Chapter 10

SWEET POTATOES*

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I. INTRODUCTION

A. Taxonomy and Morphology

The sweet potato (*Ipomoea batatas*) belongs to the Convolvulaceae or morning glory family and is dicotyledonous. Typical of this family, the distinguishing characteristics of the sweet potato include: the presence of latex in its sap, trailing stems (some species are erect, others climbing), bicollateral vascular bundles, simple leaves arranged alternately around the stem, complete flowers (superior pistil, five stamens, and a trumpet-shaped corolla), fruit which is a capsule and seed containing an embryo with folded cotyledons.[1]

The fleshy sweet potato storage root (not a tuber) does not have eyes or scars as found on some other roots and tubers, but it does possess the ability to develop adventitious buds on sprouts or vine cuttings which is advantageous in reproducing the crop vegetatively. Sweet potato is not grown commercially from seed because it cross pollinates readily and each seed from a single plant may be different from any other seed.

There are two important types of sweet potatoes grown commercially. When cooked, one has a seemingly dry, mealy flesh; the other a flesh of a soft, moist, sugary consistency when cooked. The latter are often sold as "yams", but the true yam is a monocotyledon of the genus *Dioscorea*.

B. Origin and History

Like many other vegetable crops, the sweet potato originated in the tropics. It continues to be grown there as a perennial even though it is grown as an annual in temperate zones, such as the U.S. The exact area of origin has long been debated, but a good explanation has been presented by Jorge Leon,[2] as follows:

> Sweet potato (*Ipomoea batatas*) was the only food crop common to tropical America and Polynesia before the discovery. As such, it has raised a long discussion on which of the two regions is its place of origin and how its early dispersal occurred (Yen, 1974). The recent discovery in coastal Peru of sweet potato tubers dating from 10,000 BC (Engel, 1970) settles the question of the origin, as this date by far antedates any agricultural development in Polynesia. However, it should be considered that, like all other plants cultivated in the coastal region of Peru, sweet potato was introduced from elsewhere, possibly from the north, the coastal area of Ecuador and Columbia, where close wild types have been found (Martin et al., 1974), or from across the Andes, like *Canna edulis* and other crops.
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> At the arrival of the Europeans, the sweet potato was known in all Tropical America, with an important area of diversity around the Caribbean. Oviedo, writing in 1530, reports that several varieties he had seen in the early days of the Conquest were already disappearing.
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> The spread of the sweet potato to the Old World was quite rapid; it was introduced in Spain, after several failures, as living plants before 1550. It is not known how it reached Africa, whether from Spain or from tropical America. A report that sweet potato was grown in San Thome in 1520 seems doubtful (Mauny, 1953). More reliable information shows that it was widely cultivated by the end of the seventeenth century in West Africa, and a century later all over the tropical areas of the continent.
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> The introduction to Polynesia, as discussed above, has not been properly explained. It could have been accidentally transported in one of the Peruvian rafts lost in the Central Pacific, which reached Polynesia where the crop was established by Indo-Americans and developed later on by Polynesians. It has been proposed also that the sweet potato may have been taken to Polynesia by one of the Spanish expeditions that visited the area starting from Peru in the sixteenth century. It was taken to China in 1594 and after a famine in Fukien, it later became an important crop.Sweet potato was introduced early to Japan from Okinawa and cultivated and adopted in the southern region up to 37°N.

Although Columbus noted the use of sweet potatoes by West Indian natives on his fourth voyage, there is no record of pre-Columbian cultivation of sweet potatoes by Indians in the continental U.S. Sweet potatoes were cultivated in Virginia as early as 1648 and are reported

Table 1
WORLD SWEET POTATO PRODUCTION[5]

	Area harvested hectare (× 1000)				Production metric tons (× 1000)			
	1961—65	1974	1975	1976	1961—65	1974	1975	1976
Africa	645	821	826	843	3876	4799	4943	5065
North and Central America	180	160	163	166	1294	1241	1276	1282
U.S.	71	49	48	48	674	631	615	622
South America	246	274	286	286	2386	2565	2692	2699
Asia	11436	13168	13431	13524	198923	124617	125966	126168
Europe	17	13	13	6	185	135	130	76
Oceana	87	104	105	105	435	553	557	565
World	12610	14540	14824	14930	107100	133911	135564	135855
Developed	410	155	143	133	7007	2422	2212	2028
Developing	2067	2237	2350	2397	14878	16361	17397	17630

to have been taken to New England in 1764. They were reportedly grown by Indians in the southern states in the 18th century. Sweet potatoes fed homesteaders and were often their only means of sustenance. This "vegetable indispensable" was the single most important food in bringing people through such trying periods as the American Revolution, the War Between the States, and Reconstruction. Black slaves called sweet potatoes "nyami", since it was similar to their African *Dioscorea*. This name was later shortened to "yam", a name still used interchangeably with sweet potato.[3]

C. Production

Sweet potatoes require at least 120 frost-free days for optimum growth and are of minimum commercial importance where mean summer temperatures are lower that 20°C. They thrive in hot weather, but little or nor growth occurs when soil or air temperatures are below 16°C. Growth appears to be optimum when soil temperatures are near 20°C and air temperatures near 30°C.[4] Sweet potatoes tolerate drought conditions, but produce best quality and yields when moisture stress is minimal.

