

## Sweetpotato Production, Processing, and Nutritional Quality

V. D. Truong<sup>1</sup>, R. Y. Avula<sup>2</sup>, K. V. Pecota<sup>3</sup>, and G. C. Yencho<sup>3</sup>

<sup>1</sup> USDA-ARS Food Science Research Unit, Department of Food, Bioprocessing and Nutrition Sciences, North Carolina State University, Raleigh, USA

<sup>2</sup> Department of Food Science and Technology, University of Georgia, Athens, USA

<sup>3</sup> Department of Horticultural Science, North Carolina State University, Raleigh, USA

### Introduction

Sweetpotato, *Ipomoea batatas* L. (Lam.), is an important economic crop in many countries. In terms of annual production, sweetpotato ranks as 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 (FAO 2016). Sweetpotato fulfills a number of basic roles in the global food system, all of which have fundamental implications for meeting food requirements, reducing poverty, and increasing food security (El-Sheikha and Ray 2017).

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* (e.g., “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  $\beta$ -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. Historically, African Americans 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 (Estes 2009).

Depending on the flesh color, sweetpotatoes contain high levels of  $\beta$ -carotene, anthocyanins, phenolics, dietary fiber, vitamins, minerals, and other bioactive compounds. The  $\beta$ -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 increased consumption of orange-fleshed sweetpotatoes improved the vitamin A status of children, pregnant women, and lactating mothers (Low et al. 2007; Hotz et al. 2012;

Van Jaarsveld et al. 2005). Further, polyphenolics from purple-fleshed sweetpotatoes exhibited diverse biological activities, including protective antioxidant, anti-inflammatory, anticancer, antidiabetic and hepatoprotective activity effects (Hu et al. 2016; Lim et al. 2013). 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. The world total production of sweetpotatoes was 106.60 million metric tons (MMT) in 2014. Since the mid-1990s, global production has ranged from a low of 101.28 MMT in 2007 to a high of 147.17 MMT in 1999 (Figure 35.1). In 2014, about three-fourth of the global production was from Asia and Pacific Islands, followed by Africa with

about 21%, while the Americas (North, Central, and South) account for about 3.6%. China was the leading producer of sweetpotatoes, with 71.54 MMT or about 67% of the global production, followed by Nigeria (3.78 MMT), Tanzania (3.5 MMT), Ethiopia (2.7 MMT), and Mozambique (2.4 MMT). The United States was the tenth largest producer, with 1.34 MMT production. Only two countries in Europe, Portugal and Spain, grow sweetpotatoes, with 22,591 and 13,550 metric tons produced in 2014.

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

The per capita consumption is highest in places where sweetpotatoes are consumed as a

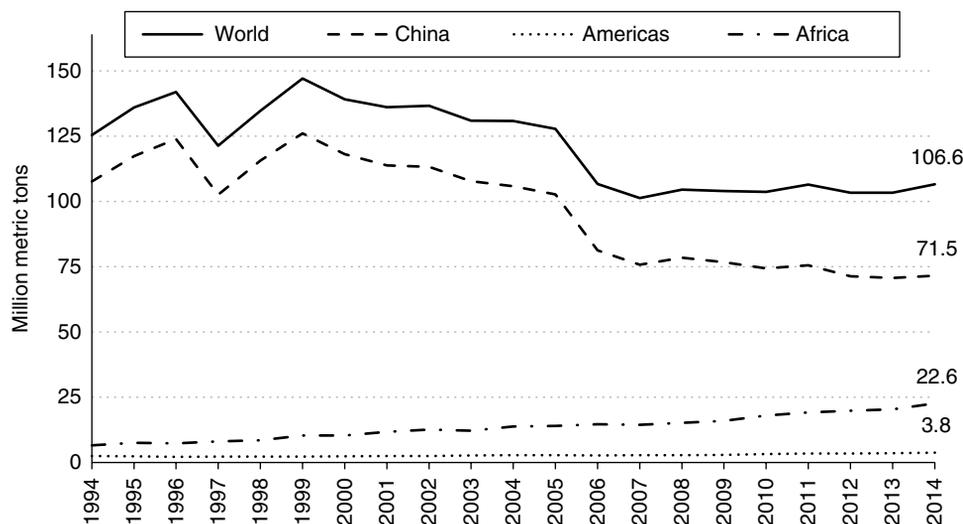


Figure 35.1 World and regional sweetpotato production for 1994–2014. Source: FAO (2016).

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 sweetpotatoes is estimated at 18 kg in Asia, 9 kg in Africa, 5 kg in Latin America. Between 2000 and 2014, sweetpotato consumption in the United States increased nearly 80%, from 1.9 kg to 3.4 kg per capita (FAO 2015; Johnson et al. 2015). Sweetpotato consumption has been greatly enhanced by the wide spread commercial availability of frozen “French-fried” sweetpotatoes. To accommodate this recent growth trend, increased modern processing capacity has been built within the southern US sweetpotato growing regions.

## 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 still some confusion that exists regarding its origin, and primary and secondary centers of diversity. Roullier et al. (2013a,b) and Grüneberg et al. (2015) have published thorough reviews of this topic. In brief, 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. Recent studies conducted by Roullier, et al. (2013 a, b) incorporating chloroplast DNA and molecular phylogeny analyses confirm this hypothesis. They also suggest that *I. batatas* most likely evolved from at least two distinct autopolyploidization events in wild populations of a single progenitor species most likely *I. trifida*. Secondary contact between sweetpotatoes domesticated in Central America and in South America, from differentiated wild *I. batatas* or *I. trifida* populations, could have led to further introgression. Molecular marker

analyses conducted by Huang and Sun (2000) and Zhang et al. (2000) also 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). Regardless of the center of origin, sweetpotato was widely established in tropical regions of the new world around 2500 B.C. (Austin 1988). It was established in Polynesia, prior to European arrival (Roullier, et al. 2013b). 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 (Bohac et al. 1995; Roullier, et al. 2013a, b).

## Botany and Physiology

The sweetpotato is a herbaceous perennial that is grown as an annual by stem cuttings or plant sprouts from storage roots (Figure 35.2). 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:

- 1) The leaves act as the photosynthetic canopy.
- 2) The stems transport energy to the roots and transport water and minerals from the roots.
- 3) The root system 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.

