INFLUENCE OF STORAGE TEMPERATURE ON CAROTENE, TOTAL CAROTENOIDS AND ASCORBIC ACID CONTENT OF SWEETPOTATOES

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(WITH FIVE FIGURES)

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Sweetpotatoes are exceeded in dollar value only by white potatoes and tomatoes among the vegetable crops in the United States. They have long been recognized as a valuable source of carbohydrates and as such they received attention as early as 1895 when HARRINGTON (**8**) published analyses of several varieties of sweetpotatoes and showed that they increased in sugars during storage. Abundant data on the effects of various factors on the carbohydrate content have been obtained (**9, 11, 14, 19, 23**). More recently, yellow-fleshed sweetpotatoes have been recognized as good sources of provitamin A (carotene) and both the yellow and the light-colored flesh are good sources of vitamin C (ascorbic acid). STEENBOCK (**25**) in 1919 reported that yellow sweetpotatoes were a good source of the "fat soluble vitamine." DELF (**4**) in 1922 reported on the antiscorbutic properties of sweetpotatoes and recommended the introduction of sweetpotatoes into the ration of the Rand miners of South Africa when fruits such as oranges, pineapples, and tangerines were not available. In 1935, MACLEOD and coworkers (**13**) reported on the effects of variety and storage on the vitamin A values of sweetpotatoes and in 1937 NEWTON and LOWRY (**20**) reported on the effect of storage on the vitamin C content.

The information regarding changes in the carotene and the ascorbic acid content of sweetpotatoes and the various factors affecting them (**10, 15, 16, 17, 18, 21, 24, 26**) has been rather confusing because of its apparently conflicting nature. Some have reported an increase in carotene during storage (**13**), some a decrease (**18**), and others no significant change (**24**). Some workers have concluded that three or four months' storage had no appreciable effect on the vitamin C content (**20**), while others concluded that sweetpotatoes stored for four to six months contributed insignificant amounts of vitamin C to the diet (**21**).

Several factors may be responsible for the varying results. With most chemical methods, some pigments that have no biological value are included with the carotene fraction, the amount varying with the method. Experimental conditions may alter the behavior of the roots; inadequate control of these conditions may lead to erroneous conclusions. Loss of weight through loss of both moisture and dry matter may cause an apparent increase in carotene. Determination of percentage of moisture only reveals little about the absolute losses of either moisture or dry matter. Additional information on the absolute loss in weight during the storage period is neces-

sary to determine whether an apparent increase in carotene is real or only apparent. The vitamin constituents occur in very small amounts and are accompanied by large quantities of foreign material; they are relatively unstable and their distribution in the root is far from uniform. Some roots may contain four times as much carotene as others of the same variety and three times as much in the proximal-end as in the distal-end of the same root (**5**). Among 30 individual roots of the Porto Rico variety the highest vitamin C content was 2.6 that of the lowest (**7**). Much of the work reported has been based on fewer roots than necessary to compensate adequately for such wide variations and insure that the results were due to the factors ascribed. The present studies are an attempt to clarify and amplify the information regarding the ascorbic acid and the carotenoid contents of sweetpotatoes and the various factors that affect them.

The first phase of the work was planned to determine 1. whether there is an actual increase in carotene during curing and storage and 2. the effects of curing and storage on the ascorbic acid content. The results published in 1948 (**6, 7**) showed quite conclusively that in the five varieties studied there was an increase in absolute amounts of carotene under the conditions of those studies and that while losses of ascorbic acid occurred during curing and storage, sweetpotatoes were still a good source of this vitamin. The second phase was planned to determine the effects of various factors that might influence the development and preservation of carotene and ascorbic acid and the conditions most favorable for the maximum amounts. Very little work on the effects of storage temperatures on the vitamin values of sweetpotatoes has been reported. This paper is a report on these effects. A general review of the literature was given in previous publications (**6, 7**) and will not be repeated here.

