Handbook of Vegetables & Vegetable Processing

EDITOR
Nirmal K. Sinha

ADMINISTRATIVE EDITOR
Y. H. Hui

ASSOCIATE EDITORS
E. Özgül Evranuz
Muhammad Siddiq
Jasim Ahmed

WILEY-BLACKWELL

Truong VD, Avula RY, Pecota K, Yencho CG. 2011. Sweetpotatoes. In: Sinha NK, editor. Handbook of vegetables & vegetable processing. New Jersey: Wiley-Blackwell. p 717-737.

Chapter 36

Sweetpotatoes

V. D. Truong, R. Y. Avula, K. Pecota, and C. G. Yencho

Introduction

Sweetpotato, *Ipomoea batatas* L. (Lam.), is an important economic crop in many countries. In terms of annual production, sweetpotato ranks the fifth most important food crop in the tropics and the seventh in the world food production after wheat, rice, maize, potato, barley, and cassava (FAOSTAT 2008).

Sweetpotato roots have high nutritional value and sensory versatility in terms of taste, texture, and flesh color (white, cream, yellow, orange, purple). The varieties with high dry matter (>25%), white-cream flesh color, and mealy firm texture after cooking are preferred by the consumers in the tropics. These varieties are known as "tropical sweetpotato" (for example, "bianito," "batiste," or "camote"). The purple-fleshed sweetpotato varieties with attractive color and high anthocyanin content are the specialty type in Asia. In the United States, the commercially popular type is the orange-fleshed sweetpotato with low dry matter content (18–25%), high β-carotene level, sweet and moist-texture after cooking. This sweetpotato type is imprecisely called "yam" which is not the true tropical yam of *Dioscorea* species. Many years ago, African American in Louisiana referred this moist-sweetpotato as "nyami" because it reminded them of the starchy tuber of that name in Africa. The Senagalese word "nyami" was eventually shortened to the trademark "yam" popular in the United States. Commercial packages with "yam" labels are required by the US Department of Agriculture to have the word "sweetpotato" in the label to avoid confusion to the consumers.

Depending on the flesh color, sweetpotatoes contain high levels of β-carotene, anthocyanins, phenolics, dietary fiber, vitamins, minerals, and other bioactive compounds. The β-carotene in orange-fleshed sweetpotatoes can play a significant role as a viable long-term food-based strategy for combating vitamin A deficiency in the world. Studies in Africa demonstrated that consumption of 125 g of orange-fleshed sweetpotatoes improved the vitamin A status of children, pregnant women, and lactating mothers (Low et al. 2001; Van Jaarsveld et al. 2005). Further, polyphenolics from purple-fleshed sweetpotatoes exhibited strong radical scavenging activity, which helps reduce the risk of stress-related diseases (Suda et al. 2003). Sweetpotato has a strong potential to contribute to better nutritional quality of our diets around the world. This chapter provides a contemporary review of production, quality, and processing aspects of sweetpotatoes.

Production and Consumption

Sweetpotato has wide production geography, from 40° north to 32° south latitude of the globe, and it is cultivated in 114 countries with a total annual production of 120–140 million metric tons in recent years (Figure 36.1). About 93% of the global sweetpotato

Handbook of Vegetables and Vegetable Processing. Edited by N. K. Sinha.

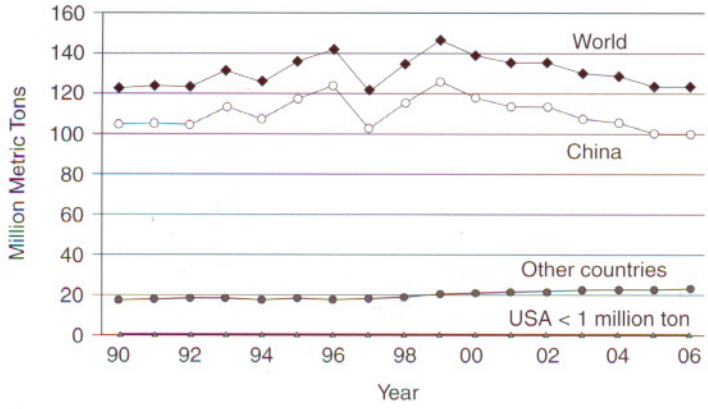

Figure 36.1 World sweetpotato production 1990–2006 (FAOSTAT 2008).

production is from Asia and Pacific Islands while only 5.5% and 1.5% are produced in Africa and Latin America. The main sweetpotato producer is China that accounts for about 80% of the global production. Japan and the United States produce 0.8% and 0.6%, respectively. Countries in the southern hemisphere such as Argentina and New Zealand produce 272,000 and 17,000 metric tons sweetpotatoes annually. Only two countries in Europe, Spain and Portugal, grow about 25,000 metric tons each, annually.

In comparison to other major staple food crops, sweetpotato has good adaptability to marginal growing conditions, short production cycle, and high yield potential. The average world yield of sweetpotato is about 14 tons per hectare. Under subsistent conditions in many areas of the tropics, the average sweetpotato yield is about 6 metric tons/hectare, far below 20–26 metric tons/hectare obtained in China, Japan, and the United States, where the improved varieties, fertilizer applications, and cultural managements have been introduced.

The per capita consumption is highest in places where sweetpotatoes are consumed as a staple food, e.g., Papua New Guinea at 550 kg per person per year, the Solomon Islands at 160 kg, Burundi and Rwanda at 130 kg, and Uganda at 85 kg. The average annual per capita consumption of sweetpotato is estimated at 18 kg in Asia, 9 kg in Africa, 5 kg in Latin America, and 2.3 kg in the United States (FAOSTAT 2008; USDA 2010).

Classification and Origin

The sweetpotato (*I. batatas* L.) is a dicotyledonous plant belonging to the morning glory or Convolvulaceae family. It is a new world crop, though there is disagreement as to the origin. Using data from morphology, ecology, and cytology, Austin (1988) has postulated that cultivated sweetpotatoes originated somewhere in the region between the Yucatan Peninsula of Mexico and the mouth of the Orinoco river in northeastern Venezuela. Molecular marker analysis places Central America as the region with the most genetic diversity and probable origin (Huang and Sun 2000; Zhang et al. 2000). Remains of dried sweetpotato roots found in Peru have been radiocarbon dated back to 8,000–10,000 years old, though it is unknown if these were collected from the wild or were domesticated (Engel 1970). Sweetpotato was widely established in tropical regions of the new world around 2500 BC (Austin 1988). It was established in Polynesia, prior to European arrival, though it is unclear as to how it got there. Europeans in the 1500s spread the sweetpotato to Africa and India, with it arriving in China prior to 1600. Secondary centers of

diversity include New Guinea, the Philippines, and parts of Africa (Yen 1982; Bohac et al. 1995).

Botany and Physiology

The sweetpotato is a herbaceous perennial that is grown as an annual by stem cuttings or plants sprout from storage roots. It has a predominately prostrate growth habit typically with 1–5 m vines that grow horizontally on the ground. The plant can be grouped into three parts: the leaves acting as the photosynthetic canopy, the stems which transports energy to the roots, and water and minerals from the roots, and the root system which absorbs water and nutrients from the soil, anchors the plant, and can act as a storage site for energy via the development of fleshy storage roots. Sweetpotato possesses three types of roots: storage, fibrous, and pencil (Kays 1985a; Firon et al. 2009). Young adventitious roots develop out of both the nodal and the internodal regions of an underground stem portion of a vine cutting. Roots from the internodal regions normally become fibrous roots and have a tetrarch arrangement of their primary vascular tissue. Roots from the nodes are pentarch or hexarch and have the potential to develop into enlarged storage roots; however, unfavorable conditions can cause many or all of these to develop into primary fibrous roots or to lignify and produce pencil roots. Pencil roots are much greater in diameter than fibrous roots, but much thinner than storage roots, or about the thickness of a pencil. Some of the first roots to emerge from the nodal regions are the roots that will develop into storage roots, making it important to minimize stress during the first month after transplanting, to ensure good storage root development. Minimizing stresses such as high nitrogen levels, low oxygen or dry conditions impacts many of the cultural practices for sweetpotato in highly developed production systems.

Storage root initiation varies widely among cultivars occurring between 1–13 weeks after planting by which time the number of storage roots per plant is determined (Ravi and Indira 1999). Length of the storage root is determined before width, with shape being determined by the differential rates of longitudinal and lateral growth (Wilson 1982). Root set even in the same field and cultivar is highly variable in sweetpotato, making it difficult to optimize size and shape uniformity (Firon et al. 2009).

Air and soil temperatures affect storage root formation and growth. Night air temperature seems to be the most critical factor for storage root growth. Night temperatures between 15 and 25°C promote storage root formation and growth while temperatures above 25°C suppress storage root formation and favor shoot growth. Night air temperatures lower than 15°C suppress storage root formation, growth, and yield. Air temperatures >30°C reduce storage root formation and growth, and promotes shoot growth. Soil temperatures between 20 and 30°C favor storage root formation and growth while a soil temperature of 15°C favors fibrous root formation. Soil temperatures >30°C promotes shoot growth at the expense of storage root growth. Long photoperiod favors storage root growth.

Storage root bulking is determined by the duration and rate of storage root growth, which varies by cultivar. Growth occurs over an extended period of time and can stop due to unfavorable growing conditions and restart once conditions improve. Cultivars exhibiting fast initiation and rapid bulking may reach a maximum yield in 12–16 weeks, while long duration bulking types require a >21-week period for maximal development. Storage root bulking rate is positively correlated with rainfall and relative humidity.

The storage roots, not to be confused with tubers, which are modified stems, range in shape from spindle-shaped to almost spherical, to irregular in length from a few centimeters to greater than 30 cm, and in weight from 0.1 kg to several kilograms. Since they are perennial, they will continue to grow, but unless protected, will often rot or be

discovered by rodents. The skin and flesh contains carotenoid and anthocyanin pigments, which when combined, determine a continuum of colors from whitish to yellow, orange, and red to purple. Most cultivars have a uniform flesh color but landraces and breeding materials can be multicolored or patterned. Roots, when cut, ooze sticky white latex from laticifers present throughout the flesh. The latex turns black as it dries and cannot be removed from the root surface without removing the skin.