Sweetpotatoes possess 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



**Figure 35.2** Sweetpotato plant, harvesting and harvested tubers in the market. *Source (From left):* USDA Plants Database, NC State Extension, USDA-AMS.

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. 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 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. Root set even in the same field and cultivar is highly variable in sweetpotatoes, 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 promote shoot growth. Soil temperatures of 20–30°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 and Field Production

### 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 the 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 economic 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. (2008) 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. (2008).

### **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 1985a). 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 of 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 was 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 are 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 post-harvest decay. Roots should not be harvested when the weather is too cold. Chilling injury is a function of temperature and duration of exposure. Temperatures 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 sweetpotatoes 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 drop-offs 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, animal feeds and traditional medicine around the world (Mohanraj and Sivasankar 2014). The nutritional values of sweetpotato roots and leaves and selected processed products are shown in Table 35.1. In Asia and Africa, the

sweetpotato leaves are eaten as green vegetables. The nutrient content of sweetpotato leaves varies among the varieties, harvest dates, crop years and cooking methods. On dry weight basis, sweetpotato leaves contain 25–37% protein, 42–61% carbohydrate, 2–5% crude fat, 23–38% total dietary fiber, 60–200 mg/100 g ascorbic acid, and 60–120 mg/100 g carotene (Almazan et al. 1997, Sun et al. 2014). They are also rich in calcium (230–1,958 mg/100 g), iron (2–22 mg), potassium (479–5,230 mg), and magnesium (220–910 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, Truong et al. 2007). Sweetpotato greens are very rich in lutein, 38–51 mg/100 g in fresh leaves, which are even higher than the lutein levels in the vegetables that are known as a source for lutein, such as kale (38 mg/100 g) and spinach (12 mg/100 g) (Menelaou et al. 2006). Novel galactolipids were recently isolated and characterized from sweetpotato leaves (Napolitano et al. 2007), indicating that this leafy vegetable can be a potential source of omega-3 polyunsaturated fatty acid. Health benefits and disease prevention of bioactive compounds in sweetpotato leaves have been reported (Johnson and Pace 2010).

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%. A wide range of dry matter content of 13–45% from a sweetpotato germplasm collection was reported by Tsou and Hong (1992) and Brabet et al. (1998). Sweetpotato roots are good source of carbohydrates and generally low in protein and fat. Protein content ranged from 1.73–9.14% 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 amino acids

**Table 35.1** Nutritional profile content in sweetpotato roots and leaves (per 100g fresh weight).

Nutrient	Unit	Sweetpotato Root				Leaves, Raw
		Raw	Boiled, Without Skin	Canned, Mashed	Snacks/Chips, Unsalted	
<i>Proximate</i>						
Water	g	77.28	80.13	73.88	4.51	86.81
Energy	kcal	86	76	101	532	42
Protein	g	1.57	1.37	1.98	2.94	2.49
Total lipid (fat)	g	0.05	0.14	0.2	32.35	0.51
Carbohydrate, by difference	g	20.12	17.72	23.19	56.82	8.82
Fiber, total dietary	g	3	2.5	1.7	8.8	5.3
Sugars, total	g	4.18	5.74	5.45	8.82	na <sup>1</sup>
<i>Minerals</i>						
Calcium	mg	30	27	30	59	78
Iron	mg	0.61	0.72	1.33	2.12	0.97
Magnesium	mg	25	18	24	65	70
Phosphorus	mg	47	32	52	145	81
Potassium	mg	337	230	210	925	508
Sodium	mg	55	27	75	35	6
Zinc	mg	0.3	0.2	0.21	0.53	na
<i>Vitamins</i>						
Vitamin C, total ascorbic acid	mg	2.4	12.8	5.2	0	11
Thiamin	mg	0.078	0.056	0.027	0.088	0.156
Riboflavin	mg	0.061	0.047	0.09	0.161	0.345
Niacin	mg	0.557	0.538	0.955	2.088	1.130
Vitamin B <sub>6</sub>	mg	0.209	0.165	0.235	0.535	1
Folate, DFE	µg	11	6	11	37	1
Vitamin B <sub>12</sub>	µg	0	0	0	0	0
Vitamin A, IU	IU	14187	15740	8699	23675	3378
Vitamin E (α-tocopherol)	mg	0.26	0.94	1.09	9.82	na
Vitamin D	IU	0	0	0	0	0
Vitamin K (phylloquinone)	µg	1.8	2.1	2.4	24.5	302.2

Source: USDA (2016), Standard Reference 28, revised May 2016.

<sup>1</sup> not analyzed.

compare significantly to the FAO reference protein (Maloney et al. 2014; 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. Residues from sweetpotato starch and juice processing of commercial varieties are good sources of dietary fiber, 16–36% of dry weight (Mei et al. 2010; Truong et al. 2012a). 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 and pasting temperatures are usually in a range of 60–76°C (Zhu and Wang, 2014). A special sweetpotato cultivar in Japan named Quick Sweet has starch gelatinization temperature of <50°C and short cooking time. Short amylopectin chain length and cracking on the hilum of starch granules contribute to the lower pasting temperature of the Quick Sweet cultivar (Takahata et al. 2010). 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 make up the majority of the total sugars in raw sweetpotato roots. During cooking, amylases act on the gelatinized starch resulting in the formation of maltose in cooked sweetpotatoes. There is substantial genetic diversity within the sweetpotato genotypes collected around the world in term of sugar content and degree of sweetness that contribute to the consumer preferences of processed products (Kays et al. 2005; Leksrisonpong et al. 2012). The glycemic indices of cooked sweetpotatoes were about 63–66, indicative of moderate glycemic index food (Allen et al. 2012).

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 35.1). Potassium is the mineral with the

greatest concentration in sweetpotato, with an average of 396 mg/100 g fwb. 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 (B<sub>1</sub>), riboflavin (B<sub>2</sub>), niacin (B<sub>6</sub>), pantothenic acid (B<sub>5</sub>), 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 35.2). 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 (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. Total carotenoid content is correlated with the dry matter content and sensory attributes involving visual, odor, taste and textural characteristics of cooked sweetpotatoes. Doubling in carotenoid content would result in a decrease of about 1.2% of dry matter content in sweetpotato varieties (Tomlins et al. 2012). Epidemiological studies indicated the beneficial effects of high carotene diets in reducing the risks of cancer, age-related macular degeneration, and heart diseases (Tanumihardjo 2008).