Materials and methods

Four varieties of sweetpotatoes were used in this study: Yellow Jersey, a dry-fleshed variety; Orange Little Stem, an intermediate type; Nancy Hall and Unit I Strain Porto Rico (called Porto Rico hereafter), moist-fleshed varieties. While the terms dry and moist are in common use in referring to the character of the flesh of sweetpotatoes, they are not indicative of the amount of moisture in the roots. Recently BOSWELL (**1**) substituted the term firm for dry and soft for moist as being more accurate in describing the character of the flesh. Both firm and soft refer to the cooked flesh. When raw, the flesh of all varieties is hard. The color of the flesh ranges from the creamy white or light yellow of the Yellow Jersey to the deep orange of the Orange Little Stem.

The sweetpotatoes were grown on a Chillum sandy loam at the Plant Industry Station, Beltsville, Maryland, in 1949. The plants were set on May 24 and 25 and were harvested between October 3 and 12 before any frost had occurred. Weather conditions for the period were near normal. Only one variety was harvested a day. The roots were washed, weighed

and placed in the curing room either the day harvested or the following day. They were cured at 85° F with high humidity for eight days and then transferred to constant temperature rooms held at 70, 60, 55, and 50° F with a relative humidity of 85%. Approximately five bushels of each variety were stored at each temperature. The uncured samples were held at 60° F overnight and analyzed the day after harvest. The cured samples were usually analyzed within two or three days after removal from the curing room to the storage room, and the stored samples at four- to six-week intervals during storage. Both carotenoid and ascorbic acid samples were taken from the same roots, the roots being split lengthwise and one half of each root being utilized for each of the two constituents.

The roots were washed at harvest to remove adhering soil and weighed individually; the weight of each root in grams was recorded on the root with an indelible pencil, and each root was reweighed at time of sampling. The analytical data can then be calculated back to the weight at harvest, and the results can be reported on the harvest weight basis.

The labile nature of vitamins and the small amount of root used per sample make it difficult to obtain a single sample that is representative of a large number of roots. For this reason, 10 replicates of five or more roots each were used. This number of roots is a larger sample than those generally used by other workers and with a few exceptions this procedure has given consistent results. By an analysis of variance, the significance of differences between and within treatments can be determined. Samples departing significantly at the 1% level from the curves as drawn in the figures are marked with a double asterisk.

For the carotenoid determinations, longitudinal sections from each of five unpeeled roots were ground in a food chopper and mixed thoroughly. Duplicate 20-gram samples were then analyzed by the WALL and KELLEY method (**27**). The carotene content was separated from the other carotenoids by chromatographing an aliquot of the petroleum-ether extract. Total carotenoids were determined on a separate portion of the extract without chromatographing. Both were read in a photoelectric colorimeter with a 440-millimicron filter. The results of the duplicates were averaged and the amount reported is the average of the 10 replicates calculated back to the weight at harvest.

Samples for ascorbic acid were taken with a cork borer from the midsection of the root as described in detail in a previous publication (**7**). Duplicate 50-gram samples were extracted with 350 ml. of 0.4% oxalic acid in a Waring Blendor according to the method of LOEFFLER and PONTING (**12**). The ascorbic acid content of the extract was determined in a photoelectric colorimeter and color and turbidity were compensated for when necessary. Duplicate samples were averaged and the amount reported is the average of the 10 replicates. All results for ascorbic acid are reported on the fresh-weight basis at time of analysis.

Samples for moisture determinations were taken in triplicate from two

of the 10 replicates used in the carotene analysis. The tissue was dried for 24 hours at 158° F in an electric oven, followed by 24 hours at the same temperature under vacuum.

Results

The carotene, total carotenoids, and ascorbic acid content of four varieties of sweetpotatoes, at harvest, after curing and during storage at 50, 55, 60, and 70° F are shown in figures 1 to 4. From these results, it is evident that temperature plays an important part in carotenoid changes in storage. At 50° F there was little if any increase in carotene or total pigments in any of the varieties studied. Instead there was a decrease which was most pro-