Vines are usually prostrate, though some may twine, and form a shallow canopy. Vines are indeterminate and will root at the nodes, often producing a secondary set of storage roots. Stems range from green to purple, and in thickness from a few millimeters to 1.5 cm. Internode distances vary considerably and have to be considered when planting transplants. Leaves are arranged spirally on the stem and are variable in size and shape, even on the same plant. Leaves range from deeply lobed to entire with many plants showing a range of shapes. Most leaves are green but may contain purple pigmentation. Recently, ornamental sweetpotatoes have been released with solid purple leaves and stems, others with light green foliage. Many of these also have compact, well-branched, and somewhat upright plant architectures.

Flowering is mostly short day, but long day and day neutral clones exist. Flowering and seed set in fields cultivated by indigenous cultures may have played a major role in the appearance of new varieties that are then propagated via cuttings. Flowering is increased during stress periods and can reduce yield, though there are high-yielding flowering varieties.

Breeding

Sweetpotato is a hexaploid with a basic chromosome number of $n = 15$ and 6 sets of chromosomes ($2n = 6x = 90$). There is still disagreement as to which specie(s) are the most likely progenitors of cultivated sweetpotato (Bohac et al. 1995; Firon et al. 2009). Only a few other *Ipomoea* species have polyploid forms and few successful crosses with diploids or other *Ipomoea* species have been made. Recent molecular genetic studies suggest that cultivated sweetpotatoes are most likely autopolyploids, with some evidence of restricted recombination (Kriegner et al. 2003; Cervantes et al. 2008).

Due to the high levels of heterozygosity present in the germplasm, there is great genetic diversity within sweetpotato, which is steadily being developed by breeders. This diversity appears to be the result of a number of factors. It has been domesticated for a long time and spread through a large number of environments for selection. It is at least partly autopolyploid, so that there is great redundancy in the genome allowing for regions to change without compromising the basic systems of the plant. Sexual reproduction in cultivated fields would allow for new types to be evaluated, and then clonally propagated, and finally, there is a fairly high rate of somatic mutation, especially when sprouted from storage roots.

Because sweetpotato is a polyploid with high levels of heterozygosity and it is mostly an obligate out-crossing species with numerous mating incompatibilities, breeding in this crop is fairly difficult (Jones 1986; Collins et al. 1999). Most traits of economical significance exhibit quantitative inheritance. Breeding efforts begun in the 1930s in the United States and elsewhere have significantly improved fungal, bacterial, and nematode resistance, beta-carotene, and anthocyanin levels, yields, storage ability, size and shape uniformity, and starch characteristics. Considerable work continues on insect and virus resistance, processing qualities, and finding regionally adapted cultivars that match consumer preferences.

Despite its worldwide importance as a food crop, funding for genetic and molecular genetic research have been very limited.

Consequently, key research to understand the inheritance of economically important traits that could help developing more efficient breeding strategies has lagged behind to that of other important crops. To date, only a few molecular genetic studies of sweetpotato have been published, with most being limited to phylogenetics and germplasm evaluation (He et al. 1995; Prakash et al. 1996; Zhang et al. 2000; Hu et al. 2004; Zhang et al. 2004), and genome characterization (Villordon and LaBonte 1995, 1996). The genetic maps of sweetpotato were recently constructed by Cervantes et al. (2005) and Kriegner et al. (2003) represent the most comprehensive genetic maps of sweetpotato. Traits of economic importance or quantitative trait loci (QTL) are now being placed on the map developed by Cervantes et al. (2005).

Soil and Climate

Sweetpotatoes are grown from 40°N to 32°S, and from sea level to 3,000 m in the tropics. Growth is negligible below 10°C and best above 24°C. Frost will kill the plants and cold temperatures damage storage roots, though the damage may not be seen until after a couple months of storage. Thus cultivation is limited to temperate regions with a minimum frost-free period of 4 months. Multiple crops per year can be grown in tropical regions with sufficient rainfall. Optimal rainfall is approximately 50 cm during the growing season. Once established, the crop can handle severe drought and resume growing when rain occurs, but drought during establishment can cause poor stands and poor root set. The best soils are sandy loams with permeable subsoils. Sweetpotatoes do not tolerate waterlogged soils well, especially near harvest where roots may rot in the field or in subsequent storage. Soils with higher bulk densities or poor aeration cause irregular shapes and poorer root set. Cultural management using mounds or ridges can allow productive use of these soils. Sweetpotatoes can tolerate a wide range of soils, with pH from 5.0 to 7.5 considered optimal, as long as there are no mineral deficiencies (Bouwkamp 1985a).

Sweetpotatoes are a relatively low input crop in terms of fertilizers. Soils with moderate fertility rarely show a yield response to additional N or P fertilizers. In deep sandy soils with low cation exchange capacity, fertilizer responses are more common especially where high-density plantings are made. Potassium usage is high and yield responses to additional K are common. Nutrient deficiencies for other elements have been described (O'Sullivan et al. 1997) and estimates of minimal tissue mineral concentrations reported (Bouwkamp 1985). Response depends largely on cultivar and growing system. Cultivars developed in low input systems will often show negative storage root yield responses when grown in high input systems, and produce excessive vine growth.

Cultural Practices

In tropical regions, sweetpotato planting is generally done by hand with timing early in the rainy season so that it dries out by harvest. In areas with a long rainy season, planting will be delayed. Some areas can produce more than one crop per season. Plants are taken from existing plantings or nurseries used to maintain plants. In temperate regions, plants are produced in the spring by first presprouting storage roots at 29°C for 10–20 days and then bedding them by laying out on soil, almost touching for large roots and 2–4 cm between small roots, and covering them with 2–4 cm of soil and clear or black plastic to keep them warm. Covers are removed as plants sprout, and plants may be mowed to maintain an equal plant height. Plants are cut above the soil line to prevent disease spread and when they are 25–30 cm tall transplanted to the field. Plants can be stored in cool conditions, 15°C, and 85% RH for up to a week with no loss of yield potential. Land preparation usually involves producing a raised bed

or mound. The mounding increases drainage, and temporarily lowers soil bulk density providing more uniform root development. In tropical regions, planting is usually done by hand while mechanical transplanters are the norm in temperate regions. Water will be added at transplanting if soil moisture is low. The vine canopy should cover the ground in 6–8 weeks, after which minimal weeding is needed. Normally, depending on cultivar and region sweetpotato roots can be ready to harvest 3–8 months after planting. In Papua New Guinea, where it is a subsistence crop, individual roots are harvested from a plant as needed, and then vines are covered with soil to encourage new storage roots to develop. In tropical regions, it is common to dig only what can be marketed at that time, so no storage is necessary. In temperate regions, the harvest is timed to optimize yield of the highest value size grade and before cold weather compromises storage ability. Here roots will be dug, often mechanically or a combination or mechanical digging and hand harvest, depending on the amount of skinning.

Japan has developed an alternative production system using cut seed pieces for the production of high starch processing lines. Storage roots are cut into 25–50 g pieces, and planted mechanically eliminating the bedding, plant cutting, and transplanting operations used in temperate production areas. Shapes are not as consistent as roots produced from plant cuttings, but this does not matter since the crop is processed. This type of system is being investigated in other temperate regions for processing types and clones suitable for ethanol production.

Common Diseases and Pests

Sweetpotato weevils (*Cylas* spp.) are the most important worldwide pests of sweetpotato. *Cylas formicaries* Fab. is the major weevil in most countries. They attack nearly all parts of the plants with larvae developing on mature stems and storage roots both in the field and in the storage. Larvae burrow throughout the storage root making it unmarketable, and, in response, the roots produce toxic sesquiterpenes leading to a bitter flavor that is also toxic to livestock. Damage can be extensive both in the field and in the storage. Control through integrated pest management (IPM) strategies has been demonstrated (Talekar 1991). The combination of several techniques were necessary to provide good control, the two most important being preventing infestations of new fields by using weevil free cuttings and by eliminating immigration of weevils from alternate hosts and weevil infested crops. Other techniques include crop rotation, sanitation, and chemical insecticides, and the use of sex pheromones to monitor weevil populations. Timing of insecticides is critical since once weevils are present inside the stems or storage roots they are difficult to reach. Biological control and breeding for resistance have not been very successful to date. In areas without the weevil, the use of sex pheromone traps to monitor for introduction and vigorously enforced quarantines can be used to prevent weevil spread.

The second most damaging insect pests are vine boring lepidopterans *Omphisa anastomasalis* (Guenee), *Megastes grandalis* Guenee, and *M. pucialis* Snell causing up to 30–50% yield losses (Talekar and Pollard 1991) in Asia, and certain parts of South America. Virus problems are severe in certain regions, but considered minor in other regions. Sweetpotato virus disease (SPVD), a combination of two viruses, causes up to 80% yield losses in parts of Africa. Viruses are found in nearly all commercial plantings because they are vegetatively propagated and rapidly spread by aphid and whitefly vectors. Quarantines restrict the free movement of planting material among countries, with most requiring plants to be virus-free before shipping. In the 1990s, most major production regions began to set up virus indexed programs to get virus indexed plants into the hands of growers. Virus assay kits have been developed for some viruses.

Postharvest Handling Practices

Storage

In temperate regions where production is limited to a summer season and marketing is continuous, sweetpotatoes are stored year round. Varieties have been selected for both low respiration and low water loss giving a storage life up to 13 months or until the next crop is harvested. Careful handling of sweetpotatoes is critical to ensure long-term storage. Bruising and skinning in the field is minimized by hand harvest or by using a combination of mechanical and hand harvesting. Roots exposed to bright sun for more than 30 minutes may have a darkening of skin called sun scalding, which is a cosmetic defect but can also be a site for postharvest decay. Roots should not be harvested when the weather is too cold. Chilling injury is a function of temperature and duration of exposure. Temperature below 10°C will cause chilling, though cooler temperatures will cause more damage. Chilling injury may not be seen for weeks after the chilling occurs and can be expressed by various symptoms including increased respiratory rate, greater susceptibility to decay, surface pitting, internal breakdown, hardcore and reduced culinary quality.

