

## Chapter 7

## FRESH ROOTS FOR HUMAN CONSUMPTION\*

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## I. INTRODUCTION

Human consumption is one of the most important uses of sweet potatoes in both temperate and tropical growing areas and they are used either as fresh or processed products. In at least one area of the tropics, Papua New Guinea, it is the main staple crop of the population.<sup>1,2</sup> In addition to marketing for local use, tropical growers are increasingly interested in the exportation of tropical vegetable crops including sweet potatoes.<sup>3</sup> Various researchers agree that the major constraints to export are the failure to maintain a high quality product after harvest and inappropriate handling techniques resulting in high postharvest losses.<sup>3,4</sup>

This chapter will present (1) a short review of nutritional components of sweet potatoes, and (2) the effect of harvest and postharvest handling and preparation techniques on the quality and nutritional components of fresh roots for human consumption.

## II. NUTRITIONAL COMPONENTS OF SWEET POTATOES

### A. Carbohydrates

The sweet potato at harvest contains between 16 and 40% dry matter.<sup>5,6</sup> Of this dry matter, 75 to 90% is carbohydrate. This carbohydrate contains starch, sugar, cellulose, pectins, and hemicellulose (Table 1). Data on carbohydrate composition must be regarded as approximate because of high variability among cultivars due to genetic, environmental, storage, and sample preparation factors. The starch is composed of 60 to 70% amylopectin, and the remainder is amylose.<sup>7,8</sup>

Sucrose is the most abundant sugar in raw sweet potatoes with smaller amounts of glucose and fructose (Table 2). Maltose was not detected and this is in agreement with McDonald<sup>9</sup> who reported that the maltose found by others was an artifact produced by treatment of raw sweet potatoes with hot solvent. Because of their relative abundance, the carbohydrates make up a large part of the caloric value of sweet potatoes, which is reported to be 4.1 kcal/g dry weight.<sup>10</sup>

### B. Dietary Fiber

Much less has been reported about the nonamyloid carbohydrates than the amyloids. These materials, including pectins, cellulose, and hemicellulose, together with lignin are loosely classified as dietary fiber. There has been a recent increase in interest in dietary fiber due to studies which have implied that increased dietary fiber may reduce the incidence of such diseases as colonic cancer, diabetes, heart disease, and certain digestive diseases.<sup>11,12</sup> Complete fiber analyses for sweet potato are limited. The data in Table 3 illustrate two examples. Cellulose was high in both reports,<sup>13,14</sup> whereas hemicellulose content for the variety 'Garnet'<sup>13</sup> was an order of magnitude greater than hemicellulose in the variety 'Porto Rico'.<sup>14</sup> Lignin<sup>14</sup> and pectin<sup>13</sup> were present in similar amounts. Other reports<sup>15</sup> are available for total fiber, but due to the recent changes in methodology, the results are not directly comparable.

Pectins have been studied more extensively than any of the other fibrous materials due to their role in the rheological properties of cooked sweet potatoes.<sup>16,17</sup> The mean total pectic content of eight cultivars<sup>17</sup> was 5.1% fresh weight, estimated to be about 20% dry weight at harvest.

### C. Protein

The sweet potato has long supplied a significant amount of the caloric requirements in the tropics. However, the protein content and its contribution to overall nutrition have been overlooked until recently. The crude protein content ranges from 1.3 to > 10% (dry basis).<sup>18,19,20</sup> Variability in protein content is due to production practices,<sup>21</sup> environmental conditions,<sup>22,23</sup> and genetic factors.<sup>22,23</sup> It has recently been recognized that the potential

Table 1  
 CARBOHYDRATE CONTENT  
 IN RAW AND BAKED  
 'GARNET' SWEET POTATOES  
 (% DRY WEIGHT)

	Raw	Baked
Starch	46.2	2.6
Sugars	22.4	37.6
Hemicellulose	3.8	1.0
Cellulose	2.7	2.5
Water insoluble pectin	0.47	0.31

Some data from Shen, M. C. and Sterling, C.,  
*Starch*, 33, 261, 1981.

exists to increase the protein content and protein quality through selection for those genetic traits.<sup>22,23</sup>

The protein of sweet potato is quite evenly distributed throughout the root; there are no statistically significant differences in circumferential or radial distribution.<sup>24</sup> Thus, it would not be possible to prepare high protein products by selectively cutting sweet potatoes.

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. NPN content ranges from 15 to 35% at harvest.<sup>25</sup> The NPN for 'Jewel' cultivar is comprised of asparagine (61%), aspartic acid (11%), glutamic acid (4%), serine (4%), and threonine (3%).<sup>26</sup> These components accounted for 88.5% of the nitrogen in the fraction. Thus, from a nutritional standpoint, most of the sweet potato NPN is available to satisfy the requirement for total utilizable nitrogen, but provides only small amounts of essential amino acids.

Most of the protein of sweet potato is reported<sup>27</sup> to be globulin, "ipomoein." Upon storage of the root, the ipomoein is partially converted into a polypeptide that is considerably different from the parent globulin in its physical and chemical properties.

A limited number of reports are available concerning the nutritional quality of isolated sweet potato protein. Amino acid analyses that are available indicate that protein from some sweet potato cultivars may be deficient in total sulfur and lysine (Table 4).<sup>18,28,29,30</sup> For 'Jewel' (Table 4), Walter and Catignani<sup>28</sup> reported both total sulfur and lysine to be limiting, while Purcell et al.<sup>18</sup> reported only total sulfur to be limiting for 'Jewel'. Nagase<sup>29</sup> reported no limiting amino acids for a Japanese cultivar. The data (Table 4) indicate that there is some amino acid variability both between cultivars and within the same cultivar. In addition, the data of Purcell et al.<sup>18</sup> for five other cultivars showed total sulfur to be limiting in all cases and that there was considerable between-cultivar variability in content of several amino acids.

