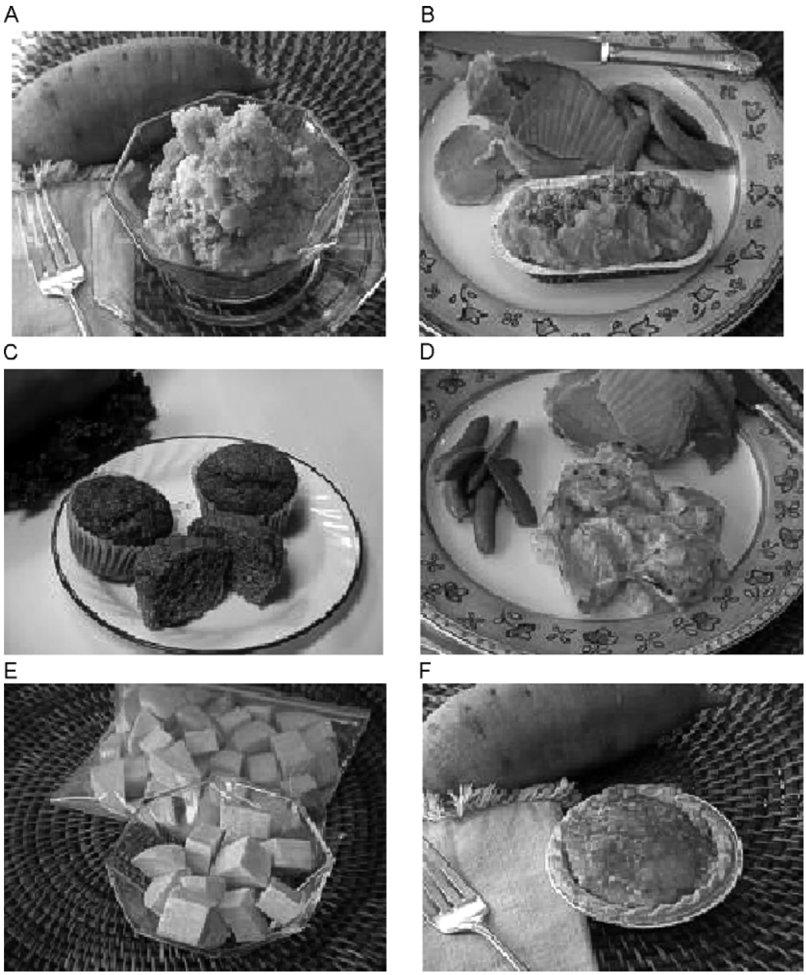

FIG. 10 Potential sweet potato products (some with limited commercialization). (A) Bread pudding, (B) casserole, (C) bran muffins, (D) scalloped sweet potato, (E) refrigerated sweet potato pieces, and (F) tart.

sweet potato pie. A nine-point hedonic scale (9 = like extremely, 5 = neither like nor dislike, and 1 = dislike extremely) was used to evaluate 10 products and similar commercially available products (controls). The products tested were sweet potato pancakes, waffles, tortillas, bread, pie, pound cake, pasta, vegetable patties, doughnuts, and pretzels. All the products were liked either moderately or slightly with the exception of the sweet potato vegetable patties, which were neither liked nor disliked. Because of their consumer acceptability, these products were recommended to NASA's Advanced Life Support Program for inclusion in a vegetarian menu plan designed for lunar/Mars space missions.

B. SWEET POTATO "KUNUZAKI" (TEWE *ET AL*., 2003)

In the northern part of Nigeria, sweet potato is processed into a local drink called *kunuzaki*. Fresh sweet potato is peeled, blended/grated or ground, sifted separated into boiled and unboiled portions, mixed, and left overnight to ferment and sugar added.

C. SWEET POTATO BEVERAGE

Van Den (1992) reported two beverages from orange-fleshed sweet potato. One of the beverages, which were highly acceptable to consumers, was fruity and resembled fruit juice drinks. Sweet potato roots were processed into precooked powder, which was sieved and mixed with cocoa powder. The sweet potato–cocoa (85:15) hot drink was also acceptable to consumers.