Sweet potato is a major world crop with over 135 million metric tons (t) produced annually (Table 1).[5] The annual U.S. production is 622 t, over half of which is produced in the states of North Carolina and Louisiana. Sweet potatoes (and other root crops) are considered by many to be inferior or "poverty food" but 17.6 million t are produced annually in the "Developing World" where its full potential is yet to be realized.[6]

Sweet potato research and extension activities are major thrusts of the International Institute of Tropical Agriculture (Nigeria),[7] the Asian Vegetable Research and Development Center (Taiwan),[8] and more than a dozen Agricultural Experiment Stations in the U.S.[9] Sweet potato improvement is a major research activity since this crop mutates readily. New cultivars are released frequently to satisfy specific needs. The U.S. markets generally prefer the moist-fleshed "yam-type" sweet potato while many other areas of the world prefer the hard, dry, white-fleshed cultivars. Two cultivars, Jewel and Centennial, currently dominate commercial production in the United States.

II. AGRONOMIC FACTORS

A. Transplants

Sweet potatoes are vegetatively propagated. In tropical regions, storage roots or vine cuttings are planted as required for each crop. In temperate regions, storage roots are stored over winter and bedded as "seed" stock for transplant production each spring. To produce high yields of good quality disease-free roots, the use of sound planting material is essential. Excellent programs administered by organizations such as the North Carolina Crop Improvement Associating and the North Carolina Foundation Seed Producers, Inc. assure the annual availability of "true to type" and disease-free seed stocks for commercial production.[10]

Seed stock (storage roots) are commonly presprouted at 30°C and high relative humidity for approximately 4 weeks prior to bedding to enhance sprouting. Bedding involves either hand or mechanical placement of seed stock on beds raised for improved drainage. Cotton seet hulls or sawdust may be placed under beds for additional heat. Most seed stocks are treated with a fungicide and the beds treated with a herbicide. A uniform covering of two inches of soil and perforated, 0.2-mm clear plastic covers are recommended. Fertilization and irrigation promote more prolific sprouting. Sprouts for transplants are generally pulled, but cutting sprouts above the ground is recommended where soil-borne diseases are suspected. Hot beds or cold frames are occasionally employed for transplant production. Vine cuttings are commonly used for planting material in tropical regions and in the U.S., when insufficient transplants are available. Direct planting of seed pieces in the field is desirable but not yet commercially practiced due to variability attributed to genetic characteristics.[11] Frequently the seed piece enlarges into one large root. Some varieties promise to yield a number of daughter roots as the seed piece decays.

B. Soils

Sweet potatoes grow well on a variety of soil types, but excel on fine sandy loams with about 1% organic matter (and underlain with a heavier soil for water retention), good internal drainage, and a soil pH of 5.8 to 6.2. Ridging to promote optimum drainage is important during the later stages of growth and development when storage roots of many cultivars are most susceptible to "souring". That is, physiological breakdown due to oxygen depletion and excess CO_2 buildup associated with waterlogged soils. Under high temperatures this can occur in a day. Weed control is accomplished by cultivating plus the use of recommended herbicides. However, once the planting is established, weed control is facilitated by the fact that this member of the morning glory family competes well and generally dominates weeds.

C. Fertilizers

Fertilization of sweet potato fields varies greatly from one locale to another depending on soil genesis and the results of soil analyses, rainfall, and the individual grower's operations. Generally, it is recommended that, since sweet potatoes use nitrogen very efficiently, only 90 to 110 lb/acre (108 to 132 kg/ha) of this element be applied; about 30 lb (36 kg/ha) at preplant, 40 lb (48 kg/ha) sidedressed at the last cultivation; and another 20 lb (24 kg/ha) broadcast 4 to 5 weeks later. An additional 20 lb/acre (24 kg/ha) of nitrogen may be used any time following rainfall, which may cause excessive leaching. Phosphorus (P_2O_5) is required at about 60 lb/acres (72 kg/ha) and should be applied before planting. Potassium (K_2) is required at about 150 lb/acre (180 kg/ha), 30 lb (36 kg) of which is preplant applied and the remainder sidedressed at the last cultivation. Many growers have developed their own fertilizer programs. However, a typical schedule in North Carolina may resemble the following: 500 to 600 lb/acre (560 to 672 kg/ha) of 6-12-6 banded in the row or broadcast as a preplant application, about 500 lb/acre (560 kg/ha) of 8-0-24 sidedressed at the last cultivation (mid-July) and 100 to 200 lb/acre (112 to 224 kg/ha) of sodium nitrate applied as a top-dressing 4 to 5 weeks after the last cultivation (mid-August) and/or as required due to excessive leaching. Since the physiological storage disorder, "blister" affects some varieties (i.e., Jewel), 0.5 lb/acre (0.6 kg/ha) of boron is also applied; usually it is formulated in the preplant fertilizer as Borax or Solubor if requested by the grower.[10]

D. Diseases

Historically, sweet potato diseases have been a major problem confronting the industry.[11] Internal cork (a virus disease) and blue stem (*Fasarium oxysporum* f. sp. *batatas*) were extremely serious when Porto Rico and other cultivars were widely grown; Centennial and Jewel possess acceptable levels of resistance. Black rot (*Ceratocystis fimbriata*) and scurf (*Monilochaetes infuscans*) have been under control for approximately 15 years with a carefully followed plan of crop rotation, sanitation, and use of certified seed. Pox (*Streptomyces impomoeae*) is a problem in some growing areas. Southern blight (*Sclerotium rolfsii*) occasionally causes local serious problems. Bacterial soft rot (*Erwinia chrysthanthemi*) has caused serious losses in some area.[12] Field diseases are generally controlled through effective seed and quarantine programs.

The root-knot nematode (principally (*Meloidogyne icognita*) is widespread in sweet potato growing areas. Some growers continue to sustain losses due to nematodes even though excellent control procedures based on soil sampling and the use of nematicides have been proven effective. Losses are compounded because yields are reduced and quality is lowered.