There are limited data available for the amino acid content of the whole sweet potato. Among the essential amino acids, only the aromatic amino acids are nonlimiting.<sup>31</sup> This difference in essential amino acid patterns between isolated protein and whole sweet potato is due to the presence of significant amounts of nonprotein nitrogen<sup>26</sup> in the latter. This material effectively dilutes the essential amino acids, thereby lowering the concentration.

As the amino acid analyses indicate, protein nutritional quality is high. Walter and Catignani<sup>28</sup> reported that the protein efficiency ration (PER) of isolates and concentrates is equal to that of casein. Whole sweet potato flour was reported<sup>32</sup> to have a PER of 2.2 and 1.8 (relative to 2.5 for casein) for 'Centennial' and 'Jewel', respectively. The PER was found to be highly dependent on the severity of the heat treatment used in the manufacture of the flour.

Table 2  
 STARCH, FRUCTOSE, GLUCOSE, AND SUCROSE CONTENT<sup>a</sup> OF RAW SWEET POTATOES<sup>b,c,d</sup>

Time after harvest	Starch		Fructose		Glucose		Sucrose	
	'Jewel'	'Centennial'	'Jewel'	'Centennial'	'Jewel'	'Centennial'	'Jewel'	'Centennial'
0 time	15.1A	15.9A	0.08D	0.08D	0.05D	0.07C	2.41C	2.58D
1 week	17.7B	10.8B	0.49C	0.25C	0.55C	0.14C	3.48B	3.40C
2 months	11.3B	10.8B	1.39A,B	0.35B	1.31B	0.35B	3.23B	5.16B
4 months	8.96C	6.19C	1.17A	0.61A	1.25B	0.66A	4.84A	5.44A
6 months	7.76C	6.24C	1.32A,B	0.56A	1.52A	0.68A	5.18A	5.69A
LSD 0.05	1.53	0.71	0.41	0.10	0.09	0.09	0.54	0.28

<sup>a</sup> Grams in 100 g fresh weight.

<sup>b</sup> Means within columns followed by the same letter are not significantly different at  $p < 0.05$ .

<sup>c</sup> Maltose not detected.

<sup>d</sup> Walter and Hoover.<sup>34</sup>

**Table 3**  
**FIBER<sup>a</sup> IN RAW SWEET**  
**POTATOES**

	Lund and Smoot <sup>14,b</sup>	Shen and Sterling <sup>13,c</sup>
Cellulose	3.76	3.26
Hemicellulose	0.46	4.95
Insoluble pectin	NR	0.50
Lignin	0.44	NR

<sup>a</sup> Percent of dry matter.

<sup>b</sup> Cultivar not identified.

<sup>c</sup> 'Jersey' cultivar.

**Table 4**  
**AMINO ACID COMPOSITION OF PROTEIN**  
**ISOLATES (g OF AMINO ACID PER 100 g PROTEIN)**

	Walter and <sup>a</sup> Catignani <sup>28</sup>	Purcell <sup>a</sup> et al. <sup>18</sup>	Nagase <sup>b,29</sup>	FAO <sup>30</sup>
Essential				
Threonine	6.4	5.5	4.6	4.0
Valine	7.9	6.8	7.9	5.0
Methionine	2.0	2.6	2.5	—
Total sulfur	3.1	3.0	4.1	3.5
Isoleucine	5.6	5.3	5.3	4.0
Leucine	7.4	7.8	8.7	7.0
Tyrosine	6.9	5.2	3.6	6.0
Phenylalanine	8.2	6.7	6.0	—
Lysine	5.2	6.8	6.5	5.5
Tryptophan	1.2 <sup>c</sup>	1.1 <sup>c</sup>	1.8 <sup>c</sup>	1.0
Chemical score				
Total sulfur	88.0	86.0	100.0	—
Lysine	95.0	100.0	100.0	—
Nonessential				
Aspartic acid	18.9	14.4	13.1	—
Serine	6.6	5.1	5.5	—
Glutamic acid	9.6	8.6	11.8	—
Proline	4.2	5.4	4.3	—
Glycine	5.3	0.3	2.6	—
Alanine	5.4	4.6	6.1	—
Histidine	2.7	2.4	4.2	—
NH <sub>3</sub>	1.6	— <sup>d</sup>	— <sup>d</sup>	—
Arginine	5.9	6.0	6.4	—

<sup>a</sup> 'Jewel' cultivar.

<sup>b</sup> Cultivar unknown.

<sup>c</sup> Tryptophan content measured colorimetrically on enzyme hydrolyzed material.

<sup>d</sup> NH<sub>3</sub> not reported.

From Walter, W. M., Jr. and Catignani, G. L., *J. Agric. Food Chem.*, 29, 797, 1981. With permission.

Horigome et al.<sup>33</sup> reported that protein isolated from a starch production facility had a PER of 1.9, which was increased to 2.5 by the addition of lysine and methionine, indicating that these amino acids are either deficient or are destroyed by the process.

**Table 5**  
**VITAMINS IN SWEET**  
**POTATOES<sup>a,b,c</sup>**

	Raw	Baked	Boiled
Thiamin	0.09	0.07	0.07
Riboflavin	0.05	0.05	0.05
Niacin	0.53	0.55	0.51

<sup>a</sup> Provitamin A, vitamin C not included.

<sup>b</sup> Watt and Merrill.<sup>41</sup> Cultivars not identified.

<sup>c</sup> Mg in 100 g.