In the United States, Gladney (2005) reformulated and processed a sweet potato beverage. Selected chemical and physical properties of the beverage (color, °Brix, pH, and ascorbic acid) were evaluated. The beverages contained 19%, 22%, and 26% sweet potato puree and other fruit juices. The results indicated that the color was similar for all beverages; however, those with higher amounts of sweet potato were darker. In general, the °Brix was higher than those reported for a fruity beverage developed by Van Den (1992).

D. SELECTED PATENTS REGARDING SWEET POTATO PRODUCTS

A technology with methods for producing cooked sweet potato products was patented in 2001 (Walter *et al*., 2001). The patent, docket, and serial numbers are: 6197363, 22696, and 9216518, respectively. The invention is a process for converting sweet potatoes into convenient and nutritional finished products for consumers and the food service industry. Similar to frozen Idaho potatoes and fries, the invention uses a method that combines cooked and pureed sweet potatoes with approximately 25% dry matter such as potato flakes or starch. Gelling agents such as alginate, methylcellulose and hydroxypropylmethyl cellulose, sucrose, calcium, and water are added. The final mixture can either be spread or injected into a rectangular mold or extruded and could be cut into bite-sized pieces, strips, wafers, and patties, frozen and packed for distribution. The resulting products have low-fat content and can be adjusted by food processors for desired fat levels.

Products made using the invention also contain a high degree of β-carotene to meet or exceed RDA.

US patent 5,204,137, which describes processes for products from sweet potato, was issued in 1993. The invention is concerned with the utilization of orange sweet potato roots, with the purpose of producing various flours, other valuable edible products, and industrial products from them. The invention is best described by reference to certain specific examples given in this patent. A partial listing of these examples includes orange sweet potato bread, orange sweet potato imitation corn bread, orange sweet potato cake dough, orange sweet potato muffins, orange sweet potato pancake mix, orange sweet potato pizza dough, orange sweet potato waffles, orange sweet potato dumplings, and so on (http://patft.uspto.gov). Patent 5,204,137 also reports earlier patents, which are described here. Dried, ground orange sweet potatoes were patented for use as an ingredient in coffee blends (US patent 100,587 issued in 1870; http://patft.uspto.gov); uncooked orange SPF was patented by Marshall (US patent 77,995; http://patft.uspto.gov) and Baylor (US patent 100,587; http://patft.uspto.gov).

E. PREPARATION, EVALUATION, AND ANALYSIS OF A FRENCH-FRY-TYPE PRODUCT FROM SWEET POTATOES

The researchers prepared a French-fry-type product from Jewel and Centennial sweet potatoes. The sweet potato roots were washed, lye peeled, sliced into strips, and blanched in hot water containing 1% sodium acid pyrophosphate. The blanched strips were partially dried at 121°C. The dehydrated strips were frozen until fried at 175°C. Panelists evaluated the color, flavor, and texture of the products on a five-point scale. The flavor and texture results indicated that a good product could be prepared from both cv. of sweet potato.

F. TEXTURAL MEASUREMENTS AND PRODUCT QUALITY OF RESTRUCTURED SWEET POTATO FRENCH FRIES (WALTER *ET AL.*, 2002)

The study investigated: (1) the applicability of using alginate–calcium gelling system to produce a high-quality sweet potato French-fry-type product from sweet potato puree, (2) the physical and sensory properties of the product, and (3) the relationship between measured instrumental texture parameters and sensory properties of this product. Cooked, pureed sweet potatoes were mixed with potato flakes, sucrose, tetrasodium pyrophosphate, alginate, and calcium sulfate, formed and gelled, cut into strips, frozen, and fried. The sweet potato fries containing 0.35-g alginate/100 g and 0.5 g-$CaSO_4$/100 g were most acceptable to consumers who evaluated them. The researchers concluded that restructured sweet potato fries with consistent texture and consumer acceptability can be made from sweet potato puree using the alginate–calcium gelling system.