Purple-fleshed sweetpotato roots have attractive reddish-purple color with high levels of anthocyanins and total phenolics (Table 35.2). The flowable purées with a solids 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-glucoside equivalent/100 g fwb, respectively. The 2, 2-diphenyl-1-picrylhydrazyl

**Table 35.2** Phytonutrients in orange- and purple-fleshed sweetpotato roots.

Varieties	Flesh Color	Dry Matter (g/100g)	$\beta$ -carotene (fwb) (mg/100g)	Anthocyanins <sup>1</sup>	Total Phenolics <sup>2</sup>
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 <sup>3</sup>	n.a.	80.2	401.6
NC 415	Dark purple	29.0 <sup>3</sup>	n.a.	69	652.5
Okinawa	Light purple	30.0 <sup>3</sup>	n.a.	21.1	458.3

Sources: Truong et al. (2007); Steed and Truong (2008); Yencho et al. (2008).

<sup>1</sup> mg cyanidin-3-glucoside/100g fw.

<sup>2</sup> mg chlorogenic acid/100g fw.

<sup>3</sup> Dry matter adjusted to 18-20% for flowable purées; n.a. = not analyzed.

(DPPH) radical scavenging activity was 47  $\mu$ mol trolox equivalent/g fwb and oxygen radical absorbance capacity (ORAC) of 26  $\mu$ mol trolox equivalent/g fwb (Steed and Truong 2008).

The purple-fleshed sweetpotato varieties have anthocyanin content up to 348 mg/100 g fwb) 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. Seventeen anthocyanins were identified by HPL-MS/MS. The major anthocyanidins, cyanidin and peonidin, contributors to the blue and red hues of purple-fleshed sweetpotatoes, can be simply quantified by acid hydrolysis of the extracted anthocyanins. This method has been adapted in the breeding programs to select clones with various levels of cyanidin or peonidin for targeted reddish-purple flesh colors (Truong et al. 2010, 2012b; Xu et al. 2015).

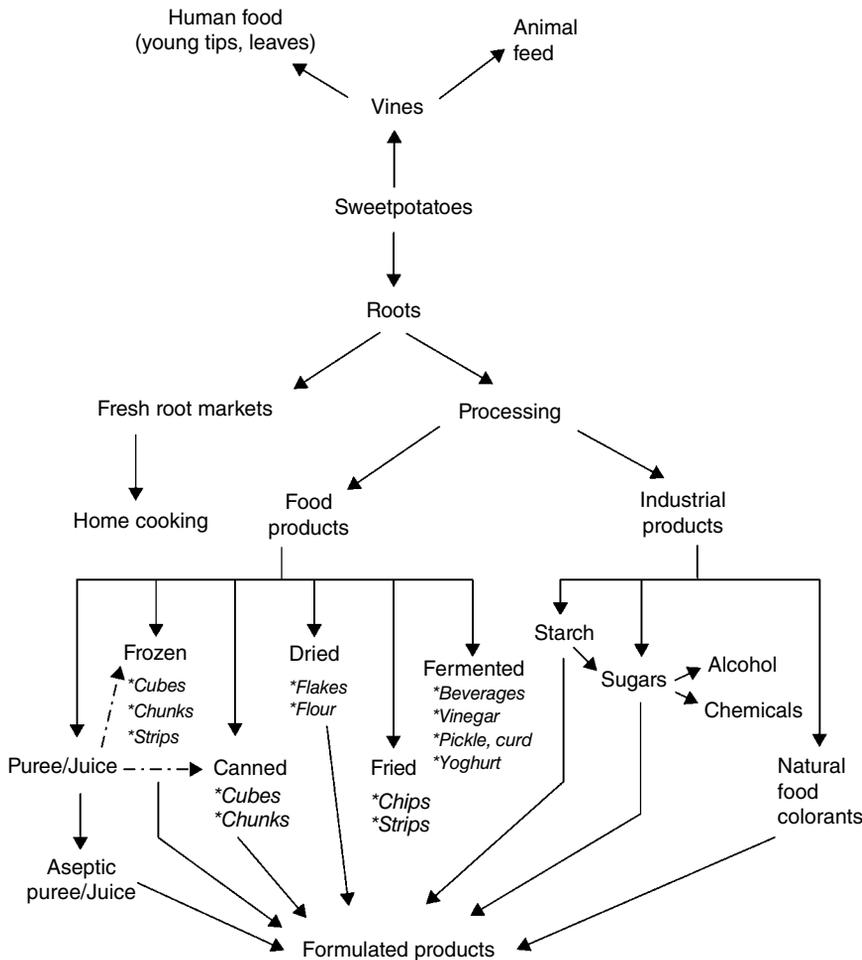
Research on nutraceutical properties of purple-fleshed sweetpotato indicated that the extracted anthocyanins exhibited strong radical scavenging activity, antimutagenic activity, and significantly reduced high blood pressure and liver injury in rats (Zhang et al. 2009). Other physiological functions of anthocyanins include anti-inflammatory activity, antimicrobial activity,

ultraviolet light protection, and reduction in memory impairment effects and colorectal cancer (Lim et al. 2013; Wu et al. 2008). A study on healthy adult men with borderline hepatitis indicated that purple-fleshed sweetpotato beverage intake (400 mg anthocyanins/day) may have a potential capacity for protection of the liver against oxidative stress (Suda et al. 2008).

## 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 35.3. 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



**Figure 35.3** Different processing and utilization streams of sweetpotatoes.

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 dryer, 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.

## **Purées and Juices**

### **Processing**

The use of sweetpotatoes in the food industry often involves processing of the roots into purées that can be subsequently frozen, canned, or packaged in aseptic conditions to produce shelf-stable products for year-round availability. In purée 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 purée 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 purée; and (2) the preservation technology that could produce shelf-stable product for convenient incorporation in processed foods.

Several techniques have been developed for purée processing in order to produce purées 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 puréeing of sweetpotatoes include washing, peeling, hand-trimming, cutting, steamed blanching or cooking, and grinding into purées which can be subjected to canning or freezing for preservation (Figure 35.3). 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 purées 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 purée processing, and this process is now commonly used in the food industry.