It has been reported<sup>34</sup> that when the sweet potato was the only source of nitrogen in the human diet, the nitrogen balance was maintained. In addition, there are areas in New Guinea in which the population obtains a significant portion of its protein requirement from sweet potatoes.<sup>1</sup> Huang<sup>35</sup> reported that sweet potato alone is not sufficiently rich in protein to satisfy the requirements of growing age children but that the crop is a source of high quality protein that should not be overlooked. In fact, a 13% equicalorie replacement of sweet potato for rice was shown<sup>36</sup> to enhance human nitrogen balance. The evidence indicates that the sweet potato not only is a source of calories, but also can improve protein nutrition when added to diets consisting mainly of cereals and grains.

#### D. Vitamins

The most abundant vitamins from a human nutrition standpoint are beta-carotene (provitamin A) and ascorbic acid (vitamin C). Beta-carotene is the major pigment of the orange flesh in those cultivars that have been studied.<sup>37-40</sup> For 'Goldrush', 90% of the carotenoids had vitamin A activity,<sup>38</sup> and for 'Centennial', 88% of the carotene had vitamin A activity. Genetic selection of cultivars is the most important factor in determining the carotenoid content, but variations in carotene content with location have been observed.<sup>41</sup>

The level of carotenes in the orange-fleshed varieties preferred in the United States are sufficiently high to provide several days' supply of vitamin A per serving. However, the preferred type in much of the tropics is either white-fleshed or cream-colored. This type of sweet potato is obviously a poor source of pro-vitamin A. Since high dry matter and light flesh color appear to be genetically linked, it may be difficult to select for an orange, dry-fleshed variety. However, this should be a goal of plant breeders because of the high incidence of vitamin A deficiency noted in some parts of the tropics.

Vitamin C is fairly abundant in sweet potatoes ranging from 20 to 50 mg per 100 g of fresh weight.<sup>42,43</sup> Thiamin, riboflavin, and niacin contents are shown in Table 5. There is one report that the vitamin E content of raw sweet potatoes is 4 mg/100 gram.<sup>44</sup>

#### E. Lipids

Lipids are a minor component of the sweet potato ranging from 0.29 to 2.7% (dry basis).<sup>45,46,47</sup> Linolenic acid is the major fatty acid followed by palmitic, linolenic, and stearic acids.<sup>46,47</sup> Boggess et al.<sup>45</sup> separated the lipids into three fractions, nonphospholipids (85.1% of the total), cephaline (9.6% of the total), and lecithin (5.3% of the total). Walter et al.<sup>47</sup> found 42.1% neutral lipid, 30.85% glycolipid, and 27.1% phospholipids.

#### F. Minerals

The mineral content of sweet potatoes has been measured by several researchers. The values (Table 6) show the variability present, as is the case in most of the components of

**Table 6**  
**MINERAL CONTENT OF RAW SWEET**  
**POTATOES**

	Reported values (mg/100 g)		
	Elkins <sup>48,a</sup>	Lopez et al. <sup>49,b</sup>	RDA (mg) <sup>c</sup>
Calcium	32.7	17.4	870
Phosphorus	48.9	39.2	800
Magnesium	22.2	18.3	352
Sodium	8.0	30.3	1000
Potassium	228.0	360.0	2000
Iron	0.85	9.59	100
Copper	0.25	0.13	2.0
Magnesium	0.59	0.24	4.0
Zinc	0.26	0.27	15.0

<sup>a</sup> Mean from analysis of 3 lots of 'Centennial' and 1 lot of 'Nemagold'.

<sup>b</sup> 'Jewel' cultivar.

<sup>c</sup> Recommended dietary allowance (50).

the sweet potato. The amount of the human requirement furnished in 100 g is small for all of the minerals, with the possible exception of potassium, which furnishes about 11.4%<sup>48</sup> or 18%<sup>49</sup> of the recommended dietary allowance (RDA)<sup>50</sup> depending upon the study. Sodium is low and, thus, would provide no problem for those on a restricted sodium intake diet.

### G. Antinutritional Factors

The only antinutritional factor reported for sweet potato is a trypsin inhibitor.<sup>51,52</sup> The presence of this material in a food causes an adverse nutritional effect by inhibition of the proteolytic action of trypsin during the digestion process.

## III. HARVEST AND POSTHARVEST HANDLING METHODS AND THEIR EFFECT ON QUALITY AND NUTRITION OF FRESH ROOTS

Harvest and postharvest handling procedures differ greatly between temperate and tropical growing areas. Mechanical harvesting and handling is practiced extensively in temperate areas. While this mechanical harvesting may result in more injury to roots than the more labor intensive harvest methods used in the tropics, the economic loss due to injury is minimized by careful postharvest treatment.<sup>53</sup> Roots grown in temperate areas are normally cured for 4 to 7 days in specially designed facilities where the temperature is maintained around 29°C and relative humidity is kept at 85 to 90%. This promotes wound periderm (cork) formation on injured surfaces of the root which in turn prevents excessive water loss and prevents pathological organisms from invading the injured roots. Once the curing procedure is complete, roots are stored at temperatures of 13 to 16°C with 85 to 95% relative humidity. Under these carefully controlled conditions roots may be kept for 12 months or longer depending on cultivar. Therefore, high quality roots may be marketed year-round in temperate areas.

In the humid tropics, sweet potato can be grown during most of the year. Although it is a perennial plant, it is grown as an annual with a growing season of 3 to 8 months and two crops a year. In some areas where rainfall (too much or too little) is a problem only one crop can be grown. The availability of fresh sweet potato roots on a continuous basis for marketing has resulted in a minimum of curing and storage procedures for roots in the

tropics. However, postharvest losses are extremely high and much of the crop may be lost before it is sold.<sup>3,4</sup> The potential for export of tropical vegetable crops including sweet potatoes from tropical countries is often limited by the failure to maintain quality and by the lack of proper handling techniques to reduce losses after harvest.<sup>3</sup>

### A. Harvest Procedures

In general, harvesting in the tropics is manual with a variety of relatively simple digging implements including sticks, spades, 4 to 6 pronged potato hoes, and occasionally knives.<sup>54,55</sup> Mechanical harvesting is usually practiced only on large-scale production areas where the terrain is suitable for machinery. Mechanization may range from a variety of plows,<sup>56,57</sup> either tractor drawn or animal drawn, to machines which remove the roots from the soil and deposit them in a collection container.<sup>58</sup> Harvest methods have a direct and dramatic effect on the quality of fresh roots for market. At time of harvest, roots are extremely susceptible to skinning and bruising. Heavy losses may occur unless digging is done very carefully.<sup>59</sup> Roots should not be thrown into piles for later packing but should be carefully placed.