Rots of mature and/or harvested storage roots probably causes losses of over 15% annually. These rots are caused by several fungi and possibly some bacteria and viruses. In most cases, however, the indirect of predisposing factors include: soils waterlogged for more than one day, bruises, chilling below 10°C, heating and drying in the sun, and poor curing conditions. These rots continue to be a problem and control is based on proper field selection and handling of harvested roots.[13]

E. Insects

Sweet potatoe weevils (*Euscepes Postfaciatus Furm* and *Cylas formicarius elegantus* Su.) are widely distributed in tropical and subtropical growing areas. Only the latter occurs in the Continental U.S. It has been controlled in most temperate areas through strict sanitation and quarantines, but within infested areas it is by far the most serious insect pest. These fleshy root feeders make holes in the periderm or short burrows in the fleshy roots, causing disfiguration which reduces attractiveness and lowers market values. Breeding programs in the tropics aimed at resistance to sweet potato weevils are important to the survival of this crop.[7] Wireworms (*Concoerus falli, Condoerus vespertinus*, and *Melanotus conmunis*, in order of importance, respectively) can cause damage by making small holes in the storage roots. These insects are controlled by broadcasting a granular insecticide over the foliage when the storage roots begin to form. Various species of white grubs occasionally damage sweet potatoes. Such damage can be minimized by avoiding soils that are high in organic matter and/or by broadcasting and incorporating a granular insecticide into the soil prior to planting. Flea beetles (*Chaetocnena confinis*) attack sweet potatoes causing damage resembling "writing" on the surface of the storage roots. This insect is best controlled by planting resistant varieties, such as Jewel. Occasionally, lepidopterous larva (i.e., *Heliophis zea*) on the foliage at harvest may damage exposed, harvested roots by feeding on them.[9]

III. HARVESTING OF SWEET POTATOES

Sweet potatoes do not ripen or mature as do most true fruits. Small sweet potatoes are as physiologically mature as the larger ones. Sweet potatoes continue to enlarge as long as they are left in the ground and growing conditions are suitable, i.e., proper temperature, moisture, and nutrients. Sweet potatoes must be harvested before the vines are killed by frost or the soil temperature drops below 13°C (55°F).[10] In areas where the growing season is sufficiently long, sweet potatoes are harvested at a time to give maximum yield of U.S. No. 1 size. If harvested too early there will be a higher percent of small sizes, if harvest is delayed too long there will be more of the larger size. Late harvest will increase total yield but the cash value of the crop will decline because most years there is a great price differential between U.S. No. 1 size and jumbos.

Most sweet potatoes are still dug out of the ground by plow and handgraded in field boxes or 20-bushel pallet bins. This labor-intensive method requires constant, close supervision to ensure that all of the sweet potatoes are "scratched out" of the ground, are graded accurately, and are handled gently to minimize damage.

Riding harvesting aids are popular because they keep laborers together and take some of the drudgery out of their work, although they do little to reduce the total labor requirement. The roots are dug and elevated on a horizontal conveyor where they are separated from their vines and graded by hand into appropriate containers. New devining equipment has been developed that virtually eliminates hand vine separation.

Mechanical harvesters are available that harvest sweet potatoes and transfer them into 20-bushel pallet bins. This equipment is best suited for freshly harvested green sales, but with careful handling with appropriate hydrohandling equipment, sweet potatoes harvested in this manner can be cured and stored for grading, packaging, and marketing at a later date. Avoiding mechanical injuries, prompt placement of roots under proper curing conditions (critically important for optimum quality maintenance) and sanitation are essential to minimize storage rots. When properly operated, paddlewheel transfer is well suited to hydrohandling.[13]

Experiments with bulk harvesting systems that will handle 100 to 200 bushel units from the field to storage are currently in progress. This "system approach" to mechanization could revolutionize sweet potato production and handling.[14]

A. Curing and Storage

Those sweet potatoes that are not sold directly from the field at harvest time should be cured for 4 to 7 days at 30°C at a relative humidity of 90% or higher. Modern storage facilities include curing facilities, consisting of floor trenches to provide heat and high humidity, fans for necessary aeration (ventilation), and adequate insulation.[15,16]

The curing process is primarily one of wound healing (periderm formation) to minimize the invasion of rotting organisms. It is important to place the roots into curing quickly after harvest. If the small scratches which occur at harvest are allowed to dry too deeply unsightly scars will form and become the site of disease invasion. Curing heals wounds by suberization and toughens the skins, thus reducing the chance for further wounding.[17] Curing slows the rate of respiration, thus slowing the loss of dry matter during storage and decreases the loss of moisture in storage.[18] Curing also improves the culinary quality by increasing the amount of amylase which converts starch to sugars during cooking.[19] The action of this enzyme gives the sweet potato a more moist or juicy mouthful and increases sweetness. Some sweet potato workers refer to the green flavor of uncured sweet potatoes, which disappears after curing.[20]

After proper curing sweet potatoes are most stable when stored at 13 to 15°C (55°F) and about 50% humidity. Temperatures below 10°C causes chill damage which results in deterioration of flavor and color. Chilled sweet potatoes are subject to rotting and disease invasion. After sweet potatoes have been chilled they are most stable at 4°C.

If the storage temperature is too high the respiration rate will increase and use up the starch. This will result in pithiness. If humidity is too low the sweet potatoes will lose moisture and become wilted. If humidity is too high they may become more subject to mold invasion.