VIII. POTENTIAL OF SWEET POTATO IN THE UGANDAN FOOD SYSTEM

Uganda is the biggest sweet potato producer in the Africa and third largest producer in the world (Scott and Maldonado, 1999). In the 1900s, sweet potato was already an important crop in the western part of Uganda (McMaster, 1962). Winter *et al.* (1992) noted that the crop was traditionally grown in appreciable quantities by the Arube tribe and Konjo of the Ruwenzori slopes. Sweet potato cultivation spread to northern Uganda during the early part of the nineteenth century (Drisberg, 1923). In the 1950s, sweet potatoes ranked as the most important crop after millet, bananas, and cassava (Hakiza *et al.*, 2000). Today in Uganda, sweet potato is a major staple food and the fifth most important food crop, with regard to land area (after bananas, beans, maize, and finger millet), but is rated third in importance on a fresh weight basis (Ministry of Agriculture, Animal Industries and Fisheries, 1992). In districts such as Lira, Pallisa, and Soroti, sweet potato is ranked as one of the three most important crops grown. The crop is an important source of carbohydrates because of rapid population growth, and its ability to produce massive amount of energy in short periods of time (Odongo *et al.*, 2004). Additionally, the importance of sweet potato increased over the last two decades because of the serious decline of cassava production subsequent to attack by the cassava mosaic disease, cassava green mite, and cassava mealy bug (Odongo *et al.*, 2004). Also from the mid-1980s, the region has experienced increased food insecurity, and the people have relied on the sweet potato for their nutritive requirements.

In Uganda, sweet potato production, which is mainly concentrated in the densely populated, mid-altitude regions, has increased from 231,000 ha in 1980 to 560,000 ha in 1999 with outputs of 1.2 and 1.9 metric tonnes, respectively (Hakiza *et al.*, 2000). During the last 5 years, sweet potato production trends have increased in the northeastern region of Uganda (Owori and Hagenimana, 2000). Bashasha *et al.* (2001) ranked sweet potato as second to banana in the western and central regions, and after finger millet in the northern and eastern regions in terms of food preference. Smith *et al.* (1996) reported that sweet potato ranks first and third as a food crop and cash crop, respectively, in Soroti District, Uganda. However, the postharvest technologies and outlets have not kept pace with the increased production.

Researchers, policymakers, and other stakeholders have become increasingly interested in the role of sweet potato in the Ugandan food system and its potential to improve nutrition, reduce food insecurity, and generate rural incomes (Bashasha *et al.*, 2001). With this recognition, the government of Uganda has given high priority to research directed at enriching the nutrient contents of the sweet potato through the development of orange-fleshed cv. and diversifying sweet potato-based products and fortification.

In Ugandan food systems, the sweet potato assumes five roles, of which four are unique to rural areas and one mainly to urban areas. According to Hall *et al.* (1998) and Mwesigwa (1995), these roles are: (1) a predominant staple providing the majority of calories for most of the year, although sweet potato production is seasonal; (2) it is a major complementary staple eaten throughout the year but with seasonal peaks; (3) a famine reserve staple typically consumed only in significant quantities during shortages of the dominant staple; (4) a source of cash income either produced strictly for sale or more commonly as a source of revenue from petty trading; and (5) a low-priced complementary staple for the poor and lower-income urban groups.

As with other developing countries, the marketing of sweet potato in Uganda is influenced by its bulkiness, perishability, transportation issues, poor physical infrastructure such as roads, poor storage, and marketing information systems, limited availability of adapted sweet potato-processing technologies, and limited demand for traditionally processed products (Owori and Hagenimana, 2000). However, the adaptation of sweet potato processing technologies and value-added products can enhance consumption among consumers. Some researchers have concluded that it is not profitable for Ugandan farmers to engage in sweet potato processing, while others have reported otherwise. For example, in Soroti, the sweet potato is consumed year-round as boiled roots; traditionally processed food products, such as dried chips; flour primarily for domestic use; household food security; and on a more limited scale for sale in rural markets (Owori and Hagenimana, 2000). Efforts are being made to expand the SPF market, and there is a potential for SPF in Uganda's baking industry. Collaborative research in Lira and Soroti districts has also demonstrated that there is a market for common snack products such as *mandazi* (doughnut), *chapati*, buns, and cakes, which have been supplemented with 30% SPF (Owori *et al.*, 2000).