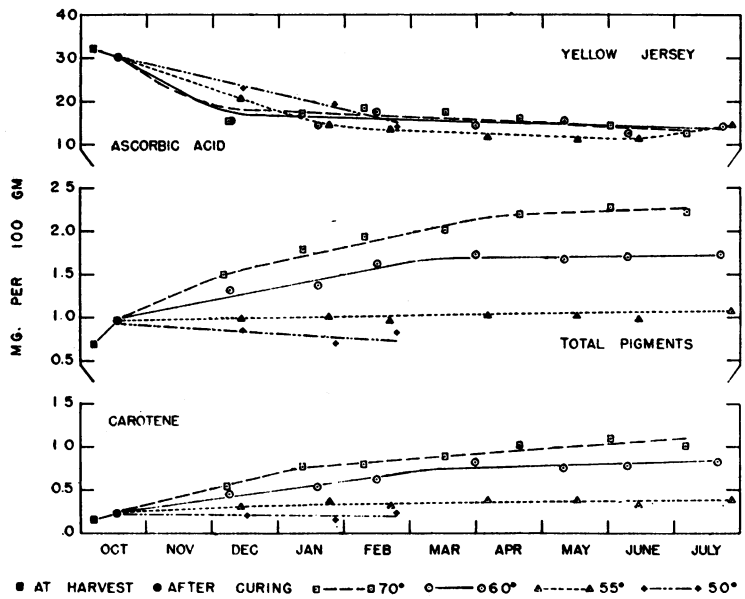

FIG. 1. Carotene, total carotenoid pigments, and ascorbic acid content of Yellow Jersey sweetpotatoes at harvest, after curing, and during storage at 50, 55, 60, and 70° F.

nounced, and statistically highly significant, in Orange Little Stem. At 55° F, the temperature usually recommended for long holding of sweetpotatoes, there was little change in the carotenoid pigments. At 60° F there was an increase of nutritional importance in all varieties except Nancy Hall. This variety slowly lost carotene and total pigments during storage at all temperatures. At 70° F the carotene and total carotenoids increased less rapidly than at 60° F except in Yellow Jersey (fig. 1). Storage temperatures were of less importance in effecting ascorbic acid content. While temperature had some effect in early storage the tendency was for the ascorbic acid content to approach a common level at the different temperatures before the storage season was over.

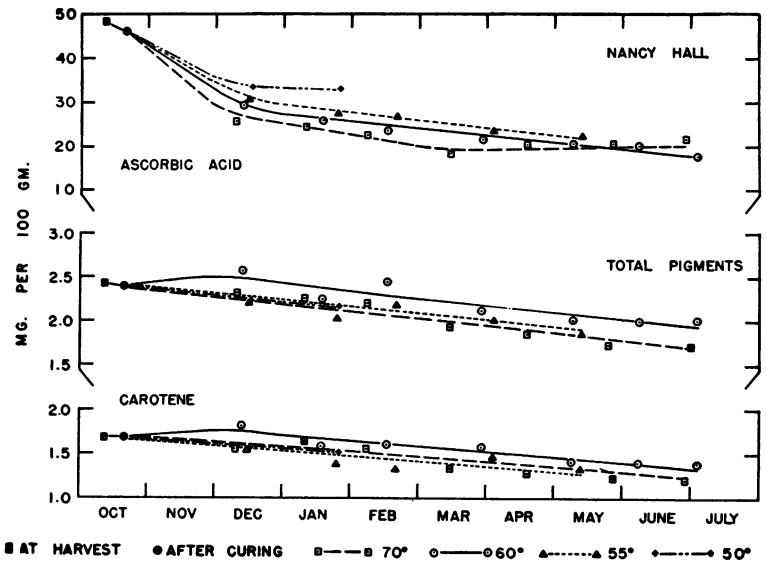

FIG. 2. Carotene, total carotenoid pigments, and ascorbic acid content of Nancy Hall sweetpotatoes at harvest, after curing, and during storage at 50, 55, 60, and 70° F.