IV. QUALITY FACTORS

In the U.S., sweet potatoes are produced mainly for fresh market sales with perhaps 30% being canned and much smaller amounts being processed into precooked dehydrated flakes and some frozen products. Fresh market sweet potatoes are graded for size, shape, smoothness, and freedom from defects. U.S. No. 1 sweet potatoes will measure $1^3/_4$ to $3^1/_2$ in. in diameter and between 3 and 9 in. in length. They should be smooth, well shaped, all of one color, and free from disease and defects.[21] The smaller size sweet potatoes are called canners and the larger size are jumbos. Internal quality has been defined by the Sweet Potato Collaborators Group.[22] The sweet potatoes are rated by sensory panels for internal color and appearance, mouthfeel, freedom from fiber and graininess, and for flavor. In the development of new varieties the sweet potatoes are rated many times for both external and internal quality and are not released unless total quality scores equal those of existing market varieties.

The U.S. Fresh Market prefers sweet potatoes in the median range of U.S. No. 1 size but would like more uniform sizes.[23] Internal color should be uniformly bright orange. When baked, the flesh should be soft and feel moist in the mouth. Sweet potatoes should taste sweet but beyond that there are no terms for describing sweet potato flavor.

The above quality factors are a function of cultivar and curing, thus proper cultivars should be selected and most quality factors are enhanced by curing. Mouthfeel and sweetness is particularly enhanced in some varieties. Those varieties which have moist mouthfeel usually have higher amounts of amylase to degrade starch into dextrins and sugars.[19] People who fry sweet potatoes, prefer uncured roots because they have less tendency to darken and carmelize than roots with higher amounts of sugar.

Sweet potatoes for canning have slightly different quality requirements. Premium canned sweet potatoes are whole-packed, small sweet potatoes, but cut pieces are also very common. Canned sweet potatoes should be firm and remain in one piece. Uncured sweet potatoes are preferred for canning.[24,25,26] Sweet potatoes for canning should have good color, uniformity of color, freedom from fibers, and lack of graininess. Firmness of the canned product is desirable.

Canned sweet potatoes are the most common processed product. Protein content is lower in canned sweet potatoes than in baked sweet potatoes. Preliminary work in our laboratory shows that much of the NPN and some of the protein is leached from the pieces of root into the syrup. When canned, Jewel sweet potatoes will contain about 30% less nitrogen (dry basis) than baked. It appears that some sucrose from the syrup is bound in the sweet potato, thus slightly increasing non-nitrogenous dry matter.[26] Canning decreases the lysine of sweet potato by leaching and by reaction of lysine and the carbohydrates.[27]

Jumbo size sweet potatoes are preferred for various communities' products because there is less peeling loss from larger roots, and jumbos are cheaper than U.S. No. 1 size.

Sweet potatoes have been processed into precooked dehydrated flakes.[28] These flakes have good potential for institutional feeding and for overseas shipment as emergency food. Conditions under which the flakes are made causes considerable reaction between lysine and carbohydrates.[29,30,31]

Cured roots with high alpha amylose content are preferred for flakes because a moderate amount of starch conversion is necessary for good quality.[27-33]

A. Chemical Composition

1. Dry Matter

Sweet potatoes usually contain about 25% dry matter. The exact amount depends upon genetic selection, water balance at harvest, condition and time of storage, and perhaps undefined internal physiological factors. Analysis of 99 genetic selections in a root maintenance planting showed a range of dry matter from 17.9 to 49.3%.[34] In another year, 16 cultivars suitable for North Carolina growing conditions and quality demands were found to contain 23.7 to 28.6% dry matter.[35] Reports on the dry matter content of 13 high yielding clones in West New Guinea listed dry matter from 22.8 to 30.79%.[36] Dry matter in 6 selections of Ugandan sweet potatoes ranged from 30.3 to 39.2%.[37]

It has been demonstrated that soil moisture levels during the growing season significantly influence root dry matter content. Available soil moisture levels above 25% caused decreases in dry matter.[38] The same study showed that nitrogen fertilization rates from 0 to 90 lb per acre had no effect on dry matter content. Regardless of treatment, dry matter was found to be the most variable quality attribute tested with variations of up to 5% from 1 year to another.

Climatic factors other than water availability may affect dry matter content but it is difficult to separate such factors from age of the roots at the time of harvest. Roots which were harvested 102 days after planting had 27.3% dry matter while those harvested at 165 days had 25.7%.[35] Dates of harvest were September 6 and November 8, thus the variable of harvest date was superimposed on time after planting. Data from an experiment with staggered dates of planting and multiple harvest permitted calculation of dry matter as a function of harvest date, and time between planting and harvest. The data showed that the dry matter content increased from 26.7% in August to 29.8% in November.[39] These same data also show that dry matter content increased from 29.0% 3 months after planting to 31.3% 6 months after planting. Apparently dry matter increases with age of roots.

After harvest, sweet potato roots continue to respire, converting carbohydrates into carbon dioxide and water. They also "sweat", i.e., give off water, thus changes of dry matter may be expected during proper storage, however the ratio between dry matter and water remains nearly constant during storage. Appleman concluded that sweet potatoes in storage may lose at least 38% of their original weight without any signifcant change in percent dry matter.[40] Others have reached essentially the same conclusion.[41,42] It is probable that roots harvested under water stress would show changes toward equilibrium water content, i.e., high moisture roots would lose water while low moisture roots would retain water.

2. *Carbohydrates*

Most of the dry matter of sweet potato is carbohydrate, 85 to 90%.[1] Factors affecting the total carbohydrate fraction are essentially the same as those that influence dry matter content. The carbohydrate fraction consists of starch, sugars, pectins, cellulose, and probably hemicellulose and pentosans. Sweet potato starch, which contains 79 to 83% amylopectin, is the major carbohydrate, and accounts for 65 to 80% of the total dry matter.[42-44] Although maltose has been reported in raw Centennial sweet potatoes,[44] others have demonstrated that maltose is not present in raw tissue but is formed when roots are ground with hot solvent. McDonald and Newson[45] reported 0.33% glucose, 0.15% fructose, 3.47% sucrose, and 0.01% inositol in raw Centennial roots. Sucrose is thus the most abundant sugar in the raw sweet potato, ranging from 2.5 to 5.2% in freshly harvested roots and increasing to 10% after storage.[45-47] Stone has also reported that glucose and fructose are minor constituents of raw roots.[48]

After roots are harvested, glucose levels continually increase during storage while sucrose levels increase only for the first 17 days after harvest.[49]

Sweet potato roots continue to respire after harvest. Glucose is the most likely substrate for respiration. It can be postulated that starch is slowly degraded to dextrins which are rapidly degraded to glucose, thus large amounts of dextrins do not accumulate. Glucose is made on demand and furnishes energy for cellular metabolism, thus it also does not accumulate in large amounts.