Time of harvest is dictated by weather, disease and insect problems, and the marketability of the roots. Roots must be harvested before flooding occurs in areas with a definite rainy season. If sweet potato weevil is a problem, then roots are harvested before the damage becomes severe.<sup>4</sup> If roots are harvested too early, yields will be reduced; if they are left too long, they may rot or become very fibrous and finally inedible.<sup>60</sup> Because they do grow as perennials, sweet potatoes may be harvested according to how much a grower can sell at any particular time. Progressive harvest of individual plots or individual plants for this purpose or for home use occurs in many areas.<sup>1,2,55,61,62</sup> Also, progressive harvest of individual plots insures a steady supply of fresh roots to the market and avoids the need for long-term storage of surplus roots. Progressive harvest of individual plants is practiced extensively in Papua New Guinea. Roots of a desirable size are removed from each plant without disturbing smaller roots on the plant. Bourke<sup>1</sup> reports that individual plants can be harvested up to four times in a year and that progressive harvest of the same plants can be carried on for a period of months or even years. However, a single harvest was shown to result in higher numbers of marketable size roots than progressive harvest although progressive harvesting resulted in a higher overall yield.<sup>63</sup> In Uganda the largest roots are removed with digging sticks; 2 to 3 months later the remainder of the crop is removed.<sup>64</sup>

Once the sweet potato roots have been harvested, they may be left in the sun to dry for a short length of time in some areas but usually not overnight.<sup>57,65,66</sup> More often they are transported to the market place and sold with a minimum of storage time, usually less than a week, and with no curing other than that which occurs naturally. However, without proper curing and storage procedures even on a short-term basis, losses can be severe. Most losses result from bruising and injury to the roots during harvesting, packing, and transport. These losses are mainly due to water loss and the invasion of fungi and bacteria. The effect on quality is dramatic and many roots are of unmarketable quality by the time they reach the marketplace.

### B. Post Harvest Handling

#### 1. Curing

Curing is rarely practiced in the tropics except that which occurs naturally. If sweet potato weevil is not a problem in a particular area, then the tops of sweet potato plants may be removed a week before harvest.<sup>4,66</sup> This allows the roots to achieve some degree of curing in the ground. However, when they are removed from the ground the new injuries again render them susceptible to disease organisms and water loss.

Proper curing occurs ideally at 29°C, and 85 to 90% relative humidity for 4 to 7 days.<sup>53</sup> The normal temperature and relative humidity in the humid tropics are very similar to those

**Table 7**  
**EFFECT OF CURING**  
**TREATMENT OF SWEET**  
**POTATOES STORED 90 DAYS**  
**(24 TO 29°C) AVERAGE OF**  
**FOUR REPLICATIONS, THREE**  
**CULTIVARS<sup>a</sup>, APRIL TO JUNE**  
**1974<sup>b</sup>**

Treatment	Weight loss (%)	Marketable (%)
Standard A	11.6	82
Modified B	9.3	85
Control C	18.2**	48**

<sup>a</sup> Cultivars Centennial, Georgia Red, Goldrush.

<sup>b</sup> Means followed by \*\* are significantly different at the 1% level.

From Gull, D. D. and Duarte, O., *Proc. Trop. Region Am. Soc. Hortic. Sci.*, 1974, 168, 170. With permission.

**Table 8**  
**THE EFFECT OF CURING**  
**DURATION ON**  
**MARKETABILITY OF**  
**CENTENNIAL, GEORGIA RED,**  
**AND GOLDRUSH SWEET**  
**POTATOES STORED 90 DAYS**  
**AFTER CURING AVERAGE OF**  
**FOUR REPLICATIONS<sup>a</sup>**

Cultivar	Days cured			
	0	3	6	9
	(% marketable)			
Centennial	26*	54*	79	83
Georgia Red	66	78	85	82
Gold Rush	35*	38	82	83

<sup>a</sup> Cultivar means followed by \* are significantly different at the 5% level.

From Gull, D. D. and Duarte, O., *Proc. Trop. Region Am. Soc. Hortic. Sci.*, 1974, 168, 170. With permission.

required for curing and some natural curing does occur provided roots are given adequate ventilation. Roots are occasionally cured by placing under a shade for 8 to 10 days at ambient temperatures.<sup>57</sup> Gull and Duarte<sup>67</sup> conducted tests using several sweet potato cultivars to determine if a simple, economical method of curing under tropical conditions could be established to prolong the storage life of roots. They used three cultivars and three methods of curing: standard method (A) which is the method most commonly used in temperate areas (30°C, 85 to 90% RH); modified method (B) consisting of crates lined with plastic at 27 to 32°C, 40 to 60% RH; and control method (C) consisting of regular crates, 27 to 32°C, 40 to 60% RH. After curing roots were placed at different storage temperatures (15°C, 25°C, and ambient). The ambient temperature ranged from 24 to 29°C in a well-constructed masonry building. Their results are shown in Tables 7 and 8.