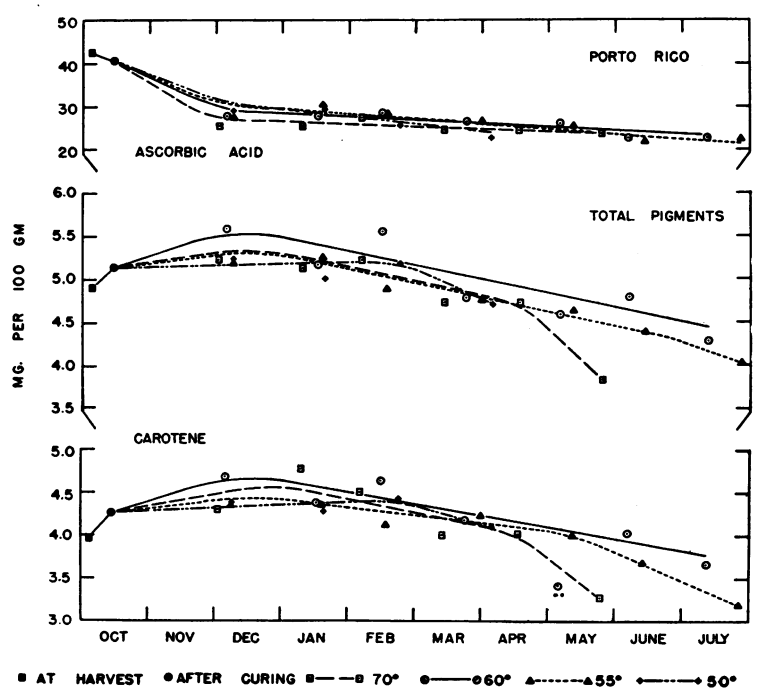

FIG. 3. Carotene, total carotenoid pigments, and ascorbic acid content of Porto Rico sweetpotatoes at harvest, after curing, and during storage at 50, 55, 60, and 70° F.

Variety is also an important factor in determining changes in the carotenoid content during storage. Yellow Jersey, the palest variety at harvest, showed a maximum increase in carotene during curing and storage. Orange Little Stem (fig. 4), the deepest colored variety, increased only 25% but this represented more in absolute amount than the larger percentage increase in Yellow Jersey. Nancy Hall (fig. 2), an intermediately colored variety, increased little if any after harvest.

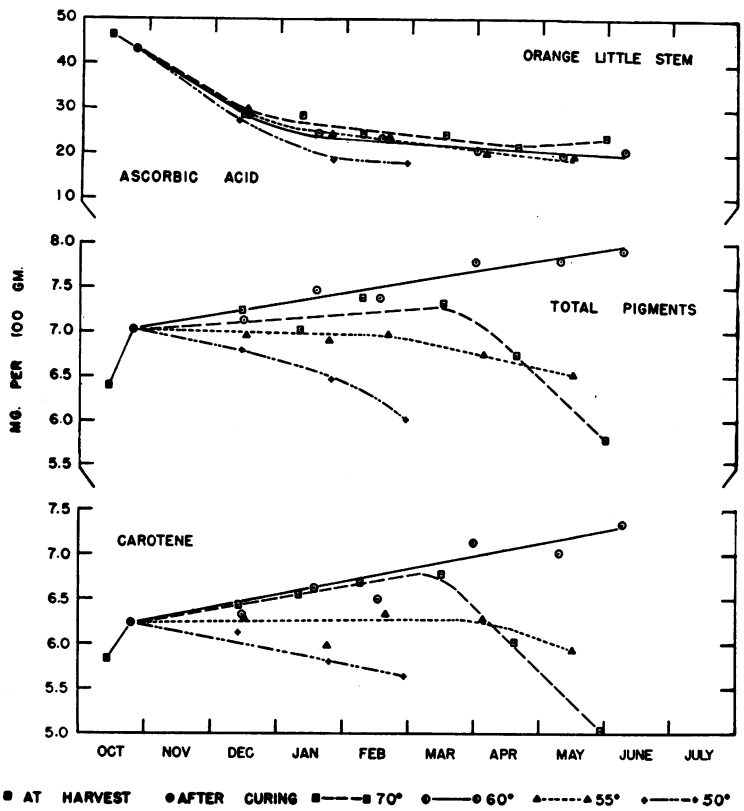

FIG. 4. Carotene, total carotenoid pigments, and ascorbic acid content of Orange Little Stem sweetpotatoes at harvest, after curing, and during storage at 50, 55, 60, and 70° F.