It is probable that the amyloid carbohydrates are the major source of biological caloric value of sweet potatoes, which is reported to be 4.11 Kcal/g dry weight.[50]

Significant changes in amyloid carbohydrates occur during cooking or processing. During heating up to 95% of the starch may be degraged to dextrins and maltose.[32,50-53] These changes are attributed to the action of alpha and beta amylases which are naturally present in the roots[32,54] These enzymes probably are involved in mobilizing carbohydrates for respiration during storage but they evidently do not become fully active until starch is gelatinized. Both enzymes seem to have appreciable tolerance to high temperature and remain active for several minutes at temperatures which disrupt the starch granules. The amount of enzyme and consequently the magnitude of carbohydrate conversion during cooking, varies according to cultivar and post harvest treátment as well as conditions of cooking.[19] There appears to be no direct changes in nutritional value due to carbohydrate conversion. Extensive carbohydrate conversion results in a sweeter, more "moist" product.

Much less has been reported about the nonamyloid carbohydrates than the amyloids. Pectins are the largest fraction of nonamyloid carbohydrates. The pectins are important in maintaining wholeness and firmness of canned sweet potatoes. They have also been investigated in an effort to explain the different rheological properties of cooked roots of different cultivars and changes of "moistness" caused by curing and storage.[55,56] The mean total pectic content of eight cultivars was 5.1% fresh weight, estimated to be about 20% dry weight at harvest. This value declined to 3.5% fresh weight after 6 months of storage. Most of the decrease was due to changes in the hydrochloric acid soluble fraction, while the ammonium oxalate soluable and water soluable fractions did not change significantly. The degree of esterification decreased during storage. Baking and processing decreased the amount of pectins and the degree of esterification. However, no direct relationship was found which correlated rheological and sensory changes of baked sweet potatoes with changes in pectin content or molecular size of the pectins.

The fiber content of sweet potatoes has been reported to range from 2.5 to 5% dry basis.[57-59] The only report available lists cellulose content of sweet potato at 2.69% dry basis.[60] We believe the fiber fraction consists of the cellulose and possibly hemicellulose and pentosans.

Stringiness or fiberousness is a quality defect which occurs in some sweet potatoes.[59] It appears that this defect is genetic and unrelated to dieting fiber. Of those varieties most subject ot stringiness only about half of the roots manifest this defect.

Sweet potatoes are generally regarded as causing flatulence. Severity and frequency of the problem has not been adequately documented but it appears that people who commonly eat sweet potatoes recognize it.[61] Flatulence has been attributed to oligosaccharides particularly raffinose and stachyose.[62] Some workers feel that flatulence may be caused by undigested starch reaching the lower intestine.[63] Unpublished research from our laboratory has indicated that two cultivars of sweet potato, Jewel and Centennial, contain no stachyose.

3. *Proteins*

Folklore and misinformation have decreed that sweet potatoes are a starchy food without significant amounts of protein. A number of animal feeding studies have indicated that sweet potatoes are nearly equal to corn on the dry weight basis.[64-68] The value of sweet potato has also been recognized for human nutrition.[35,69,70]

Worldwide reports indicate that protein levels of sweet potato range from 1.73 to 11.8% protein dry basis.[34,58,66,71,72] Cultivar or genetic selection is a major factor influencing the amount of protein in the roots.[33,35,41]

The time between planting and harvest has a minor influence on protein content.[34] Nitrogen and water balance influence protein content,[36,73] but the relationship is not fully defined.[36] There are large unexplained differences in protein content due to location at which the sweet potatoes are grown.[74] Jewel sweet potatoes were found to produce 4.13% protein in one location in North Carolina while the same cultivar produce 8.81% protein in a different location in North Carolina in the same year. Centennial and Jewel sweet potatoes grown in North Carolina had twice as much protein as the same cultivars from the same root mintenance collection grown in Los Banos, Laguna, Philippines.[75] Differences of protein within a cultivar may be a complex function of soil water and soil nitrogen levels.

The amount of nitrogen applied as fertilizer may account for about half of the observed difference in protein content.[36,76] Sulfer and potassium fertilization apparently have no effect on protein content although potassium increases the yield in North Carolina soils.

Some protein is lost during storage but the rate of loss is less than the rate at which carbohydrates are lost, thus the relative concentration of protein increases during storage.[77] The limit to the degree of concentration in storage is not known. In our laboratory we have measured stored roots with 16% protein, which we estimate contained about 6% protein at harvest. However, these roots were pithy, and microsopic examination showed a greatly decreased number of starch grains all of which were very small.

Appreciable amounts of nitrogen are found in the nonprotein nitrogen (NPN) fraction. The NPN fraction is defined as nitrogen not precipitated by 12% trichloroacetic acid and thus is of low molecular weight. Studies in our laboratory have shown 30 to 40% of the nitrogen in Jewel is in NPN.[77] It is believed that most of the nitrogen is in asparagine. Nearly all of the remainder of the nitrogen can be accounted for by other amino acids. One must exercise caution in assigning protein nutritional value using Kjeldahl nitrogen values alone. Although NPN is available for amino acid synthesis, it contributes very little to the amounts of essential amino acids of sweet potato.