As shown in Figure 35.4, the peeled sweetpotatoes either can be cut into cubes of 2 cm, strips of 2 × 2 × 6 cm, and slices of 0.5–0.95 cm thickness or mashed using a hammer mill with rotating blades to chop and push the materials through a 1.5–2.3 mm mesh screen (Walter and Schwartz 1993). Next, the materials are steamed blanching at 65–75°C that activates the amylases and gelatinizes the starch for hydrolysis. For the process with slices, strips, and cubes, comminuting the blanching materials into purée is carried out at this point using a hammer mill. The blanching purée 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.  $\alpha$ - and  $\beta$ -amylases hydrolyze the starch producing maltose, maltotriose, glucose, and dextrins.

### **Packaging and Preservation**

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

Preservation by canning for low-acid food such as sweetpotato purées (pH, 5.8–6.3) usually involves high thermal treatment of the product because heat transfer in the purée is mainly by conduction. High thermal treatment



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 color and viscosity comparable to the non-sterilized purée and was shelf-stable for at least 12 months.

Purple-fleshed sweetpotato purées were also successfully processed into high quality aseptic product using the continuous flow microwave system (Steed et al. 2008). With this technology, shelf-stable purées 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 purées from other fruits and vegetables (Kumar et al. 2008). In this new process, sweetpotato purée is loaded into a hopper, and pumped through the system. Microwaves from a generator are delivered to sterilize the purée 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. 2014). The first commercial venture on aseptically packaged sweetpotato purée using this microwave-assisted sterilization technology has been carried out. With rapid heating, high retention of carotene and anthocyanins (>85%) in the purées can be achieved, and this development opens up a new market opportunity for the sweetpotato industry.

Sweetpotato purées 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 (Collins and Washam-Hutsell 1986; Collins and Walter 1992; Truong and Walter 1994). The sweetpotato purées are also used in fruit/vegetable based beverages and restructured products (Truong 1992; Truong et al. 1995). Other commercial utilization of sweetpotato purée includes jam and ketchup (Truong 1994; Fawzia et al. 1999).

The uses of sweetpotato purées in processing into flakes and powders, and 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 purées, it is expected that more processed food products from the purée will be developed.

Sweetpotato purées have also been used as ingredient in various formulated fruit and vegetable juices (Padmaja, 2009; Truong, 1994). However, heat treatment in sweetpotato purée processing gelatinizes starch and produces thick slurry with cooked flavor, which may not be preferred in several juicy products. These problems can be overcome by alternative processes involving grinding raw sweetpotatoes and acid treatment to inactivate oxidizing enzymes during juice extraction. Aside from the juice, which is subjected to thermal processing for packaging and preservation as described above, the ungelatinized starch and flour with high dietary fiber can be recovered as co-products from this alternative process (Truong et al. 2012a). Polyphenols in purple-fleshed sweetpotato juice can be sorbed in protein-rich matrices such as soy flour, light roast peanut flour, and rice protein concentrate to create functional food ingredients rich in both proteins and bioactive compounds from sweetpotatoes. Using the same strategy, sweetpotato flour efficiently sorbed, concentrated, and stabilized antioxidant polyphenols in fruit juices such as blueberries, blackcurrant, and muscadine grape (Grace et al. 2015).

### **Frozen Products**

Sweetpotatoes can be frozen in different forms such as whole roots, halves, quarters, slices, cubes, French fries, paste, or as purée. 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 purées 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  $-40^{\circ}\text{C}$  (Woolfe 1992). In large-scale production of French fries, partially fried products are frozen for distribution to institutional and retail 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 nonenzymatic 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, in either syrup or water. Sweetpotatoes can also be puréed 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  $77^{\circ}\text{C}$  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  $62^{\circ}\text{C}$  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  $95^{\circ}\text{C}$  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  $77^{\circ}\text{C}$  to ensure a good vacuum of the finished cans (Bouwkamp 1985b). After closing, the cans should be retorted according to the processing schedules and quickly cooled after retorting to an internal temperature of  $35^{\circ}\text{C}$  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, and Flour**

Sweetpotato roots are processed into dehydrated forms such as dried chips, cubes, 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; Waramboi et al. 2014). 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 35.5). 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. 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

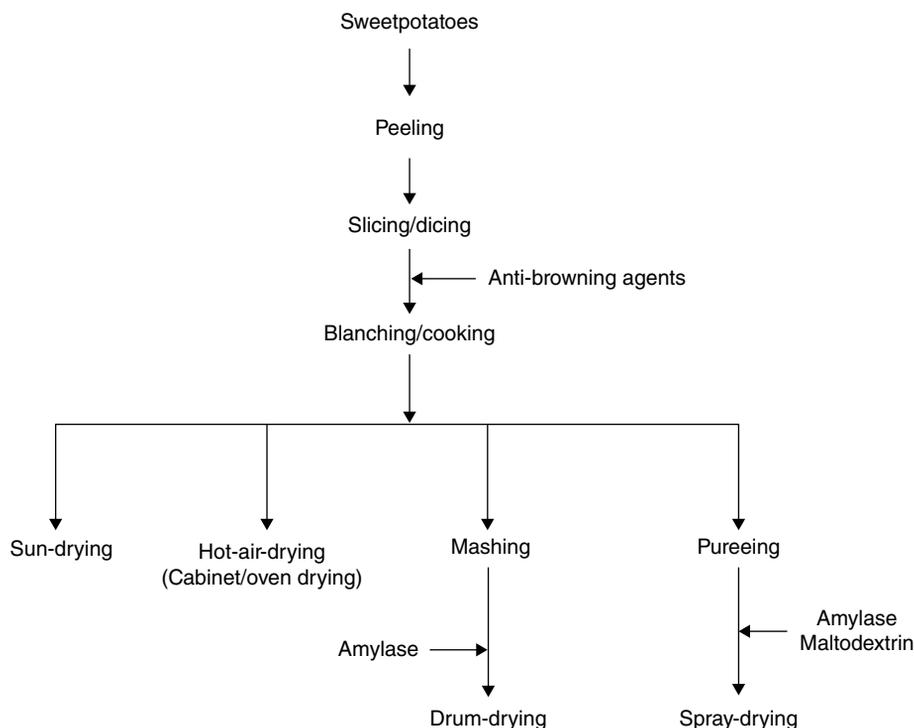


Figure 35.5 Drying technologies applied to dehydrated sweetpotato products.