After harvest, roots are immediately "cured" at 29–33°C and 85–90% RH with proper ventilation for 4–7 days. Curing heals wounds that occur during the harvest, first by a lignification beneath cells damaged at harvest, and second by the formation of a wound periderm beneath the lignified cells in a process called suberization. The healing provides a pathogen barrier and reduces desiccation at the wound site resulting in less weight loss during storage. Uncured roots do not store well but properly cured roots stored at 13–15°C and 85–95% relative humidity will be marketable for up to 12 months (Edmunds et al. 2008). Good airflow is essential to maintain oxygen and carbon dioxide exchange and allow for heat transfer. Cultivars vary tremendously as to how long they will store and maintain the necessary quality. Curing also produces changes in the culinary characteristics increasing moistness and sweetness (Walter 1987).

Sweetpotatoes continue to respire during storage, converting starch to sugar, which is then oxidized to carbon dioxide and water providing energy for the living cells. Over time, the loss of dry matter will cause pithiness, a textural defect caused by an increase in intercellular space, up to the point where there are air pockets in the root tissue. This is greatly accelerated by warmer temperatures. Once temperatures go above 16°C, the roots will begin to sprout which greatly increases the respiration rate and weight loss (Edmunds et al. 2008). Large commercial storage facilities in developed nations can maintain very precise conditions to optimize root storability and quality. In developing countries, storage of sweeetpotatoes has been done for hundreds of years and is still practiced using various pit, or underground storage structures. The success of these structures depends on how close they come to maintaining the ideal temperature, moisture, and oxygen levels as described. Storage losses due to rodents, weevils, and rots tend to be high, and the length of time often limited to a few months.

Packing and Shipping

Market requirements, especially shape and size requirements, for sweetpotatoes vary by region. Where it is a subsistence food, shape and size are not as important, but where it is a luxury item, appearance is very important. In the United States, highly mechanized packing lines are used to grade for strict size and shape parameters. Lines typically start with a tank of water into which roots are dumped, this wets the roots for washing and allows roots to be metered onto a conveyor system. Roots go through water rinse to remove soil followed by an eliminator to remove trash and small unmarketable roots, usually accomplished by going across a set of rollers at a

specified width. Roots are then sorted, usually by hand, to remove decaying or otherwise unmarketable roots. Roots that will be shipped for retail are then generally treated with a fungicide to reduce decay. This is followed by sizing into various classes, some by diameter, or with electronic sizers measuring both length and diameter. Roots are put into boxes, and boxes onto pallets for efficient handling.

Bruising on packing lines can greatly affect shelf life of the sweetpotatoes and care should be taken in design and setup of the packing lines to reduce any impacts. The dump tank, drops off and onto conveyors, turns, and packing line speed and length account for much of the damage and should be minimized (Edmunds et al. 2008). Market life, which begins when roots are removed from bulk storage bins, of a sweetpotato is generally 2–3 weeks. The most common disease in storage and packed sweetpotatoes is Rhizopus soft rot caused by the fungus *Rhizopus stolonifer.* Present in most stored sweetpotatoes, it will contaminate packing lines and enter through wounds produced during packing. Sanitation and minimizing wounds on packing lines is the most effective control, and the main reason for the fungicide treatment. Care must be taken to ensure that shipping containers are maintained at 13°C to prevent excessive respiration or chilling damage.

Nutritional Composition of Sweetpotatoes

All the plant parts, roots, vines, and young leaves of sweetpotatoes are used as foods and animal feeds around the world. The nutritional values of sweetpotato roots and leaves are shown in Table 36.1. In Asia and Africa, the sweetpotato leaves are eaten as green vegetables. Almazan et al. (1997) reported the nutrient content of sweetpotato greens on dry weight basis as 25–37% protein, 23–38% total dietary fiber, 60–200 mg/100 g ascorbic acid, and 60–120 mg/100 g carotene. They are also rich in calcium (480–740 mg), iron (11–18 mg), potassium (3,380–5,230 mg), and magnesium (270–550 mg). The high level of phenolics (1.4–17.1 mg/100 g dry weight), anthocyanins, and radical-scavenging activities in sweetpotato leaves indicates their potential benefits on human health and nutrition (Islam 2006). The sweetpotato greens is very rich in lutein, 38–51 mg/100 g fresh leaves which are even higher than the lutein levels in the vegetables which are known as a source for lutein, e.g., kale (38 mg/100 g) and spinach (12 mg/100 g) (Menelaou et al. 2006).

Table 36.1 Nutrient content (g/100g fresh weight) in raw sweetpotato roots and leaves

Nutrient	Roots	Leaves
Water	77.28	87.96
Energy, kcal	86.00	35.00
Protein	1.57	4.00
Lipid	0.05	0.30
Ash	0.99	1.36
Carbohydrate*	20.12	6.38
Total dietary fiber	3.00	2.00
Total sugars	4.18	n.a.
Sucrose	2.52	n.a.
Glucose	0.96	n.a.
Fructose	0.70	n.a.
Starch	12.65	n.a.

Source: USDA Agricultural Research Service Nutrient Data Laboratory, 2009, http://www.nal.usda.gov/fnic/foodcomp/search/
n.a., not analyzed.

The nutrient composition of sweetpotato roots varies widely depending on the cultivar, growing conditions, maturity, and storage. Overall, sweetpotato roots have a high moisture level with an average dry matter content of 25–30%. Tsou and Hong (1992) reported a wide range of dry matter content of 13–41% from a sweetpotato germplasm collection. Sweetpotato roots are good source of carbohydrates and generally low in protein and fat. Protein content ranged from 1.73 to 9.14% on dry weight with substantial levels of nonprotein nitrogen (Yeoh and Truong 1996). Sweetpotato protein overall, however, is of good quality and the levels of essential

Table 36.2 Phytonutrients in orange- and purple-fleshed sweetpotato roots

Varieties	Flesh color	Dry matter (g/100g)	β-carotene (fwb) (mg/100g)	Antho-cyanins*	Total phenolic†
Beauregard	Orange	20.5	9.4	n.a.	88.9
Covington	Orange	20.3	9.1	3.8	58.4
Stokes purple	Dark purple	36.4‡	n.a.	80.2	401.6
NC 415	Dark purple	29.0‡	n.a.	69	652.5
Okinawa	Light purple	30.0‡	n.a.	21.1	458.3

Sources: Truong et al. 2007; Steed and Truong, 2008; Yencho et al. 2008.
*mg cyanidin-3-glucoside/100g fw.
†mg chlorogenic acid/100g fw.
‡Dry matter adjusted to 18-20% for flowable purees; n.a. = not analyzed.

amino acids compare significantly to the FAO reference protein (Walter et al. 1983).

Most of the dry matter in sweetpotatoes consists of carbohydrates, primarily starch and sugars and to a lesser extent pectins, cellulose, and hemicellulose. Dietary fiber in sweetpotato roots range from 2 to 4% of fresh weight (Huang et al. 1999). Starch comprises 60–70% of the total dry matter, but the values vary for different types of cultivars. As with other starches, sweetpotato starch granules are made up of amylose (20%) and amylopectin (Woolfe 1992). Much variability in sugars exists between sweetpotato types. Truong et al. (1986) found total sugars to vary from 5.6% in a Filipino cultivar to 38% in a Louisiana cultivar on a dry weight basis (db). Sucrose, glucose, and fructose made up the majority of the total sugars in raw sweetpotato roots. During cooking, amylases act upon the gelatinized starch resulting in the formation of maltose in cooked sweetpotatoes.

Ash content of sweetpotatoes is approximately 3% of the dry weight or between 0.3% and 1.0% of the fresh weight basis (fwb) (Table 36.1). Potassium was the element with the greatest concentration in sweetpotato roots with an average of 396 mg/100 g fresh weight. Phosphorous, calcium, magnesium, iron, copper, and magnesium are also present in significant amounts (Woolfe 1992).

Sweetpotato roots also contain vitamins such as ascorbic acid, thiamin (B1), riboflavin (B2), niacin (B6), pantothenic acid (B5), folic acid, and vitamin E. Bradbury and Singh (1986) reported values between 9.5 and 25.0 mg/100 g (fwb) for ascorbic acid and 7.3–13.6 mg/100 g (fwb) for dehydroascorbic acid resulting in a total vitamin C range of 17.3–34.5 mg/100 g for the sweetpotato roots. Orange-fleshed sweetpotatoes are rich in β-carotene (Table 36.2). A wider range of β-carotene content in cooked orange-fleshed sweetpotatoes, 6.7–16.0 mg/100 g fwb, has been reported by different investigators (Huang et al. 1999; Bovell-Benjamin 2007). The sweetpotato carotenoids exist in an all *trans* configuration, which exhibits the highest provitamin A activity among the carotenoids. van Jaarsveld et al. (2005) advocate the increased consumption of orange-fleshed sweetpotatoes as an effective approach to improve the vitamin A nutrition in the developing countries. Epidemiological studies indicated the beneficial effects of high carotene diets in reducing the risks of cancer, age-related macula degeneration, and heart diseases (Tanumihardjo 2008).