The protein of sweet potato is quite evenly distributed throughout the root. There is a small but statistically significant concentration at the stem end.[78] There is no statistically significant circumferential or radial distribution. It would not be possible to prepare high protein products by selectively cutting sweet potatoes. There is also no justification to the belief that peeling removes the most nutritious part of the root.

Sweet potato protein is of good quality and compares favorably with the FAO reference.[79] Various reports[34,80,81] suggest that tryptophan or total sulfer may be marginally limiting. The essential amino acids calculated as grams per 100 g protein are as follows:

	Sweet Potato[34]	FAO[77]
Isoleucine	6.1	4.0
Leucine	8.4	7.0
Lysine	5.8	5.4
Methionine	2.7	
Total Sulfur	3.3	3.5
Phenylalanine	7.1	6.1
Tyrosine	5.6	
Threonine	5.9	4.0
Tryptophan	1.0	1.0
Valine	7.6	5.0

4. Lipids and Fatty Acids

Lipids are a minor class of components in sweet potatoes, ranging from .29 to 2.7% dry basis.[34,43,81] Boggess studied changes in lipid composition during storage.[82,83] Short chain, C_{10}-C_{12}, fatty acids decreased during storage. Changes were more rapid at low temperatures. The amounts of other fatty acids increased in storage, suggesting fatty acid synthesis. Boggess compared the lipids of nine varieties of sweet potatoes and found a range of total lipids from 1.24 to 2.50% dry basis.[83]

The total lipids varied more than individual components. The means of lipid fractions were:

Nonphospholipids	85.1%
Cephalin	9.6%
Lecithin	5.3%

Linoleic acid was the major fatty acid in all varieties, 47.8% of the total lipids and palmitic was the next most abundant at 34.6%, followed by linolenic 7.1%, steric 6.1% and oleic

1.3%. Other fatty acids were individually less than 1% of the total. Walter et al. studied the lipids of Centennial by different methods.[84] They found 42.1% neutral fats, 30.8% glycolipids, and 27.1% phospholipids. Relative abundance of the major fatty acids was similar to the findings of Boggess.[83] Among the neutral lipids they found 2.8% hydrocarbons and 2.5% sterols. The major sugar in the glycolipids was galactose. Small amounts of glucose were also found. Ethanolamine, choline, and inositol were major components of the phospholipids.

Carotenes account for about 2.3% of the lipids in Jewel and Centennial and would be found among the hydrocarbons. Carotenes are, therefore, the major component of the hydrocarbon fraction.

5. Carotenoids

Carotenoids in sweet potatoes are important both for color and nutrition. A recent consumer survey indicated that U.S. consumers prefer the most orange internal color available.[22] This does not seem to be related to a desire for vitamin A value because most consumers do not relate color to nutritional value.[60] The desire for deep orange color does not apply to everyone in the U.S., nor does it apply in other nations. It seems to be common knowledge (not documented) that Cuban and Puerto Rican immigrants prefer a white or pale yellow internal color for sweet potatoes. Some older people in the U.S. fondly remember the Jersey which was pale yellow or the Porto Rico of past years which was yellow to pale orange sweet potatoes. Miller and Covington reported carotene contents of 15 mg% (mg/100g) wet basis, estimated to be about 60 mg% dry basis.[85] More recently some cultivars have been found to contain 72 mg% dry basis.[129] Beta-carotene is the major pigment of the orange flesh sweet potato which have been studied.[85-89] Two cultivars have been studed in detail and beta-carotene is the only significant source of vitamin A value.[88,89] The carotenoid fraction of Goldrush contained 89.9% beta-carotene and 0.7% gamma-carotene. The vitamin A isomers of Centennial included beta-carotene 86.4%, alpha-carotene 0.9%, and gamma-carotene 0.8%.

In our laboratory we studied the carotenoids of an experimental selection, Julian 288-1 which showed a noticeable range of flesh color from a single planting. Total carotenoids ranged from 5.6 to 32.0 mg% dry basis. The amount of epoxides and hydroxy carotenoids remained nearly constant but the beta-carotene varied from nearly 0 to about 25 mg%. The non-beta-carotene fraction appeared similar to that of Centennial, although some of the minor pigments found in Centennial were not found. We were unable to find alpha- and zeta-carotenes. This experience serves as a warning that pale yellow flesh color may not necessarily indicate a significant amount of vitamin A value.

Genetic selection of cultivars is the most important factor in determining the amount of carotenoids in sweet potatoes, but other factors may significantly alter the amount. Examination of canned samples by the National Sweet Potato Collaborators Group has frequently shown that some selections are orange at one reporting station and a pale yellow at others. It has been noted[90] that roots of a single cultivar at one station in Mississippi sometimes would have twice as much carotene as from another station. No explanation for this variance was offered. However, flesh color in the Centennial cultivar has been shown to be adversely affected by available soil moisture levels above 25% and by nitrogen fertilization rates above 90 lb/acre.[36]

Carotenoids change during storage. In some cultivars it appears that carotenoids increase storage while in others the carotene decreases.[91]

Processing, including baking or boiling, of sweet potatoes may cause minor changes in carotenoid content (vitamin A value) due to heat mediated isomerization.[92] Provitamin A has been shown in many processing studies to be remarkably heat stable and to be only slightly affected by cooking or processing. Consequently, losses of vitamin A value from sweet potatoes during processing are minimal. Occasionally processing appears to increase the amount of carotenoids. Most of the increase can be rationalized as loss of water content of leaching of water soluble dry matter.[92]