use in wheat–sweetpotato bread (van Hal 2000). However, poor control of energy input and product quality; interruption of drying caused by cloud, rain, 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 (e.g., 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 dryers such as cabinet, tunnel, drum, or spray dryers 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 dryers. As in purée 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 purées 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 dryer 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  $\alpha$ -amylase was used to hydrolyze a part of the pregelatinized purée, which is then blended with the untreated portion. SAPP or citric acid is added to the purée before drying to control non-enzymatic browning, which causes discoloration of the reconstituted flakes. Avula et al. (2006) prepared drum-dried flour by subjecting sweetpotato mash to a double-drum dryer 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<sup>2</sup>. The sheets of dried sweetpotato were collected, crushed, and milled into flour in a hammer mill provided with a 500- $\mu$ m sieve. Drum-drying caused a reaction of the  $\epsilon$ -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 purées was reported by several investigators (Grabowski

et al. 2006; Peng et al. 2013). The purée was subjected to pretreatment with  $\alpha$ -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 purée 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 pregelatinized 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. For commercial success, the product should be of consistent quality regardless of root storage duration. Consistent quality SPFF can be produced year round from SP roots stored under appropriate conditions. Sweetpotato French fries have relatively low fat content, 10% fresh weight (fw), and high carotene content, 10 mg/100 g fw (Truong et al. 2014). 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). Frying at lower temperature under vacuum (130°C) and deoiling by centrifuging system can produce good-quality chips with low fat content (Ravli et al. 2013). 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 might significantly contribute to the browning of fried chips (Lim et al. 2014). 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  $\times$  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  $-34^{\circ}\text{C}$  until the slices are fried for consumption (Schwartz et al. 1987). Partial drying reduces oil absorption and increases 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 Pascua 2009, unpublished).

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. Aside from quality, acrylamide formation could be a potential health concern. Lim et al. (2014) reported acrylamide levels of 296–2849  $\mu\text{g}/\text{kg}$  in sweetpotato chips fried in various oil types and unsaturated oils with lipid oxidation tend to cause high acrylamide formation. Integrating common processing treatments such as water blanching and soaking sweetpotato strips in sodium acid pyrophosphate could reduce acrylamide levels by 85% or  $<100 \mu\text{g}/\text{kg}$  in sweetpotato French fries, the desired level for white potato French fries (Truong et al. 2014). 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 during long-term storage.

### 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. Recently, sweetpotato vodka with 40% alcohol has been produced and commercialized by companies in the United States.

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 are 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 has been reviewed by Ray et al. (2010).

### Summary

Sweetpotato, an important economic crop in many countries, ranks the fifth most important food crop in the tropics and the seventh in world food production after wheat, rice, maize, potato, barley, and cassava. All the plant parts, roots, vines, and young leaves of sweetpotatoes are used as foods, animal feeds, and traditional medicine around the world. Most of the dry matter in sweetpotatoes consists of carbohydrates, primarily starch and sugars, and to a lesser extent pectins, cellulose, and hemicellulose. Residues from sweetpotato starch and juice processing of commercial varieties are good sources of dietary fiber. Sweetpotatoes are processed into purée, juice, and canned, frozen, dried, and snack products. Development of high yield sweetpotato varieties with high nutritional values and good eating quality, along with improving processing technologies for the development of food products and functional ingredients from sweetpotatoes would meet the consumer demands for healthy foods and eventually increase the consumption of this nutritious vegetable in the human diet.

## References

- Allen JC, Corbitt AD, Maloney KP, Butt MS, Truong VD. 2012. Glycemic index of sweetpotato as affected by cooking methods. *Open Nutr J* 6:1–11.
- 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 Sweetpotato 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. *LWT—Food Sci & Technol* 39:20–26.
- Bohac JR, Dukes PD, Austin DF. 1995. *Sweetpotato Ipomoea batatas* (Convolvulaceae). In: *Evolution of Crop Plants* (Smartt J, Simmonds NW, editors). Essex: Longman Scientific and Technical, pp. 57–62.
- Bouwkamp J. 1985a. Production requirements. In: *Sweetpotato Products: A Natural Resource for the Tropics* (Bouwkamp JC, editor). Boca Raton, FL: CRC Press, pp. 9–34.
- Bouwkamp JC. 1985b. Processing of sweetpotatoes—canning, freezing, dehydrating. In: *Sweetpotato Products: A Natural Resource for the Tropics* (Bouwkamp JC, editor). Boca Raton, FL: CRC Press, pp. 185–203.
- Bovell-Benjamin AC. 2007. Sweetpotato: 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 Sweetpotato Clones from World Germplasm Collection Held 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, Yenchu 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-sweetpotato mixtures fermented with yogurt bacteria. *J Food Sci* 56:685–688.
- Collins JL, Walter WM Jr. 1992. Processing and processed products. In: *Fifty Years of Cooperative Sweetpotato Research 1939–1989* (Jones A, Bouwkamp JC, editors). 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 sweetpotato 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: *Global Genetic Resources for Insect-Resistant Crops* (Clement SL, Quisenberry SS, editors). Boca Raton, FL: CRC Press, pp. 193–205.
- Coronel P, Truong VD, Simunovic J, Sandeep KP, Cartwright GD. 2005. Aseptic processing of sweetpotato purées using a continuous flow microwave system. *J Food Sci* 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.
- El-Sheikha AF, Ray RC. 2017. Potential impacts of bioprocessing of sweetpotato: Review. *Crit Rev Food Sci & Nutr* 57:455–471.
- Engel F. 1970. Exploration of the Chilca Canyon, Peru. *Curr Anthropol* 11:55–58.
- Estes EA. 2009. Marketing sweetpotatoes in the United States: A serious challenge for small-to-moderate volume growers. In *The Sweetpotatoes* (Loebenstein G, Thottappilly G, editors). Dordrecht, Netherlands: Springer. pp. 269–283.
- FAO. 2015. *Food and Agriculture Organization Statistical Production Yearbook*. Rome: FAO.
- FAO. 2016. Crop Production Data. Available at <http://www.fao.org/faostat/en/#data/QC> (accessed December 29, 2016).
- Fawzia A, Karuri EG, Hagenimana V. 1999. Sweetpotato 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: *The Sweetpotato* (Loebenstein G, Thottappilly G, editors). Dordrecht, Netherlands: Springer, BV, pp. 13–26.
- Grabowski JA, Truong VD, Daubert CR. 2006. Spray drying of amylase hydrolyzed sweetpotato purée and physicochemical properties of powder. *J Food Sci* 71:E209–E217.
- Grabowski JA, Truong VD, Daubert CR. 2008. Nutritional and rheological characterization of spray dried sweetpotato powder. *LWT – Food Sci & Technol* 41:206–216.
- Grace MH, Truong AN, Truong VD, Raskin I, Lila M. 2015. Novel value-added uses for sweetpotato juice and flour in polyphenol- and protein-enriched functional food ingredients. *Food Sci & Nutr* 3:415–424.
- Grüneberg WJ, Ma D, Mwanga, ROM, Carey EE, Huamani K, Diaz F, Eyzaguirre R, Guaf E, Jusuf M, Karuniawan A, Tjintokohadi K, Song Y-S, Anil SR, Hossain M, Rahaman, E, Attaluri SI, Somé K, Afuape SO, Adofo K, Lukonge E, Karanja L, Ndirigwe J, Ssemakula G, Agili S, Randrianaivoarivony JM, Chiona M, Chipungu F, Laurie SM, Ricardo J, Andrade M, Fernandes FR, Mello AS, Khan MA, Labonte DR and Yencho GC. 2015. Advances in Sweetpotato Breeding from 1992 to 2012. pp 3–68. In: *Potato and Sweetpotato in Africa: Transforming the Value Chains for Food and Nutrition Security* (Low J, Nyongesa M, Quinn S, Parker M, editors). Wallingford, UK: CAB International. 662 pp.
- Hathorne CS, Biswas MA, Gichuhi PN, Bovell-Benjamin AC. (2008). Comparison of breads supplemented with sweetpotato flour and high-gluten dough enhancers. *LWT—Food Sci & Technol* 41:803–815.
- He GH, Prakash CS, Jarret RL. 1995. Analysis of genetic diversity in sweetpotato (*Ipomoea batatas*) germplasm collection using DNA amplification fingerprinting. *Genome* 38:938–945.
- Hotz C, Loechl C, de Brauw A, Eozenou P, Gilligan D, Moursi M, Munhaua B, van Jaarsveld P, Carriquiry A, Meenakshi JV. 2012. A large-scale intervention to introduce orange sweetpotato in rural Mozambique increases vitamin A intakes among children and women. *Brit J Nutr* 108:163–176.
- Hoover MW, Harmon SJ. 1967. Carbohydrate changes in sweetpotato 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.
- 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 Hort* 102:375–386.
- Hu Y, Deng L, Chen J, Zhou S, Liu S, Fu Y, Yang C, Liao Z, Chen M. 2016. An analytical pipeline to compare and characterise the anthocyanin antioxidant activities of purple sweetpotato cultivars. *Food Chem* 194: 46–54.