Bashasha and Scott (2001) conducted a study in northeastern Uganda to assess the status and market potential of processed sweet potato, namely, *inginyo* and *amukeke*. Their results indicated that sweet potato was processed primarily for household food security. Respondents reported lack of time, high labor cost, and lack of market as the main bottlenecks, while peeling and slicing were the most labor-intensive activities. Owori and Hagenimana (2000) conducted research to improve the quality (odor, color, sensory, nutritional, and microbiological) of SPF processed from nonsoaked and soaked slices and recommended appropriate processing techniques for small-scale production. Soaking the sweet potatoes for 90 minutes decreased the odor intensity of the flour, and browning reduced with increased soaking time. The nutrient content of the SPF reduced slowly as soaking time increased, moisture content increased, ash, starch, protein, total and reducing sugars decreased. The research demonstrated that routine microbiological analysis of SPF was needed to control the production process, and soaking sliced sweet potato roots for 90 minutes before sun drying is the most suitable method for small-scale production. In another research process, Mudiope *et al.* (2000) conducted a survey in Kumi subcounty, Uganda to evaluate the role of sweet potato in the farming system by measuring the production, marketing, and processing constraints facing the crop. Production constraints such as labor shortage and lack of planting materials were the major limitations in the sweet potato farming system. Constraints in processing of sweet potatoes included lack of processing tools.

Peters (1998) examined related aspects of sweet potato production, processing, utilization, and marketing to set postharvest research strategies for addressing food security and income generation in Uganda. The relevant findings indicated the need for more research focused on planting material, appropriate technology for processing, storage of fresh or processed roots, and the commercial potential for SPF as a substitute for wheat flour. Peters (1998) also indicated that SPF could be marketed as "*atap*" (a low-quality flour consumed by the general population as a staple). The outcomes of the above-mentioned studies stress the need for further research efforts to address the production and processing aspects of the sweet potato to enable it to play a greater role in ensuring food security in Uganda.

Over the last decade or more, sweet potato production has increased in Uganda while the decline in cassava production has allowed the crop to play a role in food security. However, the sweet potato has the potential to play a much more substantial role in the Ugandan food system. Further fundamental research is needed to upgrade the quality of sweet potato production, processing and product development, and identify ways to effectively educate Ugandans regarding exploitation of the nutritional benefits of the sweet potato, and how it can play a role in eradicating VAD and food insecurity.

IX. SWEET POTATO PROCESSING AND UTILIZATION EFFORTS IN KENYA

In Kenya, East Africa, sweet potato is an important secondary and "food security" crop when maize supply is low and in times of drought (Gakonyo, 1993b; Mutuura *et al.*, 1992). For example, Mutuura *et al.* (1992) reported that in western Kenya, 40–60% of households ate sweet potatoes more than four times weekly, while 65–95% consumed them once per week during the "hunger season" and when maize was plentiful, respectively. Alumira and Obara (1997) reported that sweet potato is not a main dietary staple in Nairobi. In their 1997 survey, the majority of participants (from middle- and low-income groups) indicated that they ate less sweet potato than 5 years ago because of changes to more "urban/modern-type" foods. Other reasons given for the decreased consumption include unavailability of sweet potato, unreliable sweet potato harvests, less land space available for production of sweet potato, and high cost for sweet potatoes. On the other hand, 37% of the participants indicated that eating habits have changed in favor of the sweet potato because they are cheap and easy to cook, they serve as an alternative when maize price is high, and they are preferred to bread at breakfast time because of the sugar content and low price.