Carotenoids are readily susceptible to autoxidation, especially in a medium of low water activity.[93-95] It appears that conditions used for manufacture of precooked dehydrated sweet potato flakes encapsulates most of the carotene in carbohydrates to prevent autoxidation, thus carotenoids in this product are more stable than in dried products made by other means.[95]

The level of carotenoids in most orange fleshed sweet potatoes grown in the U.S. is sufficiently high to provide a weeks supply of vitamin A with one generous serving. Vitamin A is one of the most widespread vitamin deficiencies in the U.S.[96] Thus, increased consumption of sweet potatoes could serve to correct this situation. During World War II, most of the war-ravaged world suffered widespread vitamin A deficiency. However, in Japan sweet potatoes were grown for chemurgy and livestock feed. People were forced by circumstances to eat sweet potatoes and as a consequence, vitamin A deficiency was rare although the Japanese sweet potatoes did not have as high a carotene content as those presently grown in the U.S. The high level of carotene in U.S. sweet potatoes may cause hypercarotenosis if eaten daily with adequate fat to assure absorption. Hypercarotenosis is not similar to hypervitaminosis A and is not considered particularly detrimental although it does impart a yellow color to the skin of the patient. The mere consumption of large amounts of sweet potatoes having an adequate level of beta-carotene does not assure protection from vitamin A deficiency unless additional fats are included in the diet to assure adsorption of the carotene.[97]

6. Vitamins

Sweet potato apparently contains all of the vitamins needed to assure metabolism of its carbohydrates. Before the various components of the B-complex were recognized it was reported that sweet potato contained 0.7 IU B-vitamin per gram, i.e., 2.8 IU per gram of dry matter of per 4.11 K_{cal}.[97] Since then all of the B-complex except B_{12} have been reported in sweet potatoes as follows:

Vitamin	μg/g dry	Ref.
Thiamine	5.6	99
	3.6	100
Riboflavin	1.2	101
	1.8	99, 100
	2.0	100
Niacin	45.3	102
	19.8	101
	22.4	90
	24.0	100
Pantothenic acid	28.0	103
	23.0	101
	44.0	99
	38.0	100
Folic acid	0.6	104
	0.2—0.8	100
Pyridoxin	12.8	100
Biotin	1.7	100
Para amino		100
Benzoic acid	.24—.48	
Choline	14.0	100

None of the vitamins decrease appreciably during processing. About 11% of the riboflavin and 28% of the pantothenic acid are lost during dehydration.[101] Baking destroys 25% of the thiamine, 12% of the riboflavin, 15% of the niacin, and 23% of the panthothenic acid. Boiling causes loss of 7 to 8% of the thiamine but other vitamins are essentially unaffected.[99] There are no data concerning stability of folic acid, pyridoxine, biotin, para aminobenzoic acid, or choline. There are not sufficient data to determine differences in cultivatars or effects of climatic and environmental conditions.

Sweet potatoes are a good source of vitamin C (ascorbic acid). As early as 1924, Pech reported that 10 g of sweet potat per day prevented scurvy in Guinea pig.[105] Sweet potatoes contain 23.5 and 33.3 mg% fresh weight of vitamin C in Triumph and Nancy Hall cultivars.[106] These values decreased 28 and 40% during 7 months of storage. During cooking 69 to 83% of the vitamin C was retained. Others have confirmed the loss of vitamin C in storage with values decreasing from 46 to 28 mg% in 4 months.[107] Crosby lists the value of vitamin C at 22 mg%.[100] In conjunction with other work we have measured the vitamin C in uncured Jewel roots after seven days in market channels, in roots cured for 4 days, then 7 days in market channels and roots cured 7 days and 7 days in the market channels. Uncured roots contained 25.0 mg%. It is obvious that vitamin C content does decline during storage. It is probable that the vitamin C content will not drop below 15 mg% as long as the roots remain healthy.

Variations in vitamin C content as related to cultivar and growing conditions have not been reported. Losses during processing have been reported. Roots estimated to have contained 24.5% before canning contained 7 mg% after canning and 4 to 5 months of storage. However, a significant part of the difference may have been due to leaching of the vitamin C into the syrup. Dehydrated flakes contained 40 to 88 mg% with a mean of 65.6% for 17 samples.[108] Correcting for differences in dry matter it is estimated that the flakes would have contained about 17 mg% when reconstituted to the same dry matter as the canned sweet potatoes. Baking or boiling causes decreases in ascorbic acid content depending upon whether the roots are cooked immediately after harvest, approximately 20% loss, or after storage for 6 months, approximately 40% loss.[109]

Some novice nutritionists have expressed concern that many processors use lye peeling to prepare sweet potatoes for canning They believe this practice destroys the vitamin C. The lye-softened tissue probably has no vitamin C at all but there is no evidence to suggest that the alkali has any effect upon vitamin C in tissues which have not been penetrated and softened. The lowest levels of vitamin C are present in the outer 4 mm of tissue.[110] It is this layer which is removed by lye peeling, thus lye peeling does not destroy the tissues having the highest concentration of Vitamin C.

Except for beta-carotene, the fat soluble vitamins have received little attention. One report cites the vitamin E level at 16 mg% dry basis.[98] One report gives the vitamin K value at 20 mg%.[111]

7. *Minerals*

There are not sufficient data available to adequately describe ranges of mineral contents due to cultivar or environment. Agricultural Handbook No. 456 provides some data on mineral values as follows:[112]

Element	Raw
Potassium	594.9
Calcium	78.6
Phosphorus	115.4
Iron	1.72

mg/100 g dry matter

The S-101 Technical Committee[113] reported on nutritional values of five cultivars produced and canned at seven stations in the southern U.S. For calcium, the mean value was 45.2 mg% (coefficient in variation 54.6%) and for iron, 4.2 mg% (coefficient of variation 39.4%). The magnitude of variation represents cultivar variation as well as location cultivar interactions. Such wide differences illustrate the difficulties which will be encountered if attempts are made to provide nutritional labeling of canned sweet potatoes. Our laboratory had determined the iron content of four cultivars both raw and canned. Our values were 3.3 mg% (dry basis) for raw roots and 0.61 mg% (dry basis) for the canned products. The low value for the canned product relative to the raw starting material is most likely due to leaching of the iron into the syrup.'