- 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.
- Johnson T, Wilson N, Worosz, MR, Fields D, Bond JK. 2015. Vegetables and Pulses Outlook: Special Article; Commodity Highlight: Sweetpotatoes. USDA, Economic Research Service. <http://www.ers.usda.gov/media/1834605/vgs-355-sa1.pdf> (accessed October 28, 2016).
- Johnson, M, Pace RD. 2010. Sweetpotato leaves: properties and synergistic interactions that promote health and prevent disease. *Nutr Rev* 68: 604–615.
- Jones A. 1986. Sweetpotato heritability estimates and their use in breeding. *HortSci* 21:14–17.
- Kays SJ. 1985a. The Physiology of yield in the sweetpotato. In: *Sweetpotato Products: A Natural Resource for the Tropics* (Bouwkamp JC, editor). Boca Raton, FL: CRC Press, pp. 79–132.
- Kays SJ. 1985b. Formulated sweetpotato products. In: *Sweetpotato Products: A Natural Resource for the Tropics* (Bouwkamp JC, editor). Boca Raton, FL: USA CRC Press, pp. 205–218.
- Kays SJ, Wang Y, McLaurin WJ. 2005. Chemical and geographical assessment of the sweetness of the cultivated sweetpotato clones of the world. *J Amer Soc Hort Sci* 130: 591–597.
- Kotecha PM, Kadam SS. 1998. Sweetpotato. In: *Handbook of Vegetable Science and Technology. Production, Composition, Storage and Processing* (Salunkhe DK, Kadam SS, editors). 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 purées. *Food Res Int* 41:454–461.
- Lekrisompong PP, Whitson ME, Truong VD, Drake MA. 2012. Sensory attributes and consumer acceptance of sweetpotato cultivars with varying flesh colors. *J Sens Stud* 27:59–69.
- Lopez-Malo A, Rios-Cass L. 2009. Solar assisted drying of foods. In: *Food Drying Science and Technology: Microbiology, Chemistry, Applications* (Hui YH, Clary C, Farid MM, Fasina OO, Noomhorm A, Welti-Chanes J, editors). Lancaster, PA: DEStech Publications, Inc., pp. 83–98.
- Lim PK, Jinap S, Sanny M, Tan CP, Khatib K. 2014. The influence of deep frying using various vegetable oils on acrylamide formation in sweetpotato (*Ipomoea batatas* L. Lam) chips. *J Food Sci* 79: T115–T212.
- Lim S, Xu J, Kim J, Chen T-Y, Su X, Standard J, Carey E, Griffin J, Herndon B, Katz B, Tomich J, Wang W. 2013. Role of anthocyanin-enriched purple-fleshed sweetpotato p40 in colorectal cancer prevention. *Mol Nutr & Food Res* 57: 1908–1917.
- Low JW, Arimond M, Osman N, Cunguara B, Zano E, Tschirley D. 2007. A food-based approach introducing orange-fleshed sweetpotatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. *J Nutr* 137: 1320–1327.
- Maloney KP, Truong VD, Allen JC. 2014. Susceptibility of sweetpotato (*Ipomoea batatas*) peel proteins to digestive enzymes. *Food Sci & Nutr* 2: 351–360.
- Matsui T, Ebuchi S, Fukui K, Matsugano M, Terahara N, Matsumono K. 2004. Caffeoylsophorose, a new  $\alpha$ -glucosidase inhibitor by fermented purple-fleshed sweetpotato. *Biosci Biotech Biochem* 68:2239–2246.
- Mei X, Mu T-H, Han J-J. 2010. Composition and physicochemical properties of dietary fiber extraction from residues of 10 varieties of