The results in Table 7 indicate that adequate curing would result if plastic box liners were used to maintain high relative humidity (modified method B). This modified procedure resulted in lower weight loss and a higher percentage of marketable roots than the control technique C and it was comparable to the more expensive standard method A. Results shown in Table 8 indicate that no benefit was derived from curing past 6 days and that there was a differential varietal response to curing. Thus, effective breeding procedures could be used to develop varieties more suitable to curing under tropical conditions. The authors concluded that curing temperatures of 28 to 31°C in tropical areas would be no major problem and that the use of plastic box liners to maintain high relative humidity would result in adequate, economical curing of sweet potato roots.

The effect of curing on the quality of freshly harvested roots has been investigated extensively in temperate growing areas. Curing sweet potatoes reduced decay<sup>68</sup> and resulted in less weight loss during the storage period after curing.<sup>69</sup> Although temperature and relative humidity may be near ideal for curing in tropical areas, roots which are immediately packed for market in sacks or crates may not have received adequate ventilation for the healing

process to occur. Ventilation is necessary to remove free moisture and prevent CO<sub>2</sub> accumulation and O<sub>2</sub> depletion.<sup>69</sup> Curing apparently has no dramatic effect on nutritional components of sweet potato although slight changes have been recorded in carbohydrates, carotene and ascorbic acid.<sup>70</sup> Reports of these changes are often contradictory and may depend on such factors as cultivar, growing environment, and exact conditions during curing.

### *1. Storage*

The continuous year-round supply of fresh roots to the market in almost all tropical countries limits the necessity for storage. In Taiwan, for example, 75% of growers in one survey sold their crop immediately after harvest with the remainder of the growers chipping the roots before sale.<sup>71</sup> In addition many growers use methods to avoid storage as much as possible.<sup>66,72</sup> To avoid storage, growers practice ground storage (progressive harvest)<sup>4,55,73</sup> or, in some areas, they use a succession of early and late cultivars including different ones for wet and dry seasons.<sup>66</sup> When ground storage is practiced roots are harvested only in amounts that can be successfully marketed; the remainder of the crop is left until needed. This is the most economical method of storage, but there are a number of problems associated with it. If sweet potato weevils or other insect pests such as beetles or termites are present, ground storage can be particularly hazardous.<sup>64,73,74</sup> In addition, roots stored for too long can become very fibrous and can crack making them unsuitable for marketing although some varieties are better suited to ground storage than other varieties.<sup>4</sup> A study of cultural practices such as crop rotation along with development of insect-resistant varieties has been suggested to develop increased and more effective ground storage.<sup>4</sup>

Once roots are removed from the ground, they are susceptible to immediate quality decline if not properly cured. The roots are living organs and remain metabolically active after harvest. Respiration continues and water losses occur. Roots that are bruised or injured during harvest frequently are more metabolically active than uninjured roots and are more likely to show a decline in quality. In addition, the sites of injuries are ideal invasion points for pathogenic and secondary-invasion organisms. These factors limit storage potential of the roots for any length of time.

Several methods of short-term storage (up to one week) are practiced in tropical growing areas. Typically, roots are packed soon after harvest into sacks, boxes or crates for transport to market (Figure 1).<sup>65,75</sup> The roots may remain in these containers for up to a week; however, after a few days quality begins to deteriorate rapidly. Much of this loss is due to rapid water loss resulting from harvest damage with no healing process of the injuries. In addition, toxic stress metabolites may be formed in the edible root as a result of infection by certain microorganisms.<sup>76</sup> These toxins have been isolated from roots purchased from local markets with only minor blemishes.<sup>76</sup>

Long-term storage is rarely used. The major constraints to long-term storage in the tropics are (1) moisture and dry matter losses (Olurunda reported losses up to 95%),<sup>4,73</sup> (2) rots due to injury during harvest and handling,<sup>75</sup> (3) sweet potato weevil damage,<sup>4,72</sup> and (4) sprouting.<sup>4,65,77</sup> All of these problems lead to a product which is of poor quality and unmarketable or inedible. Attempts have been made to utilize several types of structures to overcome these constraints and lengthen the storage period and have met with some success. Among these structures are ground pits, mounds, sheds, caves, and houses.

Ground pits have been used extensively. Best<sup>78</sup> describes two types of pits used by early New Zealand Maoris: (1) semi-subterranean pits consisting of excavations into sloping ground or on terraces and lined with dried plant material with a roof of timber covered with earth so that the pit could be sealed; and (2) subterranean pits which were dug into the ground, filled and sealed. Little or no ventilation was provided in either case and heavy losses resulted due to decay and possible rodent damage. In Barbados, sweet potatoes have been stored for up to 4 months in pits,<sup>59</sup> but, in general, storage life is extended only to one or two months



FIGURE 1. Freshly harvested sweet potatoes prepared for export in St. Vincent, West Indies. (Photograph by W. W. Collins.)

because of spoilage and sprouting.<sup>60</sup> In the Philippines, roots were stored in a trench 50 cm deep covered with sand and sheltered by a roof; however 30% of the roots decayed and 45% sprouted.<sup>57</sup> In Trinidad, West Indies, immediate storage in pits when the temperature was about 24.5°C and the relative humidity about 82.5% resulted in less weight loss than if the roots were cured for 2 to 6 days in a house or in the sun.<sup>57</sup>

Mounds (also called clamps) are also used for storage. Keleny<sup>79</sup> suggests a well-designed aboveground mound structure with ventilation provided by trenches beneath a bed of perforated boards. A small flue structure through the center of the pile provides additional ventilation. The pile base is then covered with dried plant material with sweet potato roots placed in a conical arrangement around the flue. The entire pile is covered with 20 cm of additional dried plant material and a 15 cm layer of soil. The completed mound can be protected from weather and rodents. In some mounds, the trench may contain a hurricane lantern to provide heat for some degree of curing.