Data available for 17 elements of nutritional significance are summarized as follows:

Element	PPM dry basis	Ref.
Calium	695	114
Chloride	1822	114
Chromium	.56	114
Cobalt	1.64, .3	114, 115
Copper	5.20, 6.2	114, 116
Iron	23.68, 64	114, 116
Magnesium	731	114
Manganese	9.60, 93	114, 116
Molyldenum	9.60	114
Nickel	2.44	114
Phosphorous	1566	114
Potassium	14388	114
Silicon	39.6	114
Sodium	1211	114
Tin	24.4	114
Zinc	10.8, 8—12	114, 117
Iodine	8—18	118

Because some minor element deficiency diseases have been associated with geographic areas in which that element is present in low amounts in the soil, it is postulated that minor element values will vary greatly from area to area and be greatly influenced by fertilizer applications.

B. Baked Sweet Potatoes

1. Volatile Flavor Components

When sweet potatoes are baking they give off a delightful aroma. The constituents of aroma may not be natural components of the root but may be formed as a consequence of baking; however, they are components of baked sweet potatoes. Thirty volatile compounds from baked sweet potatoes have been identified.[119] Among these are some highly aromatic compounds: 2,3-butane dione, benzaldehyde,phenyl acetaldehyde, linalool, and B-ionone. Some of the volatile constituents have been correlated with good sweet potato flavor and some with bad flavor.[120]

Some chromatographic peaks which are associated with good or bad flavor of sweet potatoes are listed:

Peak No.	Compound	Effect on flavor
2	*N*-Hexane	−
3	2,3-Pentanedione	+
4	2-Methyl-tetra hydrofuran 3-one	0

5	Furfuraldelyde	–
7	2-Furyemethylketone	+
9	5-Methyl-2-furaldelyde	–
12	Trimethylbenzene	–
13	Octanal	0
14	2-Pentyl-furan	–
17	Unidentified	+
18	Unidentified	–
19	Unidentified	–
21	*N*-nonanal	0
22	Linalool	+
25	Unidentified	0
26	Unidentified	–

– large amounts decrease flavor.
\+ large amounts increase flavor.
0 amount does not affect flavor.

V. TOXINS

There have been no reports of the presence of toxic substances in healthy sweet potato roots.[121] Indeed, even in sprouting roots there are no toxic compounds formed analogous to the glycolalkaloid, solanine which is known to be produced by sprouting Irish potatoes.[121]

However, toxins are produced when sweet potatoes are subjected to mechanical injury or to microbial attack. Unlike aflatoxin found in mold-infected peanuts and corn, the toxin in sweet potato is a phytoalexin, i.e., it is manufactured by the sweet potato tissue and not by the pathogen. The toxins which are formed are furanoterpenoids described by Uritani.[122] Later work by Wilson and co-workers[123] was begun when compounds of the furanoterpenoid class were identified as the causative factor in the incident in which cattle died after eating moldy sweet potatoes.

The major furanoterpenoid produced by pathogen-infested tissue is ipomeamarone. This compound is a hepatotoxin of relatively low toxicity (LD_{50}230 mg/kg interperitoneal). Some furanoterpenoids are, however, more toxic and attack other tissues. 4-Ipomeamorone is a lung edema toxin and has an LD_{50} of 30 mg/Kg (oral ingestion).[124]

A number of pathogens and even mechanical damage can result in toxin formation. However, the black rot organism (*C. fimbriata*) elicits the greatest response.[125] There are indications that tendency to toxin formation is under genetic control but it does not appear that the problem can be entirely eliminated by selecting cultivars which do not produce these phytoalexins.

A very carefully conducted study[126] has shown that the toxic furanoterpenoids are not produced beyond the infected tissue. Presumably if the consumer excised and discarded the damaged tissue of a moldy sweet potato before cooking, there would be little if any exposure to toxic furanoterpenoids. This is probably academic, however, because the majority of consumers would discard moldy sweet potatoes *in toto*. Other data from this study has indicated that when toxin-infected roots are lye peeled and then trimmed before canning as is done in commercial production, no toxin is found. As a matter of fact, numerous random canned sweet potato samples produced in different areas of the country have been analyzed. No furanoterpenoids have been found in any of these samples. Although the possibility of a problem does exist, the early reports apparently exaggerated its magnitude and seriousness.

In spite of potentially high yields, no chemurgy of sweet potato exists in the U.S. Small scale studies have shown that sweet potatoes can be fractionated into economically valuable biochemical fractions by simple laboratory procedures.[127] The proposed fractionation scheme yields starch, fiber, chromoplasts, protein concentrate, and syrup. The chromoplast concentrate contains 28,600 IU of vitaminA value per gram and 30% protein. The protein concentrate is a bland light gray powder containing over 80% protein. It can be used in baking breads and pastries to supplement lysine deficient grains.

There is a significant sweet potato starch industry in existance in Japan.[128] At the present time most of the starch (80 to 85%) is utilized to produce sweeteners and syrups. The remainder of the production is used in the food, beverage, textile and paper industries. Since the starch is hydrolyzed in the producing factory, it need not be separated and dried but is fed directly to the conversion equipment thus effecting a substantial savings in cost.

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