- sweetpotato by a sievign method. *J Agric & Food Chem* 58: 7305–7310.
- Menelaou E, Kachatryan A, Losso J. 2006. Lutein content in sweetpotato leaves. *HortSci* 41:1269–1271.
- Mohanraj R, Sivasankar S. 2014. Sweetpotato (*Ipomoea batatas* [L.] Lam)—A valuable medicinal food: A Review. *J Med Food* 17: 733–741.
- Mohapatra S, Panda SH, Sahoo SK, Sivakumar PS, Ray RC. 2007.  $\beta$ -Carotene-rich sweetpotato curd: production, nutritional and proximate composition. *Int J Food Sci & Technol* 42:1305–1314.
- Napolitano A, Carbone V, Saggese P, Takagaki K, Pizza C. 2007. Novel galactolipids from the leaves of *Ipomoea batatas* L.: Characterization by liquid chromatography coupled with electrospray ionization-quadrupole time-of-flight tandem mass spectrometry. *J Agric & Food Chem* 55:10289–10297.
- O’Sullivan JN, Asher CJ, Blamey FPC. 1997. *Nutrient Disorders of Sweetpotato*. 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 agroecological sites using small scale processing technologies. *Afr Potato Assoc Conf Proc* 5:483–490.
- Padmaja G. 2009. Uses and nutritional data of sweetpotato. In: *The Sweetpotato* (Loebenstein G, Thottapilly G, editors). Dordrecht, Netherlands: Springer, pp. 189–233.
- Panda SH, Naskar SK, Shivakumar PS, Ray RC. 2009b. Lactic acid fermentation of anthocyanin-rich sweetpotato (*Ipomoea batatas* L.) into lacto-juice. *Int J Food Sci & Technol* 44:288–296.
- Panda SH, Panda S, Shiva Kumar PS, Ray RC. 2009a. Anthocyanin-rich sweetpotato lacto-pickle: Production, nutritional and proximate composition. *Int J Food Sci & Technol* 44:445–455.
- Peng Z, Li J, Guan Y, Zhao G. 2013. Effect of carriers on physicochemical properties, antioxidant activities and biological components of spray-dried purple sweetpotato flours. *LWT—Food Sci & Technol* 51: 348–355.
- Perez RH, Tan JD. 2006. Production of acidophilus milk enriched with purées from colored sweetpotato (*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 purée. *J Food Protec* 71:639–642.
- Peters D, Wheately C. 1997. Small-scale agro enterprises provide opportunities for income generation: Sweetpotato flour in East Java, Indonesia. *Quarterly 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 Amer Soc Hort Sci* 121:1059–1062.
- Ravi V, Indira P. 1999. Crop physiology of sweetpotato. In: *Horticultural Reviews*, Vol. 23 (Janick J, editor). Amers, IA: John Wiley & Sons, pp. 277–284.
- Ravli Y, Da Silva P, Moreira RG. 2013. Two-stage frying process for high-quality sweet-potato chips. *J Food Eng* 118:31–40.
- Ray RC, Naskar SK, Tomlins KI. 2010. Bio-processing of sweetpotato in food, feed and bio-ethanol. In *Sweetpotatoes: Postharvest Aspects in Food, Feed and Industry* (Ray RC, Tomlins KI, editors). New York, NY: Nova Science Publishers, Inc. pp. 163–191.
- Roullier C, Duputié A, Wennekes P, Benoit L, Bringas VME, Rossel G, Tay D, McKey, D and Lebot, V 2013a. Disentangling the Origins of Cultivated Sweetpotato (*Ipomoea batatas* (L.) Lam.). *PLoS ONE* 8(5): e62707.