Purple-fleshed sweetpotato roots have attractive reddish-purple color with high levels of anthocyanins and total phenolics (Table 36.2). The flowable purees with a solid content of 18% processed from this sweetpotato type had total phenolic and anthocyanin contents of 314 mg chlorogenic acid equivalent/100 g fwb and 58 mg cyanidin-3-glucosdie equivalent/100 g fwb, respectively. The 2, 2-diphenyl-1-picrylhydrazyl (DPPH)

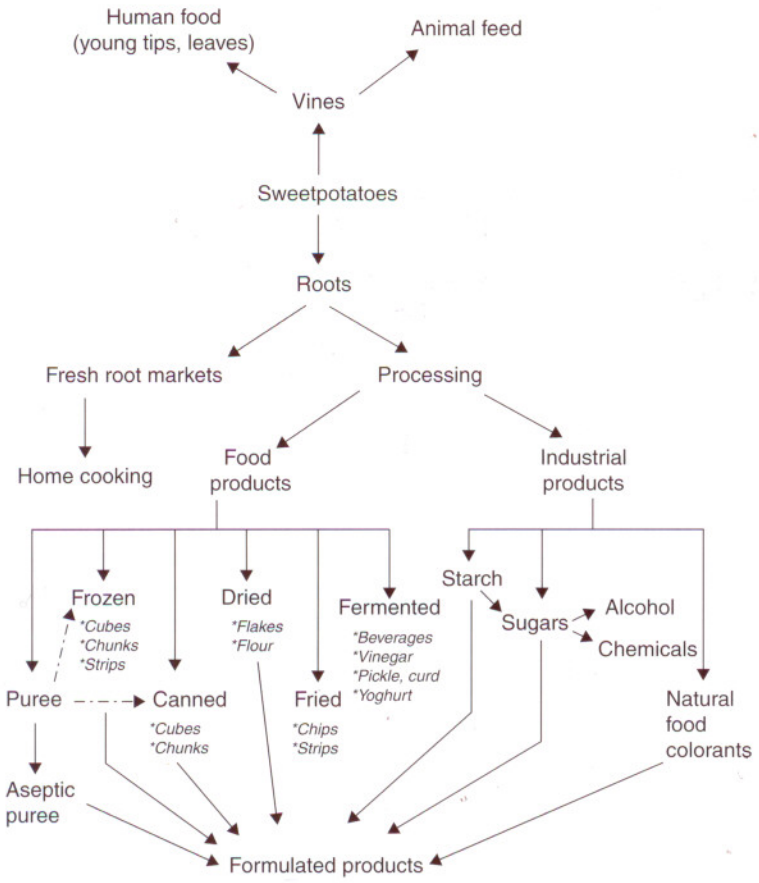

Figure 36.2 Various processing and utilization of sweetpotatoes.

radical scavenging activity was 47 μmol trolox equivalent/g fwb and oxygen radical absorbance capacity (ORAC) of 26 μmol trolox equivalent/g fwb (Steed and Truong 2008). The purple-fleshed sweetpotatoes have polyphenolic content and antioxidant activities in a competitive level with other food commodities known to be a good source of antioxidants such as black bean, red onion, black berries, cultivated blueberries, sweet cherries, and strawberries. Several clinical studies indicated that consumption of purple-fleshed sweetpotatoes may have potential health benefits against oxidative stress associated with liver injury (Suda et al. 2008) and other chronic diseases (Suda et al. 2003).

Processing and Utilization

Sweetpotato roots and other plant parts are used as human food, animal feed, and processing industry. Various processing technologies that convert sweetpotatoes into functional ingredients, food, and industrial products are summarized in Figure 36.2. For industrial processing, starch, sugars, and natural colorants are the major intermediate products that can be used in both food and nonfood processing industry. Sweetpotato varieties with high levels of dry matter (35–41%), total starch (25–27%), and extractable starch (20–23%) are available for starch processing (Brabet et al. 1998). There

are many small and medium factories in Asia producing about 26% of starch production (Bovell-Benjamin 2007). The process for manufacturing sweetpotato starch is basically similar to the starch extraction from other sources. The roots are ground in limewater (pH 8.6–9.2) to prevent browning due to polyphenol oxidase, to dissolve pigments, and to flocculate the impurities. The extracted starch is separated from the pulp by thoroughly washing over a series of screens, bleaching with sodium hypochlorite, and then settling by gravity or centrifugation. In small-scale establishments, starch is stored wet in concrete tanks or sun-dried to a moisture content of about 12%, pulverized and screened. Centrifugation and mechanical drying, such as flash drier, are commonly used for medium-scale factories. Sweetpotato starch is used in the production of traditional noodles, vermicelli, thickening agents, or converted into sugar syrups which are used in many processed food products. The sweetpotato starch and sugars are also utilized in the production of fuel alcohol, monosodium glutamate, microbial enzymes, citric acid, lactic acid, and other chemicals (Kotecha and Kadam 1998; Padmaja 2009). In Japan, the orange- and purple-fleshed sweetpotatoes have been used in commercial production of natural beta-carotene and anthocyanin pigments in beverages and other food products. The following sections describe recent developments in processing of sweetpotatoes into functional ingredients and common food products.

Purees

Processing

The use of sweetpotatoes in the food industry often involves processing of the roots into purees that can be subsequently frozen, canned, or packaged in aseptic conditions to produce shelf-stable products for year-round availability. In puree processing, roots of all sizes and shapes can be utilized and, therefore, the entire harvested crop is utilized including the 30–40% off-grade from the fresh root markets (Kays 1985b; Walter and Schwartz 1993). The challenges in puree processing industry are: (1) the difficulty in adjusting the process to account for differences in cultivar types, root handling, curing, and storage; and processing techniques in order to produce consistent, and high quality puree; and (2) the preservation technology that could produce shelf-stable product for convenient incorporation in processed foods.

Several techniques have been developed for puree processing in order to produce purees with consistent quality, despite the variations due to cultivar differences in carbohydrate content, starch degrading enzyme activities, and postharvest handling practices (Kays 1985b; Collins and Walter 1992). Process operations for pureeing of sweetpotatoes include washing, peeling, hand-trimming, cutting, steamed blanching or cooking, and grinding into purees which can be subjected to canning or freezing for preservation (Figure 36.2). Raw sweetpotatoes can be peeled by abrasive rollers, lye solution, or steam flashing. Lye peeling is no longer a common method in the industry due to the issues on equipment corrosion and waste disposal. The peeled sweetpotatoes are then washed thoroughly to remove all disintegrated peel, followed by trimming, cutting into slices or dices. The purees can be simply produced by steam cooking of the chunks, slices, strips, cubes, or ground particles, and passing the cooked materials through a pulp finisher. Hoover and Harmon (1967) developed an enzyme activation technique using the endogenous amylolytic enzymes for starch hydrolysis in sweetpotato puree processing, and this process is now commonly used in the food industry. As shown in Figure 36.3, the peeled sweetpotatoes can be either cut into cubes of 2 cm, strips of 2 × 2 × 6 cm, and slices of 0.5–0.95 cm thickness (Walter and Schwartz 1993) or mashed using a hammer mill with rotating blades to chop and push the materials

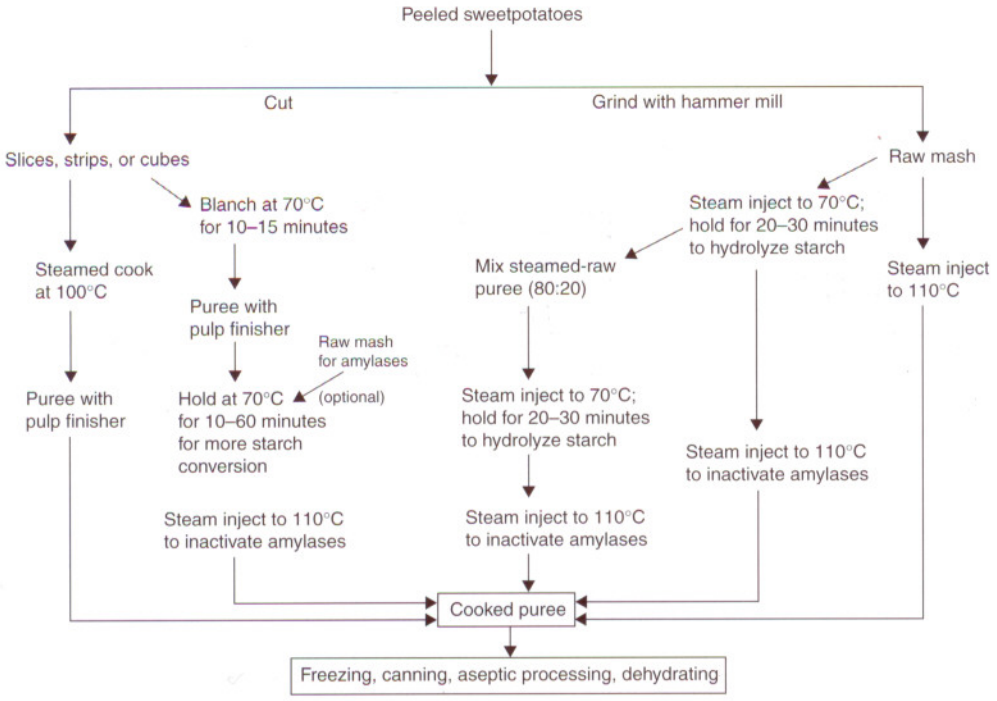

Figure 36.3 Different processes for sweetpotato puree production (Truong and Avula 2010).

through a 1.5–2.3 mm mesh screen (Szyperski et al. 1986). Next, the materials are steamed blanched at 65–75°C which activates the amylases and gelatinizes the starch for hydrolysis. For the process with slices, strips, and cubes, comminuting the blanched materials into puree is carried out at this point using a hammer mill. The blanched puree is pumped into a surge tank and hold at 65–75°C for further starch hydrolysis depending on the targeted maltose levels. Raw sweetpotato mash as a source of amylases can be optionally added at this stage to increase starch conversion. α- and β-amylases hydrolyze the starch producing maltose, maltotriose, glucose, and dextrins.

Packaging and Preservation

The finish-cooked puree can be packaged in cans and retorted to produce shelf-stable product. The puree can also be filled in plastic containers for refrigerated or frozen storage (Kays 1985; Collins and Walter 1992; Walter and Wilson 1992; Pérez-Díaz et al. 2008).

Preservation by canning for low acid food such as sweetpotato purees (pH, 5.8–6.3) usually involves high thermal treatment of the product because heat transfer in the puree is mainly by conduction. High thermal treatment (e.g., 165 minutes at 121°C for an institutional #10 can size) also results in severe degradation of color, flavor, texture, and nutrients. The slow rate of heat transfer from the wall to the center of the can to attain commercial sterilization of the product limits the maximum can size of number 10 for canned sweetpotato purees. This size limitation is another obstruction for the wider uses of sweetpotato purees as a food ingredient in the food industry. Nevertheless, canning does not have the need for special storage; lower capital investment and unit of production is less when compared to refrigerated and frozen puree. On

the other hand, frozen puree is an established method for preservation and provides least degradation of nutritional and sensory quality as compared to canning. However, preservation by freezing requires considerable investment in frozen distribution and storage as well as space, energy, time, and requires defrosting before use. Currently, only limited amount of canned and frozen sweetpotato purees are commercially produced by a few companies in the United States and Japan.