Late in the storage season it was observed that the Porto Rico sweetpotatoes used in this study were infected with internal cork. No indication of this disorder was observed at harvest, shortly after curing, or early in the storage period, but by late May, 65% of the roots stored at 70° F showed the disease as compared with 7% at the lower temperatures (**28**). Intracellular changes doubtless take place prior to the death of the cell and the accompanying visual evidence of the disease. Carotenoids are less stable than most other cell constituents and some loss would probably occur in the infected areas even before these areas could be recognized. If such infected

tissue were included in a sample, the carotenoid content of that sample would be correspondingly less than in normal tissue. It may therefore be questioned whether these results (fig. 3) are typical for this variety. In this respect the following observations are pertinent: 1. No indications of internal cork were observed at harvest, shortly after curing, or early in the storage period. 2. The increase in carotenoids during curing and in early storage at the higher temperatures is in agreement with previous results (**6**) and with other varieties used in the present study. 3. The failure of the carotenoids to increase appreciably at the lower storage temperatures agrees with the results from the other varieties used in this study. 4. Sound tissue in affected roots gave no indication of reduced carotenoid content as compared with tissue in roots showing no infection, *i.e.*, non-affected tissue in infected roots behaved normally in respect to carotenoid metabolism. 5. There were significant losses in carotenoid pigments late in the storage period, the greatest loss occurred, and the greatest amount of internal cork developed, in roots stored at 70° F.

From the results reported (figs. 1 to 4) it would appear that Yellow Jersey and Orange Little Stem are more sensitive to changes in storage temperatures than are Nancy Hall and Porto Rico. Nancy Hall did not increase significantly in carotenoid pigments during storage and the differences observed in this variety apparently are due to differences in rate of destruction at the different temperatures. Judging from this variety alone a storage temperature of 60° F would appear to be less destructive of carotene than the other temperatures used. With the other varieties the rate of synthesis, as well as the rate of destruction is a factor and the final result is dependent upon the algebraic sum of the two processes.

The different varieties of sweetpotatoes differed greatly in the color of the flesh. This difference in color is of major importance since most of the increase in color is due to carotene, a precursor of vitamin A. This is shown in table I in which the different varieties are listed from left to right, in

TABLE I

EFFECT OF VARIETY AND STORAGE TEMPERATURE ON THE PERCENTAGE OF CAROTENE IN THE CAROTENOID PIGMENTS OF SWEETPOTATOES.

Treatment	Times sampled	Carotene/total carotenoids × 100				
		Yellow Jersey	Nancy Hall	Porto Rico	Orange Little Stem	Average
At harvest		21.4	68.7	81.0	91.1	65.6
After curing		22.8	69.6	82.9	88.7	66.0
Storage temp. (°F)						
70	6	42.9	69.9	86.4	90.2	72.4
60	6	41.6	69.9	83.2	89.9	71.2
55	5	34.8	68.0	85.4	90.3	69.6
50	2	22.8	70.6	83.9	89.9	66.8
Average for 4 temperatures		35.5	69.6	84.7	90.1	

order of increasing color intensity, and the carotene is expressed as a percentage of the total carotenoid pigments. The post-harvest increases are also primarily carotene as evidenced by the higher percentage figures during storage. Even within individual roots the more deeply colored areas contained a higher percentage of carotene than the paler areas. For example, carotenoids formed in Yellow Jersey during storage sometimes results in yellow bands interspersed with lighter colored areas. Tissue taken from these deeply pigmented areas was found to contain as much as 7.77 mg. of carotenoids per 100 gm., 81% of which was carotene. Our regular sample of the same lot, taken at the same time, contained 1.94 mg. of which 41%