- Roullier C, Benoit L, McKey DB, and Lebot V. 2013b. Historical collections reveal patterns of diffusion of sweetpotato in Oceania obscured by modern plant movements and recombination. *PNAS* 110: 2205–2210.
- 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 sweetpotato (*Ipomea batatas* cv. *Ayamurasaki*) roots. *Food Sci & Technol Res* 11:390–394.
- Sakamoto S, Bouwkamp JC. 1985. Industrial products from sweetpotatoes. In: *Sweetpotato Products: A Natural Source for the Tropics* (Bouwkamp JC, editor). Boca Raton, FL: CRC Press, pp. 219–233.
- Schwartz SJ, Walter WM, Carroll DE, Giesbrecht FG. 1987. Chemical, physical and sensory properties of a sweetpotato French-fry type product during frozen storage. *J Food Sci* 52:617–619, 633.
- Simunovic J, Swartzel KR, Truong VD, Cartwright G, Coronel P, Sandeep KP, Parrott D. 2014. Methods and apparatuses for thermal treatment of foods and other biomaterials, and products obtained thereby. Patent No. 8,742,305 B2.
- Steed LE, Truong VD. 2008. Anthocyanin content, antioxidant activity and selected physical properties of flowable purple-fleshed sweetpotato purées. *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 sweetpotato purées. *J Food Sci* 73: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 sweetpotato beverage effects on serum hepatic biomarker levels of healthy adult men with borderline hepatitis. *Eur J Clin Nutr* 62:60–67.
- Sun H, Mu T, Xi L, Zhang M, Chen J. 2014. Sweetpotato (*Ipomoea batatas* L.) leaves as nutritional and functional foods. *Food Chem* 156: 380–389.
- Talekar NS. 1991. Integrated Control of *Cylas formicarius*. In: *Sweetpotato Pest Management: A Global Perspective* (Jansson RK, Raman KV, editors). Boulder Co: Westview Press, pp. 139–156.
- Talekar NS, Pollard GV. 1991. Vine borers of sweetpotato. In: *Sweetpotato Pest Management: A Global Perspective* (Jansson RK, Raman KV, editors). Boulder Co: Westview Press.
- Takahata Y, Tanaka M, Oyani M, Katayama K, Kitahara K, Nakayachi O, Nakayama H, Yoshinaga M. 2010. Inhibition of the expression of the starch synthase II gene leads to lower pasting temperature in sweetpotato starch. *Plant Cell Rep* 29:535–543.
- Tanumihardjo SA. 2008. Food-based approaches for ensuring adequate vitamin A nutrition. *Compr Rev Food Sci & Food Safety* 7:373–381.
- Tomlins K, Owori C, Bechoff A, Menya G, Westby A. 2012. Relationship among the carotenoid content and sensory attributes of sweetpotato. *Food Chem* 131: 14–21.
- Truong VD. 1992. Sweetpotato beverages: Product development and technology transfer. In: *Sweetpotato Technology for the 21st Century* (Hill WA, Bonsi CK, Loretan PA, editors). Tuskegee, AL: Tuskegee University, pp. 389–399.
- Truong VD. 1994. Development and transfer of processing technologies for fruity food products from sweetpotato. *Acta Hort* 380:413–420.
- Truong VD, Walter WM Jr. 1994. Physical and sensory properties of sweetpotato purée texturized with cellulose derivatives. *J Food Sci* 59:175–1180.
- Truong VD, Avula RY. 2010. Sweetpotato purées and dehydrated forms for functional food ingredients. In: *Sweetpotatoes: Postharvest Aspects in Food, Feed and Industry* (Ray RC, Tomlins KI, editors). 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 sweetpotato. *J Agric & Food Chem* 34:421–425.
- Truong VD, Walter WM Jr, Giesbrecht FG. 1995. Texturization of sweetpotato purée with alginate: Effects of tetrasodium pyrophosphate and calcium sulfate. *J Food Sci* 60:1054–1059, 1074.
- 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, 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: C343–C349.
- Truong VD, Deighton N, Thompson RL, McFeeters RF, Dean LL, Pecota KV, Yencho G. 2010. Characterization of Anthocyanins and Anthocyanidins in Purple-Fleshed Sweetpotatoes by HPLC-DAD and LC-ESI/MS-MS. *J Agric & Food Chem* 58:404–410.
- Truong AN, Simunovic J, Truong VD. 2012a. Process development for producing pasteurized anthocyanin-rich juice and recovering starch from purple-fleshed sweetpotatoes. Abstract and Poster Presentation # 230-24, Annual Meeting, Institute of Food Technologists, Las Vegas, NV, June 25–28, 2012.
- Truong VD, Hu Z, Thompson RL, Yencho G, Pecota KV. 2012b. Pressurized liquid extraction and quantification of anthocyanins in purple-fleshed sweetpotato genotypes. *J Food Compos & Anal* 26:96–103.
- Truong VD, Pascua YT, Reynolds R, Thompson RL, Palazoglu K, Mogol B, Gokmen V. 2014. Processing treatments for mitigating acrylamide formation in sweetpotato French fries. *J Agric & Food Chem* 62:310–316.
- Tsou SCS, Hong TL. 1992. The nutrition and utilization of sweetpotato. In: *Sweetpotato Technology for the 21st Century* (Hill WA, Bonsi CK, Loretan PA, editors). Tuskegee, AL: Tuskegee University, pp. 359–366.
- USDA (United State Department of Agriculture). 2016. USDA Nutrient Database. Available at <https://ndb.nal.usda.gov/ndb/search/list> (accessed January 26, 2017).
- Valdez CC, Lopez CY, Schwartz S, Bulux J, Solomons NW. 2001. Sweetpotato buds: the origins of a “designer” food to combat hypovitaminosis A in Guatemala. Processing, vitamin A content and preservation characteristics. *Nutr Res* 21:61–70.
- Van Hal M. 2000. Quality of sweetpotato 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.  $\beta$ -carotene rich orange-fleshed sweetpotato improves the vitamin A status of primary school children assessed with the modified-relative-dose-response test. *Amer J Clin Nutr* 81:1080–1087.
- Villordon A, LaBonte D. 1996. Genetic variation among sweetpotatoes propagated through nodal and adventitious sprouts. *J Amer Soc Hort Sci* 121:170–174.
- Villordon AQ, Labonte DR. 1995. Variation in randomly amplified DNA markers and storage root yield in Jewel sweetpotato clones. *J Amer 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 sweetpotato flour. *J Agric & Food Chem* 31:947–949.
- Walter WM Jr, Schwartz SJ. 1993. Controlled heat processing of Jewel sweetpotatoes for purée production. *J Food Qual* 16:71–80.
- Walter WM Jr, Sylvia KE, Truong VD. 1998. Alkaline 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 sweetpotato products. In: *Sweetpotato Technology for the 21st Century* (Hill WA, Bonsi

- CK, Loretan PA, editors). Tuskegee, AL, pp. 400–406.
- Waramboi JG, Gidley MJ, Sopade PA. 2014. Influence of extrusion on expansion, functional and digestibility properties of whole sweetpotato flour. *LWT- Food Sci & Technol* 59: 1136–1145.
- Woolfe JA. 1992. *Sweetpotato: an untapped food resource*. Cambridge, UK: Cambridge Univ. Press, 643p.
- Wu D-M, Lu J, Zheng Y-L, Zhou Z, Shan Q, Ma D-F. 2008. Purple sweetpotato color repairs D-galactose-induced spatial learning and memory impairment by regulating the expression of synaptic proteins. *Neurobiol Learning & Memory* 90:19–27
- Xu J, Su X, Lim S, Griffin J, Carey E, Katz B, Tomich J, Smith JS, Wang W. 2015. Characterization and stability of anthocyanins in purple-fleshed sweetpotato P40. *Food Chem.* 186: 90–96.
- Yamakawa O. 2000. New cultivation and utilization system for sweetpotato 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.
- Yeoh HH, Truong VD. 1996. Amino acid composition and nitrogen-to-protein conversion factors for sweetpotato. *Trop Sci* 36:243–246.
- Zhang D, Cervantes J, Huaman Z, Carey E, Ghislain M. 2000. Assessing genetic diversity of sweetpotato (*Ipomoea batatas* (L.) Lam.) cultivars from tropical America using AFLP. *Genet Resour & Crop Evol* 47:659–665.
- Zhang DP, Rossel G, Krieger 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.
- Zhang Z-F, Fan S-H, Zheng Y-L, Lu J, Wu D.-M, Shan Q, Hu B. 2009. Purple sweetpotato color attenuates oxidative stress and inflammatory response induced by D-galactose in mouse liver. *Food Chem & Toxicol* 47: 496–501.
- Zhu F and Wang S. 2014. Physicochemical properties, molecular structure and uses of sweetpotato starch. *Trends Food Sci & Technol* 36:68–78.