Aseptic processing is considered as a potential alternative to overcome the stated problems associated with canning and low-temperature preservation. As opposed to conventional canning, the use of high temperature ($\geq$125°C) for a short period of time in aseptic processing can produce a higher quality product with equal or better level of microbiological safety as that in a conventional canning system. A process for rapid sterilization and aseptic packaging of the orange-fleshed sweetpotato purees using a continuous flow microwave system operated at 915 MHz has been successfully developed by Coronel et al. (2005). This process has the advantage of avoiding long retort processing schedules, maintaining high quality retention, and producing shelf-stable products. The resulting product packed in flexible plastic containers had the color and viscosity comparable to the nonsterilized puree and was shelf-stable for at least 12 months. Purple-fleshed sweetpotato purees were also successfully processed into high quality aseptic product using the continuous flow microwave system (Steed et al. 2008). With this technology, shelf-stable purees with consistently high quality can be packaged into various container sizes (up to 300 gallons) for conveniently utilizing as food ingredients in the food processing industry. This technology can be extended to highly viscous biomaterials and purees from other fruits and vegetables (Kumar et al. 2008). In this new process, sweetpotato puree is loaded into a hopper, and pumped through the system. Microwaves from a generator are delivered to sterilize the puree at 130–135°C, to retain in the holding tube for 30 seconds, to rapidly cool in a tubular heat exchanger, and then to aseptically package in aluminum-polyethylene laminated bags (Simunovic et al. 2006). The first commercial venture on aseptically packaged sweetpotato puree using this microwave-assisted sterilization technology has been carried out. With rapid heating, high retention of carotene and anthocyanins (>85%) in the purees can be achieved, and this development opens up a new market opportunity for the sweetpotato industry.

Sweetpotato purees has been used as an ingredient in numerous formulated food products, including baby food, casseroles, puddings, pies, cakes, ice cream, leather, bread, patties, and soups (Hoover et al. 1983; Collins and Washam-Hutsell 1986; Collins and Walter 1992; Truong and Walter 1994). The sweetpotato purees are also used in fruit/vegetable-based beverages and restructured products (Truong 1992; Truong et al. 1995; Utomo et al. 2005). Other commercial utilization of sweetpotato puree includes jam and ketchup (Truong 1994; Fawzia et al. 1999). The uses of sweetpotato purees in various fermented food products are described in a section below. With the recent commercial development of the microwave-assisted processing and aseptic packaging of sweetpotato purees, it is expected that more processed food products from the puree will be developed. In the United States, sweetpotato puree has been used for dehydrating into flakes or powder for various food applications.

Frozen Products

Sweetpotatoes can be frozen in different forms such as whole roots, halves, quarters, slices, cubes, French fries, paste, or as puree. The processing steps include peeling, sizing, cutting, blanching or cooking, packaging, and freezing. Sizing is important to assure appropriate blanching or cooking and freezing

time when the roots are to be frozen whole (Bouwkamp 1985b). Packaging may precede freezing such as frozen purees or may follow freezing when the roots or cut pieces are individually quick frozen (IQF). In Japan, sweetpotato slices/crushed roots mixed with 35% sugar are packed in plastic bags and blast frozen at −40°C (Woolfe 1992). In large-scale production of French fries, partially fried products are frozen for distribution to institutional and retailed consumers. Good quality fries could be produced by blanching the strips in 60% sucrose solution for 4.5 minutes or for 3 minutes in boiling water containing 0.25% sodium acid pyrophosphate (SAPP) and 0.25% calcium chloride (Padmaja 2009). Textural properties of the frozen French fries are affected by root storage, and the problem can be overcome by calcium treatment and low-temperature blanching. Loss in ascorbic acid and color score were reported for French fries stored frozen for 1 year (Schwartz et al. 1987). Discoloration is a major problem for frozen sweetpotato products. Enzymatic discoloration caused by polyphenol oxidase is characterized by a brown, dark gray, or black color. This discoloration can be minimized or prevented by heat inactivation of the enzymes prior to peeling, soaking the cut pieces in solutions containing sulfites and acidulants. The nonenzyamtic discoloration is caused by phenolics complexing with iron and other metals, which can be prevented by pyrophosphates in the blanching medium or added directly into several products (Walter and Wilson 1992).

Canned Products

Canned sweetpotatoes are widely consumed among the sweetpotato products available to consumers in the United States. Sweetpotatoes can be canned whole, halved, or cut into chunks, either in syrup or water. Sweetpotatoes can also be pureed and canned as a solid pack. The unit operations leading to the production of canned sweetpotato roots include peeling, cutting, sizing, blanching, filling, syruping, exhausting, and retorting. Blanching in water at 77°C for 1–3 minutes is done to drive out gases, maintain can vacuum, and increase the initial temperature of the contents of the cans (Bouwkamp 1985b; Padmaja 2009). However, low-temperature blanching at 62°C increases firmness and intactness retention of canned sweetpotatoes as compared to the unblanched samples or samples blanched at higher temperatures (Truong et al. 1998). Immediately after blanching, the material is packed in cans and covered with syrup at 95°C to prevent discoloration. Sugar (20–40%) or water is used depending on consumer preferences. Cans should be exhausted long enough for the internal temperature to reach 77°C to ensure a good vacuum of the finished cans (Bouwkamp 1985b). After closing, the cans should be retorted according to the processing schedules, quickly cooled after retorting to an internal temperature of 35°C to avoid "stackburn" and slow drying of the can which may lead to rusting. Firmness is one of the most important attributes determining the quality and marketability of canned sweetpotato roots. Firmness was slightly greater for sweetpotatoes packed with sucrose than with corn syrup, and canning in syrups with high sugar concentrations produced firmer roots. Variations between the same cultivars grown in different locations, application of fertilizers, and irrigation influence firmness (Bouwkamp 1985b). Sweetpotatoes canned immediately after harvest are firmer than those previously cured or stored. Changes in pectic fractions are responsible for the decreased firmness of previously stored, canned roots. Adjustment of pH in sweetpotato tissue by acidification or alkali treatment and calcium treatments improved the firmness of canned products and French fries processed from cured and stored roots (Walter et al. 1998).

Dehydrated Forms: Slices, Granules, Flakes, Flour

Sweetpotato roots are processed into dehydrated forms such as dried chips, cubes,

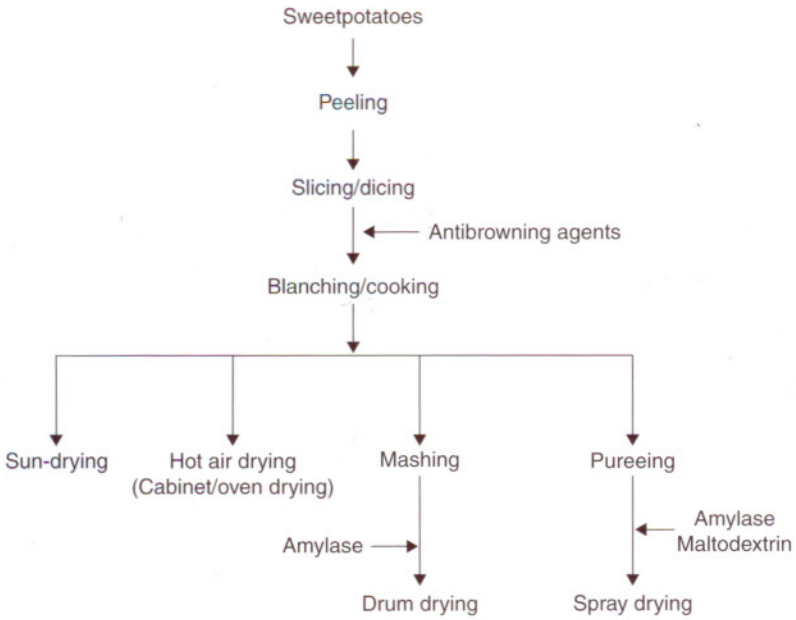

Figure 36.4 Drying technologies applied to dehydrated sweetpotato products.

granules, flakes, and flour for storage and use in food preparations including soups, bakery products, vermicelli, noodles, extruded snack foods, and breakfast cereals (Peters and Wheately 1997; Padmaja 2009; Truong and Avula 2010). Drying produces a light, compact, relatively inexpensive, easily stored, and transported material. Processing methods vary in sophistication from simple slicing and field sun-drying of roots as practiced at the village levels in many tropical countries to the large-scale, multistage production of dehydrated products by large food companies (Figure 36.4). Functionality, nutrient retention, and product storability of dehydrated products of sweetpotato roots are important to provide competitiveness of these ingredients in food processing.

Sun- and Solar Drying

Sun-drying has long been practiced in developing countries, where there is a pronounced dry season, to produce dried chips and flour from both white- and colored-fleshed sweetpotato varieties. Sweetpotato roots are cut into 2–3 mm thick slices and optionally blanched in boiling water for several minutes. The slices may be subjected to metabisulfite treatment before or during blanching to prevent browning. The blanched or unblanched slices are sun-dried until the slices reached a moisture content of about 6–10%. Drying times vary from 4 hours to 5 days depending on climatic conditions, and the dried slices are ground into flour. To inhibit microbial growth during drying, fresh roots are soaked in 8–10% salt solution (Winaro 1982). Owori and Hagenimana (2000) developed processes for small-scale production of flour with the desired degree of odor, color, and nutritional and microbiological quality. In Indonesia, sun-dried chips are fried and packed in polyethylene for retail sale (Kotecha and Kadam 1998). Sweetpotato flour has been produced for decades in Peru to use in the wheat-sweetpotato bread (van Hal 2000). However, poor control of energy input and product quality, interruption of drying caused by cloud, rain, and nightfall, and frequent

contamination by microorganisms, dust, and insects are the disadvantages of sun-drying (Woolfe 1992). Microbial evaluation of sun-dried sweetpotato slices showed the presence of 12 fungal species whereas the oven-dried slices had no fungal growth (Okungbowa and Osagie 2009). These problems can be overcome by using modern solar-assisted dryers that effectively utilize solar energy for control drying, resulting in good quality products. Several types of solar dryers with external means, like fans, furnace, for moving solar energy in the form of heated air from the solar collector to the drying bed that have been used for fruits and other vegetables (Lopez-Malo and Rios-Cass 2009), can be applied in drying sweetpotatoes.