The Department of Science and Agriculture of the Federation of the West Indies developed a successful method of clamp storage for Barbados.<sup>80</sup> Clamps are located on well-drained sites which are dug out to a depth of 3 to 4 feet over a rectangular area 3 feet wide and as long as necessary. The floor is lined with dried grass and other dried vegetation. Roots are stacked to a depth of 3 feet; the heap is then covered with dried vegetation, soil at least 1 foot deep, and more dried vegetation to prevent washing. Sweet potato roots lost as much as 20% of their weight but were still palatable after 4 months storage. Only roots free of diseases and insects should be stored in this way.

Other methods of storage include stacking in sheds,<sup>55</sup> in well-ventilated storehouses,<sup>65</sup> on raised platforms,<sup>60</sup> in heaps on floors of barns or houses,<sup>73</sup> and in baskets or in roof spaces.<sup>66</sup>

It is generally recognized that these storage areas must be dry and well-ventilated. Roots must be free of pests. Often fires are built to provide some additional heat and roots may become slightly smoked;<sup>72</sup> in other areas roots may be covered with ashes.<sup>73</sup> Roots have been successfully stored in these types of structures for up to 4 weeks.<sup>66</sup>

Research results comparing clamps with house and pit storage in Papua New Guinea showed that sweet potatoes can be successfully stored for 30 to 50 days depending on location and exact structure.<sup>72</sup> Clamp storage is suggested only for the highland tropical areas where temperatures are lower. Lowland storage in Papua New Guinea was found to be just as efficient and less expensive in specially constructed houses utilizing a center fire for curing and hanging wet bags for maintaining high relative humidity. Storage in these houses was successful for 2 to 3 weeks.

It is apparent that storage presents a major problem to the availability of fresh high quality roots in the tropical marketplace. Without cool storage temperatures roots cannot be stored for more than 3 to 4 months under the most ideal available conditions and usually not for more than a few weeks. Sweet potato roots consistently decrease in quality even under ideal conditions. Under the less than ideal conditions available to most tropical growers, the changes are even more drastic.

The effects of storage on quality of fresh roots are increased rotting, shriveling, and pithiness due to weight and water loss, sprouting, and insect and rodent damage. Rotting, shriveling, and pithiness can be minimized by placing in storage only roots free of disease and injury.

Several methods have been used to decrease sprouting in storage. Sprouting was reduced in roots stored for 4 to 8 weeks by spraying the crop two weeks before harvest with a maleic hydrazide solution or putting freshly harvested roots in containers with confetti that had been treated with a methyl ester of naphthalene acetic acid in acetone.<sup>57</sup> No effect on weight loss was apparent. CIPC<sup>81</sup> and thiourea<sup>82</sup> have also been used for this purpose with variable success.

One of the most serious problems in storage of sweet potatoes is the sweet potato weevil. Hahn and Anot<sup>83</sup> report a weevil mortality rate of 89.5% if the storage temperature of sweet potato roots can be reduced to 20°C.<sup>83</sup> This would control reproduction and spread of the weevils in storage. In addition, they studied the effect of immersing sweet potato weevil-infested roots in water to prevent subsequent weevil damage in storage. Adult weevils died within 10 min of immersion in water at 52 or 62°C and within 30 min in water at 42°C. All larvae died within 10 min in hot water and within 12 hr in tap water. In the same study, they showed that weevils will survive in underground storage (buried) but length of survival depends on depth of storage. Quick death occurs within 5 cm of the soil surface (90% within 5 days). All weevils died within 3 days if kept at the soil surface. These mortality rates are probably due to high daytime temperatures occurring at those depths. At lower levels, insects survived longer but most were dead after eight days. In addition to the devastating effect on storage life and quality of roots, weevil infestation also results in the production of certain terpene compounds which make damaged roots unsuitable for human consumption.<sup>84</sup>

The effect of storage on nutrition has been studied extensively under temperate storage conditions. During storage starch is lost through metabolism, while the levels of the sugars increase. After 6 months' storage under ideal conditions, sucrose levels in two cultivars exceeded 5%, while in 'Jewel' fructose and glucose levels are greater than 1.3% (Table 2). The data in Table 2 illustrate changes during storage and variability between cultivars.

Some nitrogen 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.<sup>25</sup> 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. These roots were pithy, and microscopic examination showed a greatly decreased

number of starch grains, all of which were very small. Nonprotein nitrogen decreases during the early part of storage and then increases.<sup>25</sup>

Storage is reported to cause an increase in carotene<sup>42</sup> probably because the dry matter content of the roots decreases during storage. For orange-fleshed cultivars, this carotene content ranges from 5 to 20 mg of vitamin A per 100 g sweet potato.<sup>42</sup> For vitamin C in the cultivars Triumph and Nancy Hall, declines of 28 and 48%, respectively, were measured during storage.<sup>42</sup> Others have reported a loss of vitamin C during storage with values falling from 46 to 28 mg/100 g in 4 months.<sup>85</sup> Very little is known about the effect of storage on other vitamins.

Pectins decrease during storage from 5.1% fresh weight at harvest to 3.5% fresh weight after 6 months of storage.<sup>17</sup> Most of the decrease was due to changes in the hydrochloric acid-soluble fraction, while the ammonium oxalate-soluble and water-soluble fractions did not change significantly. The degree of esterification decreased during storage.<sup>17</sup>

#### IV. PREPARATION SYSTEMS AND THEIR EFFECT ON NUTRITIONAL COMPONENTS

The sweet potato is consumed throughout the tropics mainly as a home-prepared dish. Baking, boiling, steaming, and frying are the forms of heat processing used. Preparation practices vary according to the location. For example, in New Guinea, boiling and baking are common. In East Africa, roots are boiled unpeeled or roasted unpeeled in the ashes of a fire before being eaten, or less commonly, the sweet potato is boiled or fried with other vegetable or root crops. In Taiwan, most sweet potatoes are eaten boiled or boiled and mixed with white rice. Thus, the heat treatments used in the tropics are relatively mild when compared to canning or dehydration on heated drums. Consequently, nutrient retention should be excellent.