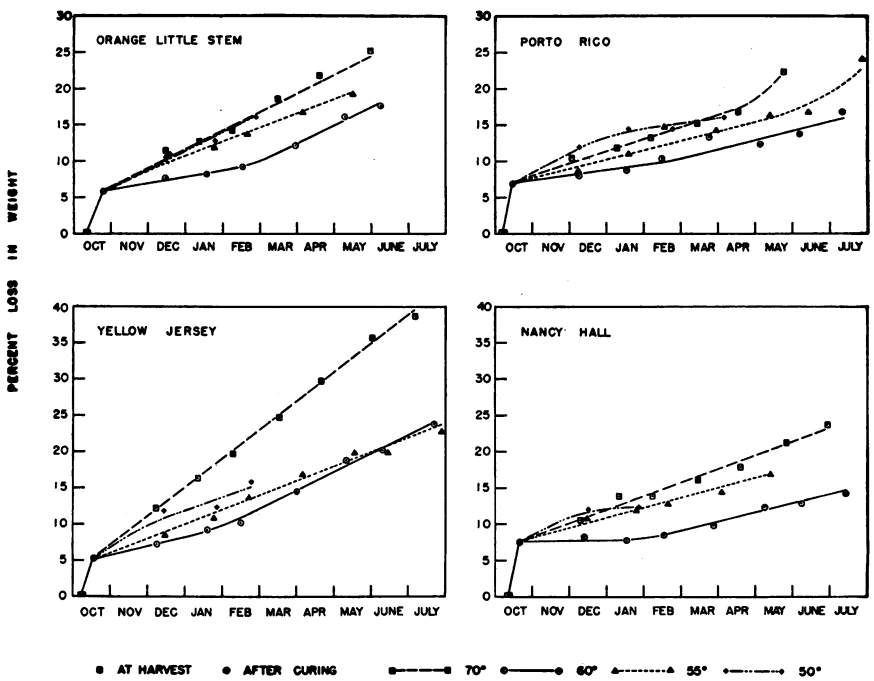

FIG. 5. Loss in weight of four varieties of sweetpotatoes during curing and in storage at 50, 55, 60, and 70° F.

was carotene. The same variety at harvest contained 0.68 mg. of carotenoids, 21% of which was carotene. At harvest Orange Little Stem, the deepest colored variety, contained about the same amount of non-carotene pigments, nine times as much total pigments, and nearly forty times as much carotene as did the Yellow Jersey.

In addition to the changes in carotenoid and ascorbic acid content some other effects of the different storage temperatures were noted. The loss in weight is shown in figure 5. The four varieties were held in the same rooms under comparable conditions with the air circulated by fans. Loss in weight was determined as described under Materials and Methods and no roots showing external decay were included. While the relative humidity was

held at 85% at all temperatures, the vapor pressure deficit, *i.e.*, the evaporating power of the air was greater at the higher temperatures and greater moisture losses might also be expected. The losses in weight were in general greatest at the two extremes of the storage range, 70 and 50° F. The least occurred at 60° F and the 55° F lots were intermediate. The greater loss at 70° F was probably largely due to sprouting, which occurred at this temperature, and perhaps to a less degree to the higher respiration rate. At 50° F there was no sprouting and the greater loss in weight at this temperature may be an indication that 50° F is too low for normal functioning of the roots. Less decay occurred at 60° F and the general appearance of the roots was perhaps best at this temperature. The smaller loss in weight is apparently a reflection of the more favorable storage temperature.

Relative loss in weight also seems to be a varietal characteristic to some extent, and is probably associated with rate of respiration. Although the percentage of moisture was relatively stable during storage (table II) Yellow Jersey stored at 60° F had lost approximately 19% in weight by May

TABLE II

EFFECT OF VARIETY AND STORAGE TEMPERATURE ON MOISTURE CONTENT OF SWEETPOTATOES.

Treatment	Times sampled	Varieties				
		Yellow Jersey	Nancy Hall	Porto Rico	Orange Little Stem	Average
		%	%	%	%	%
At harvest		71.2	66.5	69.6	74.1	70.4
After curing		69.8	63.7	68.3	73.4	68.8
Storage temp. (°F)						
70	6	68.3	65.2	69.3	75.0	69.4
60	6	70.2	66.1	69.3	75.2	70.2
55	5	70.4	64.8	68.5	73.6	69.3
50	2	70.5	65.3	68.4	72.5	69.2
Average for 4 temperatures		69.8	65.3	68.9	74.1	

as compared with 16% for Orange Little Stem, and 12% for Porto Rico and Nancy Hall.

In 1915 HASSELBRING and HAWKINS (9) reported that there was little change in the percentage of moisture of sweetpotatoes during storage. Data in table II show that temperature of storage also has little effect on the moisture content. Different varieties ranged from 65% in Nancy Hall, average all storage temperatures, to 74% in Orange Little Stem. Yet the combined averages for the four varieties stored at the different temperatures varied within one per cent. In products stored near 32° F much of the loss in weight is often due to loss of moisture. In sweetpotatoes which are stored at higher temperatures, loss of dry matter used in respiration is also of importance. The maximum losses in weight ranged from 22 to 38% in

the different varieties. Since the moisture content remained relatively constant, roughly one fourth to one third of the loss in weight was loss of dry matter.