Mechanical Drying

Mechanical driers such as cabinet, tunnel, drum, or spray driers are used in large commercial enterprises. Cabinet and tunnel drying are based on the same principle as solar drying, except that the air is heated by fuel. The dehydration conditions such as drying temperature, drying time, and air velocity can be controlled in these driers. As in puree processing, raw sweetpotatoes can be peeled by abrasive rollers or steam flashing, followed by washing, trimming, cutting into slices/dices, soaking in solution containing antibrowning substances such as sulfite, SAPP, and steam-blanching for about 7 minutes. The slices/dices are spread on trays and dried in the cabinet or tunnel dryers at about 50–80°C for 4–12 hours to a moisture content of less than 7%. The drying ratio of fresh to finished product is about 3:1 to 5:1 depending on the dry matter content in sweetpotatoes. To produce good quality flour, sweetpotato roots should be low in total free sugars, reducing sugars (<2%), ash content, amylase activity, polyphenol oxidase content, and should have high dry matter with white color (Bovell-Benjamin 2007). The dehydrated product should be suitably packaged in aluminum-laminated packages or plastic containers to exclude air and moisture for good storage stability (Avula et al. 2006; Hathorne et al. 2008). A high temperature-short time drying process, 150°C for 10 minutes, was developed by Antonio et al. (2008) for osmotic dehydration of sweetpotatoes.

Drum drying of sweetpotato purees is commercially practiced in the United States for producing sweetpotato flakes/powder which can be reconstituted into mashed sweetpotatoes or incorporated into a variety of other products such as pies, pastries, cakes, casseroles, and other food preparations. The cooked and comminuted sweetpotatoes are dried in a double drum drier heated with steam. The flakes were milled into <60 mesh particles and stored under nitrogen at −20°C (Valdez et al. 2001). Szyperski et al. (1986) developed an alternative drum drying process to produce a consistent product independent of raw material variations. A commercial α-amylase was used to hydrolyze a part of the pregelatinized puree, which is then blended with the untreated portion. SAPP or citric acid is added to the puree before drying to control non-enzymic browning which causes discoloration of the reconstituted flakes. Avula et al. (2006) prepared drum dried flour by subjecting sweetpotato mash to a double drum drier of 60 cm width and 35 cm diameter. The speed of the drum was maintained at 3 rpm with a clearance of 0.3 mm and at a steam pressure of 6 kg/cm^2. The sheets of dried sweetpotato were collected, crushed, and milled into flour in a hammer mill provided with a 500 μm sieve. Drum drying caused a reaction of the ε-amino group of lysine with reducing groups of carbohydrates, which caused the lysine to be destroyed irreversibly and formation of browning compounds (Walter et al. 1983).

Spray drying of sweetpotato purees was reported by Grabowski et al. (2006). The puree was subjected to pretreatment with α-amylase to reduce viscosity and maltodextrin was used to aid in spray drying. Maltodextrin facilitates product recovery by raising the glass

transition temperature of the product thereby reducing stickiness and partially encapsulating the material. The puree was spray dried using a dryer equipped with a rotary atomizer and a mixed-flow air-product pattern. The final characteristics and functionality of the spray-dried sweetpotato powders are affected by predrying treatments and spray drying temperature. Rheological properties of the reconstituted slurries from spray-dried sweetpotato powders behaved similarly to the pregelatizied starch (Grabowski et al. 2008). It was demonstrated that good quality sweetpotato powder produced by spray drying has potential applications in food and nutraceutical products.

Fried Products: Chips, French Fries

Sweetpotato chips and French fries are popular in many countries. In the past few years, several food companies in the United States have ventured into processing of sweetpotato chips and French fries with high beta-carotene content from orange-fleshed sweetpotatoes in response to the growing demands of the consumers on healthy foods. Reconstituted sweetpotato chips were developed in China, and extruded snack products with alternative shapes to those of conventional chips were produced in Japan, with characteristics similar to those of extruded potato snacks (Woolfe 1992).

For chip processing, unpeeled or peeled roots are sliced into 0.8–2.0 mm thin chips which are blanched for 2 minutes at 93°C, then drained and partially dehydrated using heated forced air at 119°C. The thickness of the chip is important since it affects the length of cooking and the quality of the finished product. Partial drying has a pronounced effect on the appearance, flavor, and texture of the finished product. Optimum frying temperature was between 143 and 154°C (Hoover and Miller 1973). Picha (1986) reported that color of the chips was positively related to reducing sugars. However, recent screening on various sweetpotato genotypes with a wide range of reducing sugar content indicated that other substances such as amino acids may significantly contribute to the browning of fried chips. Following frying, the chips are drained and salted/sugared. After cooling, the chips will be packaged immediately to exclude water and oxygen. For French fries, sweetpotato roots are cut into strips 1.9 cm thick × 6.4 cm thick, blanched in boiling water containing 1% SAPP to inhibit polyphenolic discoloration, followed by partial drying at 120°C for 5 minutes, frozen, and stored at −34°C until the slices are fried for consumption (Schwartz et al. 1987). Partial drying reduces oil absorption and increase sensory quality of French fries (Walter and Hoover 1986). Coating of sweetpotato strips with starch-based materials improved appearance and textural properties of sweetpotato French fries (Truong and Thibault 2009).

The quality of fried chips and French fries are affected by sweetpotato varieties, postharvest handling, and storage conditions. Changes in reducing sugars, amino acids, and other substances involved in the discoloration of sweetpotatoes affect the color of this product type. Textural properties and oil content of the fried products are influenced by dry matter and starch content. An integrated approach including selection of suitable varieties, growing conditions, and appropriate postharvest handling and storage conditions should be considered in order to produce sweetpotato chips and French fries with consistent quality all year round.

Fermented Products

Being rich in starch, sugars, and other nutrients, sweetpotatoes have been used in the production of many fermented products. In Japan, high-starch sweetpotato varieties are used in "shochu" fermentation. Shochu is traditional distilled liquor from sweetpotatoes or other sources such as rice, barley, corn, or potato (Sakamoto and Bouwkamp 1985).

Sweetpotato shochu is very popular, especially in southern Japan. The process involves the inoculation of steamed sweetpotato slurry with a starter "Koji" containing *Aspergillus niger* or *A. kawachii* as an enzyme source for starch conversion to sugars followed by fermentation to alcohol by yeast *Saccharomyces cerevisiae*. The whole process usually takes 12–14 days to yield a broth having 13–15% alcohol, which is then distilled and blended to produce shochu with 20–40% alcohol.

Wine and beer are the recent alcoholic beverages from the orange- and purple-fleshed sweetpotatoes (Yamakawa 2000). Red vinegar with high antioxidant activity and antihyperglycemic effect made from purple-fleshed sweetpotatoes was developed (Matsui et al. 2004). Sweetpotatoes also used as substrates in soy sauce fermentation (Data et al. 1986). Other fermented sweetpotato products rich in carotene and anthocyanins that have been developed in recent years include yogurt (Collins et al. 1990), curd (Mohapatra et al., 2007), fermented beverages (Saigusa et al. 2005), lacto-pickle (Panda et al. 2009a), lacto-juice (Panda et al. 2009b) and probiotic milk-sweetpotato drink (Perez and Tan 2006). The application of bioprocessing technology and the progress in the development of fermented products from sweetpotatoes was recently review by Ray et al. (2010).

References

Almazan AM, Begum F, Johnson C. 1997. Nutritional quality of sweetpotato greens from greenhouse plants. *J Food Compos Anal* 10:246–253.

Antonio GC, Alves DG, Azoubel PM, Murr FEX, Park KJ. 2008. Influence of osmotic dehydration and high temperature short time processes on dried sweetpotato (*Ipomoea batatas* Lam.). *J Food Eng* 84:375–382.

Austin DF. 1988. The taxonomy, evolution, and genetic diversity of sweetpotato and related wild species. In: *Exploration, Maintenance, and Utilization of the Sweet Potato Genetic Resources*. Lima, Peru: International Potato Center, pp. 27–60.

Avula RY, Guha M, Tharanathan RN, Ramteke RS. 2006. Changes in characteristics of sweetpotato flour prepared by different drying techniques. *Lebensm Wiss Technol* 39:20–26.

Bohac JR, Dukes PD, Austin DF. 1995. *Sweet potato Ipomoea batatas* (Convolvulaceae). In: Smartt J, Simmonds NW (editors), *Evolution of Crop Plants*, 2nd edition. Essex: Longman Scientific and Technical, pp. 57–62.

Bouwkamp J. 1985a. Production requirements. In: Bouwkamp JC (editor), *Sweet Potato Products: A Natural Resource for the Tropics*. Boca Raton, FL: CRC Press, pp. 9–34.

Bouwkamp JC. 1985b. Processing of sweet potatoes – canning, freezing, dehydrating. In: Bouwkamp JC (editor), *Sweet Potato Products: A Natural Source for the Tropics*. Boca Raton, FL: CRC Press, pp. 185–203.

Bovell-Benjamin AC. 2007. Sweet potato: a review of its past, present, and future role in human nutrition. *Adv Food Nutr Res* 52:1–48.

Brabet C, Reynoso D, Dufour D, Mestres C, Arredondo J, Scott G. 1998. *Starch Content and Properties of 106 Sweet Potato Clones from World Germplasm Collection Help at CIP*. Peru: International Potato Center, Annual Report 1997–1998, pp. 279–286.

Bradbury JH, Singh U. 1986. Ascorbic and dehydroascorbic acid content of tropical root crops from the South Pacific. *J Food Sci* 51:975–978.