The preferred type of sweet potato in most of the world including the tropics is a root which when cooked has "dry" mouthfeel similar to the white potato (*Solanum* spp.), a white to light yellow flesh color, and a moderately sweet taste. Villareal<sup>86</sup> and co-workers at the Asian Vegetable Research and Development Center (AVRDC) established several categories of sweet potato, depending upon the utilization goal. For human consumption, as a staple part of the diet, the preferred type would be a white-fleshed, low sugar, high starch type, while a dessert type root would be an orange, moist-fleshed sweet type. The logic behind this classification is to increase consumption and take advantage of the potential for high per-unit productivity possible with this crop. The classification and goals seem to have a sound basis. The orange color and sweet taste relegate sweet potatoes to a special use category and limit its consumption. If cultivars are developed embodying the concept of high starch, white color, and low sugar, the sweet potato may indeed become accepted in the tropics as a staple item and, thus, serve to alleviate malnutrition. This strategy is based on the concept that a food, no matter how nutritious, is of no value unless it is eaten.

Textural properties of cooked sweet potato have been the subject of many investigations. Gore<sup>87,88</sup> reported that a diastase in sweet potato converted large amounts of starch into maltose during slow cooking. Later, workers<sup>89</sup> showed that sweet potato also contains an  $\alpha$ -amylase, Walter et al.<sup>90</sup> reported that the degree of moist (or dry) texture is due to the amount of starch left after baking, the amounts and sizes of dextrans and the amount of sugar present. All of these parameters are influenced by the activity of the amylolytic enzymes. Shen and Sterling<sup>13</sup> reported that amylolytic enzyme activity was less affected by heat in the moist type than in the dry type and that hemicellulosic fibrils of the cell wall break down more rapidly in the moist types. Thus, the degree of moist mouthfeel appears to be a function of the starch, dextrin, and sugar content of the cooked roots. These components, in turn, are dependent upon the activity of the amylolytic enzymes during cooking. There also appears to be some difference in the cell wall structure of moist and dry types.

The quality factor of color (or lack of color) has been extensively studied by plant breeders. Orange flesh has been shown to be negatively associated with high dry matter.<sup>91,92</sup> Thus, the goal of producing a white, high dry matter low sugar-type sweet potato is genetically favored. Conversely, development of orange-fleshed (high vitamin A) cultivars with high dry matter will be more difficult. A recent study<sup>93</sup> showed that acceptability varies according to nationality of the consumer, but that flavor (sweetness) and color are good quality characteristics for predicting general acceptability for steamed sweet potatoes.

Significant changes in the carbohydrate fraction occur during cooking. If the roots are cut into strips and rapidly cooked, significant amounts of starch remain after cooking (Table 9), whereas, if whole roots are baked, starch is more completely converted into dextrins and sugars.<sup>13,94,95</sup> In baked roots, the degree of starch conversion is dependent upon the cultivar. The "dry" types do not convert nearly as much starch during cooking as do the "moist" types.<sup>13,90,94,95</sup> It should be noted (Table 9) that maltose is the main sugar produced during cooking. The quantities of the other sugars decrease during cooking probably due to reaction between the reducing groups of the sugars and nitrogenous material. Sucrose, of course, would have to first undergo heat-mediated hydrolysis, thereby freeing the reducing groups for reaction. A paper which appeared in 1931<sup>96</sup> reported very dissimilar results. These workers examined sweet potatoes cooked by boiling, steaming, and baking. They found that sugars and dextrins decreased during cooking and starch content increased. We have no explanation for these results except that the methods used did not give an accurate measure of the various carbohydrates.

The changes in amylolytic carbohydrate levels are attributed to the action of  $\alpha$ - and  $\beta$ -amylases which are naturally present in the roots.<sup>89,97</sup> 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 postharvest treatment as well as conditions of cooking.<sup>90</sup> There appear to be no direct changes in nutritional value due to carbohydrate conversion. Baking and processing decrease the amount of pectins and the degree of esterification. However, no direct relationship was found that correlated rheological and sensory changes of baked sweet potatoes with changes in pectin content or molecular size of the pectins. Cooking decreases the amount of insoluble pectin and thereby decreases its role as a component of fiber. Cellulose is decreased slightly by cooking, and hemicellulose in 'Garnet' variety is significantly decreased (Table 4). In a dry-fleshed variety, 'Jersey', both components decreased slightly during baking.<sup>13</sup> There is no report of the effect of cooking on lignin content. The storage history of the root also affects fiber content. Hemicellulose of cooked sweet potatoes is about 40% less in roots stored 7 months before cooking than in roots cooked at harvest.<sup>95</sup>

Trypsin inhibitors are affected by cooking. Presently, the preponderance of evidence<sup>51,98</sup> indicates that any cooking process which causes the root to reach 90°C or more for several minutes will effectively inactivate the inhibitor. However, it has been found that a short-time, high-temperature treatment used in the preparation of animal feed is not an effective way to destroy the inhibitor.<sup>99</sup> The trypsin inhibitor has been implicated as a factor in the disease *Enteritis necroticans*.<sup>100</sup> However, unless the roots are consumed raw over long periods, it does not appear that the inhibitor from sweet potatoes could be a factor in the occurrence of this disease.

Since heat treatments used in the tropics are relatively mild, little damage to the protein nutritional quality is expected. Purcell and Walter<sup>101</sup> reported that baking caused less nutritional damage than did either canning or drum drying. The major nutritional change due to heat processing is the loss of lysine, probably via reaction with reducing groups of sugars.