The production of sweet potato in Kenya has increased from 55,000 ha in 1988 to 65,000 ha in 1996 (FAO, 1997). The average annual per capita sweet potato consumption is approximately 24 kg (Scott and Ewell, 1992). In the western part of Kenya, including the Lake Victoria basin and Nyanza Province, sweet potato is grown widely and is mostly a woman-tended crop (Nungo *et al.*, 2000; Oyunga-Ogubi *et al.*, 2005). In the Nyanza Province, 82% of households grow sweet potato (Oyunga-Ogubi *et al.*, 2005). VAD is widespread in Kenya, and most of the dietary vitamin A is supplied by carotenoids (GoK and UNICEF, 1995). Plant foods such as the sweet potato with concentrated provitamin A can contribute to decreasing food insecurity and VAD in Kenya. However, full exploitation of the sweet potato is limited by its bulkiness, perishability, high cost per unit sold, poor consumers' perceptions, and the varieties cultivated (GTZ, 1998).

The predominant sweet potato cv. grown and consumed in Kenya are white or pale-yellow flesh types, which are low in β-carotene (Hagenimana *et al.*, 1998b). In contrast, orange-fleshed varieties, which are rich in β-carotene, are not so popular. The orange-fleshed sweet potato is an affordable, rich, year-round source of β-carotene, therefore, efforts are being made to adopt it in Kenya. If farmers and consumers switch from nonorange to orange-fleshed sweet potato cv., it is hypothesized that this could have a substantial impact on vitamin A status. Hagenimana *et al.* (1998b) concluded that the high carotenoid level of orange-fleshed sweet potato cv. would provide an excellent and appropriate mechanism for combating VAD. In an 18-month village-level study in western Kenya, Low *et al.* (1997) and Hagenimana *et al.* (1999) confirmed that potential exists to successfully substitute orange-fleshed sweet potatoes for the commonly used white-fleshed varieties.

In Kenya, SPF was consumed in large quantities in the 1950s when some families used the flour to make porridge mixed with sorghum of finger millet flour (GTZ, 1998). However, with the introduction of maize, utilization of SPF declined as it became an inferior crop associated with poverty (GTZ, 1998). According to Nungo *et al.* (2000) and Gakonyo (1993a), processing and utilization of sweet potato in Kenya have been limited to washing, roasting, boiling, and mashing with other foods. Since 1995, the Allendu Women Group from Allendu location has been processing and marketing sweet potato products including *chapati, mandazi*, crisps, chips, and cakes. However, accurate data on the volume of sweet potato processed are unavailable.

Oyunga-Ogubi *et al.* (2005) reported that improved provitamin A content was seen in population groups when SPF was incorporated into traditional products such as buns, *chapatis*, and *mandazis* in Rongo, Ndhiwa, and Kendu Bay districts in Nyanza Province. Nungo *et al.* (2000) prepared, tested, and evaluated several recipes made from sweet potato leaves and roots for color, taste, texture, and acceptability, and compared them to other recipes from cassava, rice, and carrots. The products were scored on a five-point scale where 5 = very desirable; 3 = moderately desirable; and 1 = undesirable. Overall, 10 sweet potato products *mshenye*, doughnuts, relish, porridge, chips, *ugali*, cake, bread, *mandazi*, and *chapati* were selected as suitable and marketable products. Mshenye and relish were very acceptable to 90% of the consumers.

Oyunga-Ogubi *et al.* (2005) investigated the adoption of an intervention technology for increasing vitamin A intake through the use to high-β-carotene sweet potatoes in the Siaya district, Kenya. They reported on the fresh roots, SPF, and novel products from traditional dishes (*mandazis, chapati, ugali*, porridge, chips, and crisps). Consumer tests showed high acceptability of the novel products. *Mandazis* and chips were preferred by males, while all products except *ugali* were highly acceptable to females. Children of different ages and gender had variable preferences. Method of preparation of products was acceptable to women. However, on increased SPF processing, equipment was an issue. Men preferred most equipment as presented, but women and children suggested changes. For example, in flour production, cleaning and peeling were tedious, and the large amount of wash water resulted in increased workload. Also, women and children felt that the rotary slicer should be modified to allow a sitting position, the drying should fit under their normal practice, and there should be education on storage of chips and flour. The researchers also concluded that there is insignificant sweet potato processing in Siaya, but there is potential for adoption of this technology particularly by women.