Cervantes-Flores JC, Yencho GC, Kriegner A, Pecota KV, Faulk MA, Mwanga ROM, Sosinski B. 2008. Development of a genetic linkage map and identification of homologous linkage groups in sweetpotato using multiple-dose AFLP markers. *Mol Breeding* 21:511–532.

Collins JL, Ebah CB, Mount JR, Demott BJ, Draughon FA. 1990. Production and evaluation of milk-sweet potato mixtures fermented with yogurt bacteria. *J Food Sci* 56:685–688.

Collins JL, Walter WM Jr. 1992. Processing and processed products. In: Jones A, Bouwkamp JC (editors), *Fifty Years of Cooperative Sweet Potato Research 1939–1989*. Southern Cooperative Series. Bulletin N0. 369. Baton Rouge, LA: Louisiana State University Agricultural Center, pp. 71–87.

Collins JL, Washam-Hutsell L. 1986. Physical, chemical, sensory and microbiological attributes of sweet potato leather. *J Food Sci* 52:646–648.

Collins WW, Carey EE, Mok IG, Thompson P, Zhang DP. 1999. Utilization of sweetpotato genetic resources to develop insect-resistance. In: Clement SL, Quisenberry SS (editors), *Global Genetic Resources for Insect-Resistant Crops*. Boca Raton, FL: CRC Press, pp. 193–205.

Coronel P, Truong V-D, Simunovic J, Sandeep KP, Cartwright GD. 2005. Aseptic processing of sweet potato purees using a continuous flow microwave system. *Journal of Food Science* 70:531–536.

Data ES, Diamante JC, Forio EE. 1986. Soy sauce production utilizing root crops flour as substitute for wheat flour (100% substitution). *Ann Trop Res (Phillip)* 8:42–50.

Edmunds B, Boyette M, Clark C, Ferrin D, Smith T, Holmes G. 2008. *Postharvest Handling of Sweetpotatoes*. NC Cooperative extension Service. AG-413–10-B.

Engel F. 1970. Exploration of the Chilca Canyon, Peru. *Curr Anthropol* 11(1):55–58.

FAOSTAT. 2008. *Food and Agriculture Organization Statistical Production Yearbook 2007–2008*. Rome: FAO.

Fawzia A, Karuri EG, Hagenimana V. 1999. Sweet potato ketchup: feasibility, acceptability and production costs in Kenya. *Afr Crop Sci J* 7:81–89.

Firon N, LaBonte D, Villordon A, McGregor C, Kfir Y, Pressman E. 2009. Botany and physiology: storage root formation and development. In: Loebstein G, Thottappilly G (editors), *The Sweetpotato*. Dordrecht, The Netherlands: Springer, B.V., pp. 13–26.

Grabowski JA, Truong V-D, Daubert CR. 2006. Spray drying of amylase hydrolyzed sweetpotato puree and physicochemical properties of powder. *J Food Sci* 71:E209–E217.

Grabowski JA, Truong V-D, Daubert CR. 2008. Nutritional and rheological characterization of spray dried sweetpotato powder. *Lebensm Wiss Technol* 41:206–216.

Hathorne CS, Biswas MA, Gichuhi PN, Bovell-Benjamin AC. (2008). Comparison of breads supplemented with sweetpotato flour and high-gluten dough enhancers. *Lebensm Wiss Technol* 41:803–815.

He GH, Prakash CS, Jarret RL. 1995. Analysis of genetic diversity in sweet potato (*Ipomoea batatas*) germplasm collection using DNA amplification fingerprinting. *Genome* 38:938–945.

Hoover MW, Harmon SJ. 1967. Carbohydrate changes in sweet potato flakes made by the enzyme activation technique. *Food Technol* 21:1529–1532.

Hoover MW, Miller NC. 1973. Process for producing sweetpotato chips. *Food Technol* 27:74–80.

Hoover MW, Walter WM Jr, Giesbrecht FG. 1983. Preparation and sensory evaluation of sweet potato patties. *J Food Sci* 48:1568–1569.

Hu JJ, Nakatani M, Lalusin AG, Fujimura T. 2004. New microsatellite markers developed from reported *Ipomoea trifida* sequences and their application to sweetpotato and its related wild species. *Sci Hortic* 102:375–386.

Huang AS, Tanudjaja L, Lum D. 1999. Content of alpha-, beta-carotene, and dietary fiber in 18 sweetpotato varieties grown in Hawaii. *J Food Compos Anal* 12:147–151.

Huang JC, Sun M. 2000. Genetic diversity and relationships of sweetpotato and its wild relatives in *Ipomoea* series *batatas* (Convolvulaceae) as revealed by inter-simple sequence repeat (ISSR) and restriction analysis of chloroplast DNA. *Theor Appl Genet* 100:1050–1060.

Islam S. 2006. Sweetpotato (*Ipomoea batatas* L.) leaf: its potential effect on human health and nutrition. *J Food Sci* 71:R13–R21.

Jones A. 1986. Sweetpotato heritability estimates and their use in breeding. *HortScience* 21:14–17.

Kays SJ. 1985a. The Physiology of yield in the sweet potato. In: Bouwkamp JC (editor), *Sweet Potato Products: A Natural Resource for the Tropics*. Boca Raton, FL: CRC Press, pp. 79–132.

Kays SJ. 1985b. Formulated sweet potato products. In: Bouwkamp JC (editor), *Sweet Potato Products: A Natural Resource for the Tropics*. Boca Raton, FL: USA CRC Press, pp. 205–218.

Kotecha PM, Kadam SS. 1998. Sweetpotato. In: Salunkhe DK, Kadam SS (editors), *Handbook of Vegetable Science and Technology. Production, Composition, Storage and Processing*. New York: Marcel Dekker, Inc., pp. 71–97.

Kriegner A, Cervantes JC, Burg K, Mwanga ROM, Zhang D. 2003. A genetic linkage map of sweetpotato [*Ipomoea batatas* (L.) Lam.] based on AFLP markers. *Mol Breeding* 11:169–185.

Kumar P, Coronel P, Truong VD, Simunovic J, Swartzel KR, Sandeep KP, Cartwright GD. 2008. Overcoming issues associated with the scale-up of a continuous flow microwave system for aseptic processing of vegetable purees. *Food Res Int* 41:454–461.

Lopez-Malo A, Rios-Cass L. 2009. Solar assisted drying of foods. In: Hui YH, Clary C, Farid MM, Fasina OO, Noomhorm A, Welti-Chanes J (editors), *Food Drying Science and Technology: Microbiology, Chemistry, Applications*. Lancaster, PA: DEStech Publications, Inc., pp. 83–98.

Low J, Walker T, Hijmans R. 2001. The potential impact of orange-fleshed sweetpotatoes on vitamin A intake in Sub-Saharan Africa. The VITAA Project, Vitamin A and Orange-fleshed Sweetpotatoes in Sub-Saharan Africa, Nairobi, May 2001. [Accessed on October 27, 2009]. Available: http://www.cipotato.org/vitaa/about_vitaa.htm.

Matsui T, Ebuchi S, Fukui K, Matsugano M, Terahara N, Matsumono K. 2004. Caffeoylsophorose, a new α-glucosidase inhibitor by fermented purple-fleshed sweetpotato. *Biosci Biotech Biochem* 68(11):2239–2246.

Menelaou E, Kachatryan A, Losso J. 2006. Lutein content in sweetpotato leaves. *HortScience* 41:1269–1271.

Mohapatra S, Panda SH, Sahoo SK, Sivakumar PS, Ray RC. 2007. β-Carotene-rich sweet potato curd: production, nutritional and proximate composition. *Int J Food Sci Technol* 42:1305–1314.

O'Sullivan JN, Asher CJ, Blamey FPC. 1997. *Nutrient Disorders of Sweet Potato*. Canberra: ACIAR Mongraph No 48.

Okungbowa FI, Osagie M. 2009. Mycoflora of sun-dried sweetpotato (*Ipomoea batatas* L.) slices in Benn City, Nigeria. *Afr J Biotechnol* 8:3326–3331.

Owori C. and Hagenimana V. (2000). Quality evaluation of sweetpotato flour processed in different agro-ecological sites using small scale processing technologies. *Afr Potato Assoc Conf Proc* 5:483–490.

Padmaja G. 2009. Uses and nutritional data of sweetpotato. In: Loebenstein G, Thottapilly G (editors), *The Sweetpotato*. Dordrecht, The Netherlands: Springer, pp. 189–233.

Panda SH, Naskar SK, Shivakumar PS, Ray RC. 2009b. Lactic acid fermentation of anthocyanin-rich sweet potato (*Ipomoea batatus* L.) into lacto-juice. *Int J Food Sci Technol* 44:288–296.

Panda SH, Panda S, Shiva Kumar PS, Ray RC. 2009a. Anthocyanin- rich sweet potato lacto-pickle:

Production, nutritional and proximate composition. *Int J Food Sci Technol* 44:445–455.

Perez RH, Tan JD. 2006. Production of acidophilus milk enriched with purees from coloured sweet potato (*Ipomoea batatas* L.) varieties. *Ann Trop Res* 28:70–85.

Pérez-Díaz IM, Truong VD, Webber A, McFeeters RF. 2008. Effects of preservatives and mild acidification on microbial growth in refrigerated sweetpotato puree. *J Food Protection* 71:639–642.

Peters D, Wheately C. 1997. Small-scale agro enterprises provide opportunities for income generation: Sweetpotato flour in East Java, Indonesia. *Q J Int Agric* 36:331–352.

Picha DH. 1986. Influence of storage duration and temperature on sweetpotato sugar content and chip color. *J Food Sci* 51:239–240.

Prakash CS, He GH, Jarret RL. 1996. DNA marker-based study of genetic relatedness in United States sweetpotato cultivars. *J Am Soc Hort Sci* 121:1059–1062.

Ravi V, Indira P. 1999. Crop physiology of sweetpotato. In: Janick J (editor), *Horticultural Reviews*, Vol. 23. John Wiley & Sons, pp. 277–284.