Table 9  
 STARCH, FRUCTOSE, GLUCOSE, SUCROSE, AND TOTAL PECTIN CONTENT OF COOKED\* SWEET  
 POTATO STRIPS<sup>b,c</sup>

Time after harvest	Starch		Fructose		Glucose		Sucrose		Maltose	
	'Jewel'	'Centennial'	'Jewel'	'Centennial'	'Jewel'	'Centennial'	'Jewel'	'Centennial'	'Jewel'	'Centennial'
0 time	9.24A	9.83A	0.07D	0.05E	0.04C	0.03E	2.11C	2.58C	4.43A	5.46A
1 week	7.30B	6.91B	0.44C	0.17D	0.48B	0.11D	2.82B,C	3.51C	3.72A,B	4.61A,B
2 months	7.08B	7.28B	1.15A	1.27C	1.22A	0.30C	3.13B	4.40B	3.75A,B	4.35B
4 months	6.22B,C	3.98C	1.09A,B	0.56A	1.19A	0.60A	4.72A	5.20A	2.89B	2.10C
6 months	5.77C	3.75C	1.14A	0.46B	1.29A	0.55B	4.36A	5.32A	1.83C	2.48C
LSD 0.05	1.17	1.45	0.25	0.07	0.17	0.05	0.88	0.66	0.73	0.97

\* Grams in 100 g fresh weight. Roots cut into strips and steam 5 min.

<sup>b</sup> Means within columns followed by the same letter are not significantly different at  $p < 0.05$ .

<sup>c</sup> Walter and Hoover.<sup>34</sup>

It is likely that boiling caused some loss of the free amino acids through leaching, as has been reported<sup>102</sup> for roots canned in liquid.

Processing, including baking or boiling, of sweet potatoes may cause minor changes in carotenoid content (vitamin A value) due to heat-mediated isomerization.<sup>103</sup> Although pro-vitamin A has been shown in many processing studies to be remarkably heat-stable and to be only slightly affected by cooking or processing, there are reports of 20 to 25% losses during baking.<sup>104</sup> Consequently, losses of vitamin A value for 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 or leaching of water-soluble dry matter.

Vitamin C is lost during cooking. McNair reported<sup>104</sup> that from 12 to 20% of the vitamin C was lost during baking and boiling; neither cooking method appeared to be more destructive than the other. The lowest amounts of vitamin C have been shown<sup>105</sup> to be located in the outer 4 mm of tissue. Thus, peeling would not remove large amounts of the vitamin. It appears that the food preparation practices in the tropics would not cause serious loss of vitamin C.

Thiamin is the least heat-stable of the other three water-soluble vitamins with about 22% destroyed by either baking or boiling. Riboflavin and niacin appear to be stable to heat processing (Table 5). Very little is known about the levels of the other water-soluble vitamins, and about variability and effect of storage on all water-soluble vitamins except vitamin C. Except for beta-carotene, the fat-soluble vitamins have received little attention. One report cites the vitamin E content at 4 mg per 100 g.<sup>106</sup>

The sweet potato produces a series of stress metabolites in response to injury, physiological stimuli, and infectious agents. The most important, from a toxicological standpoint, are a family of furanoterpenoids<sup>107</sup> which have been shown to contain pulmonary toxins<sup>108</sup> and hepatotoxins.<sup>109</sup> These toxins are found in sweet potatoes infected by *Ceratocystis fimbriata* (black rot fungus) and by several *Fusarium* species (rot fungi). The toxins are also produced by cut injury or exposure of wounded tissue to mercuric chloride.<sup>109</sup> Since we are concerned in this chapter with the food supply, we shall discuss only toxin production via microbial infection and mechanical injury.

The most abundant of the toxins isolated from infected tissue, ipomeamarone, is a hepatotoxin. It has been shown<sup>110</sup> that baking destroyed more than 90% of the ipomeamarone and significant amounts of the lung edema toxin, 4-ipomeanol. This is in conflict with the report of Wilson et al.<sup>76</sup> who reported that cooking did not destroy significant amounts of ipomeamarone. From a human health perspective, the research results of Catalano et al.<sup>111</sup> are important. These workers reported peeling and trimming sweet potatoes from 3 to 10 mm beyond the infected area effectively reduces the toxin content to barely detectable or not detectable even when the infected tissue contained more than 1000 ppm. More importantly, normal commercial processing conditions of lye peeling, followed by trimming, also removed the toxin. In fact, no ipomeamarone has been detected in canned sweet potatoes randomly selected from the normal marketing chains.<sup>110</sup> The series of papers<sup>76,108,109</sup> regarding the presence of toxins in sweet potatoes apparently made the problem seem much worse than is actually the case. For example, Boyd and Wilson<sup>112</sup> reported that selected sweet potatoes from food markets in Nashville, Tenn., and Lexington, Ky., had high levels of ipomeamarone. However, no mention was made of the extent of decay and of whether or not trimming away diseased areas had any effect on toxin levels. It is highly unlikely that a consumer would eat a partially rotted or seriously blemished sweet potato without first trimming away the damaged area. The main danger then is that the infected roots might be fed to animals. In fact, in the U.S. the only documented cases of poisoning outside the laboratory have been for farm animals fed moldy sweet potatoes.<sup>76</sup>

## V. SUMMARY

Commercial potential of the sweet potato in the tropics has been limited by low yields, failure under tropical conditions to maintain quality of the fresh roots, and failure to reduce total losses due to the perishability of this crop. High costs of cooling and/or heating and ventilation make it impractical to use handling methods which have been shown to maximize storage life and minimize storage losses. Therefore, efforts should most likely be directed toward developing harvest and handling systems using the resources available in the tropics. Variety development should also proceed to identify types that are more suited to those resources. Proper handling and packaging (i.e., cardboard or wooden ventilated boxes instead of sacks), cultural practices to minimize diseases and even curing under ambient conditions can lead to a commercial product with improved quality and storage life for human consumption.<sup>78,113</sup>

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CRC Press, Inc.  
Boca Raton, Florida