Hagenimana *et al.* (1999) identified orange-fleshed sweet potato varieties with high acceptability of appearance and taste that are appropriate for consumption by adults and young children in Kenya. In both Ndhiwa/Nyarongi and Rongo districts, consumer evaluation of the taste and appearance of cooked sweet potatoes indicated that cv. of orange-fleshed sweet potatoes were acceptable to community members. Pumpkin cv. was preferred for use in weaning foods. Local cv. ranked high in terms of taste and appearance in all districts. Also processed food products, such as *mandazis* made from new sweet potato cv. were acceptable to food processors and consumers. Mashed and flour products were preferred over grated products. The processing of modified food products did not require additional labor or production costs. A cost analysis indicated that substituting sweet potato for wheat flour in *mandazis* made the product more profitable for market vendors, and substituting sweet potato for other ingredients increased the β-carotene content of processed food products. *Mandazis, chapatis*, and buns with and without sweet potato contained approximately 100- and 800- to 3200-mg β-carotene/100 g, respectively (Hagenimana *et al*., 1999).

As part of the promotion of orange-fleshed sweet potato, farmers in some parts of Kenya have received hands-on demonstrations to make various sweet potato products, including vegetable stew (relish), mashed food (*mshenye/Irio*), *chapati*, samosa, and biscuits (Gichuki *et al*., 2005). In sum, preliminary studies indicate that orange-fleshed sweet potatoes are available and acceptable to western Kenyans and are a good addition to the diets to reduce VAD. Processing of the orange-fleshed sweet potato into value-added products for year-round consumption and to increase provitamin A intake is limited. However, encouraging processing and expanding the use of the orange-fleshed sweet potato in the Kenyan food system will help to meet food requirements, improve nutritional status, enhance food security, and reduce poverty.

X. CONCLUSIONS

The sweet potato combines a number of advantages from nutritional to socioeconomic to environmental, which makes it a potentially good candidate for reducing the increasing food insecurity, VAD, and the under- and overnutrition that is occurring globally, especially in developing countries. However, consumers' poor perception of the sweet potato in many developing countries, its static production, lack of storage technology for fresh sweet potato, lack of processing equipment, scarcity of data on the demand for fresh sweet potato or its products, inadequate processing and postharvest technology, and lack of knowledge regarding its nutritional benefits must be overcome. Repositioning sweet potato production and its potential for value-added products will contribute substantially to utilizing its benefits and many uses. Accurate estimates of the market demand for value-added sweet potato-based products have not been established, but advertisement and promotion will enhance their utilization.

XI. RECOMMENDATIONS

Multidisciplinary, integrated research and development activities aimed at improving production, storage, postharvest and processing technologies, and quality of the sweet potato and its potential value-added products are critical issues, which should be addressed globally. Additionally, widespread, effective farmer and consumer education (awareness) regarding the exploitation of the nutritional, health and economical benefits of the sweet potato, and how it can play a role in eradicating VAD and food insecurity should be undertaken. Other important issues that need to be addressed urgently include: (1) research that will lead to the development of nutritious, consumer-acceptable value-added products from the roots and leaves of the sweet potato; (2) determination of the critical physical and chemical factors modulating the acceptance of sweet potato by consumers; (3) more urgent collaborative efforts by plant breeders, horticulturists, sensory scientists, and nutritionists to characterize and improve the starch and flour properties of sweet potato cv.; (4) although SPF is one of the most promising sweet potato products, its quality and storage stability need to be further researched; (5) providing farmers and consumers with acceptable recipes and samples of value-added products are also necessary approaches to increase production and consumption of the crop; and (6) low-cost, appropriate sweet potato processing technologies, and policies for their transfer to developing countries should be developed. Finally, governments, policy makers, and stakeholders should adopt food-based strategies that encourage and expand utilization of the orange-fleshed sweet potato cv. instead of the white-fleshed cv. Such strategies will assist in meeting food requirements, improve nutritional status, enhance food security, reduce poverty, and could effectively improve vitamin A status of young children in particular, and populations in general.

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