Ray RC, Naskar SK, Tomlins KI. 2010. Bio-processing of sweetpotato in food, feed and bio-ethanol. In Ray RC, Tomlins KI (editors). *Sweetpotatoes: Post-Harvest Aspects in Food, Feed and Industry*. New York: Nova Science Publishers, Inc. pp. 163–191.

Saigusa N, Terahara N, Ohba R. 2005. Evaluation of DPPH-radical-scavenging activity and antimutagenicity and analysis of anthocyanins in an alcoholic fermented beverage produced from cooked or raw purple-fleshed sweet potato (*Ipomea batatas* cv. *Ayamurasaki*) roots. *Food Sci Technol Res* 11(4):390–394.

Sakamoto S, Bouwkamp JC. 1985. Industrial products from sweetpotatoes. In: Bouwkamp JC (editor), *Sweetpotato Products: A Natural Source for the Tropics*. Boca Raton, FL: CRC Press, pp. 219–233.

Schwartz SJ, Walter WM, Carroll DE, Giesbrecht FG. 1987. Chemical, physical and sensory properties of a sweet potato French-fry type product during frozen storage. *J Food Sci* 52:617–619, 633.

Simunovic J, Swartzel KR, Truong VD, Cartwright GD, Coronel P, Sandeep KP, Parrott DL. 2006. Methods and apparatus for thermal treatment of foods and biomaterials, and products obtained thereby. Patent Pending. US Patent Publication # US-2006–0151533-A1, 07/13/06, and World Intellectual Property Organization # WO 2006–053329-A2, 05/18/06.

Steed LE, Truong VD. 2008. Anthocyanin content, antioxidant activity and selected physical properties of flowable purple-fleshed sweet potato purees. *J Food Sci* 73:S215–S221.

Steed LE, Truong VD, Simunovic J, Sandeep KP, Kumar P, Cartwright GD, Swartzel KR. 2008. Continuous flow microwave-assisted processing and aseptic packaging of purple-fleshed sweet potato purees. *J Food Sci* 73(9):E455–E462.

Suda I, Ishikawa F, Hatakeyama M, Miyawaki M, Kudo T, Hirano K, Ito K, Ito A, Yamakawa O, Horiuchi S. 2008. Intake of purple sweet potato beverage affects on serum hepatic biomarker levels of healthy adult men with borderline hepatitis. *Eur J Clin Nutr* 62:60–67.

Suda I, Oki T, Masuda M, Kobayashi M, Nishiba Y, Furuta S. 2003. Physiological functionality of purple-fleshed sweet potatoes containing anthocyanins and their utilization in foods. *Jpn Agric Res Q* 37:167–173.

Szyperski RJ, Hammann DD, Walter WM Jr. 1986. Controlled α-amylase process for improved sweet potato puree. *J Food Sci* 51:360–363, 377.

Talekar NS. 1991. Integrated Control of *Cylas formicarius*. In: Jansson RK, Raman KV (editors), *Sweet Potato Pest Management: A Global Perspective*. Boulder Co: Westview Press, pp. 139–156.

Talekar NS, Pollard GV. 1991. Vine borers of sweet potato. In: Jansson RK, Raman KV (editors), *Sweet Potato Pest Management: A Global Perspective*. Boulder Co: Westview Press.

Tanumihardjo SA. 2008. Food-based approaches for ensuring adequate vitamin A nutrition. *Compr Rev Food Sci Food Saf* 7:373–381.

Truong VD. 1992. Sweet potato beverages: Product development and technology transfer. In: Hill WA, Bonsi CK, Loretan PA. (editors), *Sweet Potato Technology for the 21st Century*. Tuskegee, AL: Tuskgee University, pp. 389–399.

Truong VD. 1994. Development and transfer of processing technologies for fruity food products from sweet potato. *Acta Hortic* 380:413–420.

Truong VD, Avula RY. 2010. Sweetpotato purees and dehydrated forms for functional food ingredients. In: Ray RC, Tomlins KI (editors) *Sweetpotatoes: Post-harvest Aspects in Food, Feed and Industry*. New York: Nova Science Publishers, Inc. pp. 117–161.

Truong VD, Biermann CJ, Marlett JA. 1986. Simple sugars, oligosaccharides, and starch concentrations in raw and cooked sweet potato. *J Agric Food Chem* 34:421–425.

Truong VD, McFeeters RF, Thompson RT, Dean LO, Shofran B. 2007. Phenolic acid content and composition in commercial sweetpotato (*Ipomea batatas* L.) cultivars in the United States. *J Food Sci* 72(6): C343–C349.

Truong VD, Thibault Y. 2009. Effects of processing methods on quality of sweetpotato French fries. Unpublished.

Truong VD, Walter WM Jr. 1994. Physical and sensory properties of sweet potato puree texturized with cellulose derivatives. *J Food Sci* 59:175–1180.

Truong VD, Walter WM Jr, Belt KL. 1998. Textural properties and sensory quality of processed sweetpotatoes as affected by low temperature blanching. *J Food Sci* 63:739–743.

Truong VD, Walter WM Jr, Giesbrecht FG. 1995. Texturization of sweet potato puree with alginate: Effects of tetrasodium pyrophosphate and calcium sulfate. *J Food Sci* 60:1054–1059, 1074.

Tsou SCS, Hong TL. 1992. The nutrition and utilization of sweetpotato. In: Hill WA, Bonsi CK, Loretan PA (editors), *Sweetpotato Technology for the 21st Century*. Tuskegee, AL: Tuskegee University, pp. 359–366.

USDA (United State Department of Agriculture), Economics, Statistics and Market Information System. US Sweetpotato Statistics. Available from: http://usda.

mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1492, Accessed on October 7, 2009.

USDA, Economic Research Service. 2010. Vegetables and Melons Outlook/VGS-338/April 22, 2010. Available from http://www.ers.usda.gov/publications/vgs/tables/swpot.pdf, Accessed on June 23, 2010.

Utomo JS, Che Man YB, Rahman RA, Saad MS. 2005. Physical and chemical characteristics of restructured sweet potato sticks made from three sweet potato cultivars. In: *Concise Papers of the Second International Symposium on Sweet potato and Cassava*, 2005 June 14–17, Kaula Lumpur, Malaysia, pp. 221–222.

Valdez CC, Lopez CY, Schwartz S, Bulux J, Solomons NW. 2001. Sweetpotato buds: the origins of a "designer" food to combat hypovitaminosis A in Gautemala. Processing, vitamin A content and preservation characteristics. *Nutr Res* 21:61–70.

Van Hal M. 2000. Quality of sweet potato flour during processing and storage. *Food Rev Int* 16:1–37.

van Jaarsveld PJ, Faber M, Tanumihardjo SA, Nestel P, Lombard CJ, Spinnler Benade AJ. 2005. β-carotene-rich orange-fleshed sweetpotato improves the vitamin A status of primary school children assessed with the modified-relative-dose-response test. *Am J Clin Nutr* 81:1080–1087.

Villordon A, LaBonte D. 1996. Genetic variation among sweetpotatoes propagated through nodal and adventitious sprouts. *J Am Soc Hort Sci* 121:170–174.

Villordon AQ, Labonte DR. 1995. Variation in randomly amplified DNA markers and storage root yield in Jewel sweet potato clones. *J Am Soc Hort Sci* 120:734–740.

Walter WM Jr. 1987. Effect of curing on sensory properties and carbohydrate composition of baked sweetpotatoes. *J Food Sci* 52:1026–1029.

Walter WM Jr, Catignani GL, Yow LL, Porter DH. 1983. Protein nutritional value of sweet potato flour. *J Agric Food Chem* 31:947–949.

Walter WM Jr, Schwartz SJ. 1993. Controlled heat processing of Jewel sweet potatoes for puree production. *J Food Qual* 16:71–80.

Walter WM Jr, Sylvia KE, Truong VD. 1998. Alkali-neutralization process maintains the firmness and sensory quality of canned sweetpotato pieces. *J Food Qual* 21:421–431.

Walter WM Jr, Wilson PW. 1992. Frozen sweet potato products. In: Hill WA, Bonsi CK, Loretan PA (editors), *Sweet Potato Technology for the 21st Century*. Tuskegee, AL, pp. 400–406.

Wilson LA. 1982. Tuberization in sweetpotato (*Ipomoea batatas (L.) Lam.*). In: Villareal RL, Griggs TD (editors), *Sweet Potato. Proceedings of the 1st International Symposium*. Shanhua, Taiwan: Asian Vegetable Research and Development Center, pp. 79–93.

Winaro FG. 1982. Sweetpotato processing and by-product utilization in the tropics. In: Villareal RL, Griggs TD (editors), *Sweetpotato*. Proceedings of the First International Symposium, AVRDC, Shanhua, Taiwan, pp. 373–84, 393.

Yamakawa O. 2000. New cultivation and utilization system for sweet potato toward the 21st century. In: Nakatani M, Komaki K (editors), *Potential of Root Crops for Food and Industrial Resources. Twelfth Symposium of International Society of Tropical Root Crops (ISTRC)*, Sept. 10–16, 2000, Tsukuba, Japan, pp. 8–13.

Yen DE. 1982. Sweet potato in historical perspective. In: Villareal RL, Griggs TD (editors), *Sweet Potato. Proceedings of the 1st International Symposium*. Shanhua, Taiwan: Asian Vegetable Research and Development Center, pp. 17–30.

Yencho GC, Pecota KV, Schultheis JR, VanEsbroeck ZP, Holmes G, Little BE, Thornton AC, Truong VD. 2008. Covington sweetpotato. *HortSci* 43:1911–1914.

Yeoh HH, Truong VD. 1996. Amino-acid composition and nitrogen-to-protein conversion factors for sweet potato. *Trop Sci* 36:243–246.

Zhang D, Cervantes J, Huaman Z, Carey E, Ghislain M. 2000. Assessing genetic diversity of sweet potato (*Ipomoea batatas* (L.) Lam.) cultivars from tropical America using AFLP. *Genet Resour Crop Evol* 47:659–665.

Zhang DP, Rossel G, Kriegner A, Hijmans R. 2004. AFLP assessment of diversity in sweetpotato from Latin America and the Pacific region: Its implications on the dispersal of the crop. *Genet Resour Crop Evol* 51:115–120