Very late in storage, sweetpotatoes of most varieties that do not succumb to more serious diseases earlier usually show some pithy breakdown. Some varieties have a shorter storage life than others. Orange Little Stem is subject to pithy breakdown early in storage. It was observed in this variety first on December 16 in the 50° F storage, and in January at 55° F but not at the higher temperatures. In March some breakdown was evident at all temperatures, but was least noticeable at 60° F. While it was observed earlier at 55° F than at 70° F, the development, once under way, was more rapid at the higher temperature, and the carotenoid content decreased rapidly as breakdown progressed.

Discussion

The post-harvest increase in carotene in sweetpotatoes is analogous to the post-harvest increase in lycopene in tomatoes harvested before fully ripe. While both carotene and lycopene are carotenoid pigments, only carotene is of nutritional significance as a precursor of vitamin A.

The pigments of sweetpotatoes are composed of both carotene and non-carotene carotenoids (**5**). The non-carotene fraction probably includes pigments in the intermediate stages of synthesis and of degradation of the carotene molecule, together with any other non-carotene carotenoids that may be present. Since this fraction is usually present in amounts well below 1 mg. per 100 gm. of tissue the structural components and the decomposition products of the carotene molecule may be the major part of the non-carotene fraction. It seems likely that this portion of the non-carotene pigments may be in a more or less continuous state of flux, varying not only in amounts but in identity from time to time as synthesis and degradation progress. Because of the difficulty of separating, eluting, and purifying the individual constituents, no attempt was made to identify them.

SHERMAN and KOEHN (**22**) reported only 0.012% of the total pigments of the Porto Rico variety to be xanthophyll and concluded that this variety is, for practical purposes, devoid of pigments other than beta-carotene. Earlier we (**6**) had presented data, showing that approximately 20% of the total pigments were non-carotene carotenoids. This apparent difference in relative amounts of the non-carotene fraction Sherman and Koehn ascribed to our procedure of determining carotene on the chromatographed extracts and the total pigments on the unchromatographed extracts and designating the difference between the two as non-carotene pigments. This procedure, they said, "does not take into account destruction of carotene during chromatographing or the difficulty of making a quantitative transfer of the whole solution to the chromatograph tube." In publishing the method, WALL and KELLEY (**27**) presented data with an average recovery of 99.5% of carotene added to plant samples, showing that there is little if any de-

struction of carotene during chromatographing. In the procedure employed (6) aliquots of the extracts were used for chromatographing, a transfer pipette being used to avoid loss in transfer. Total pigments were determined from a portion of the remaining extract simply as a matter of convenience making it unnecessary to elute the tightly held pigments. The results are comparable, as shown in table III where values from 10 samples of Porto Rico extracts determined by the two procedures are presented.

An examination of the data of Sherman and Koehn reveals that their results are not greatly different from ours. Of the 5.7872 gm. of carotene (carotenoids) which they calculated to be present in their original material, they recovered, crystalline and in oil solution, 4.2142 gm. or 73% as carotene. Additional non-carotene carotenoids were present in the oil solution to the extent of 0.5302 gm. bringing the total carotenoids recovered to 4.7444 gm. or 82% of the total. Because of its unreliability phasic separation has

TABLE III

EFFECTS OF CHROMATOGRAPHING VS. NOT CHROMATOGRAPHING ON THE APPARENT AMOUNTS OF NON-CAROTENE PIGMENTS IN PORTO RICO SWEETPOTATOES.

	Milligrams per 100 grams in sample no.										Average
	1	2	3	4	5	6	7	8	9	10	
Extract not chromatographed	4.30	6.40	4.82	2.82	5.64	4.96	5.64	3.55	5.32	4.72	4.817
Carotene	3.65	5.36	4.24	2.12	4.82	4.15	5.04	3.10	4.76	4.09	4.133
Other pigments by difference	.65	1.04	.58	.70	.82	.81	.60	.45	.56	.63	.684
Other pigments eluted from chromatograph tube	.59	1.02	.58	.76	.92	.76	.54	.52	.59	.64	.692

been largely replaced in carotene studies by chromatography. The 0.54 mg. of material recovered by Sherman and Koehn in their methanol solution is relatively insignificant as compared with the 530 mg. of non-carotene pigments present in their oil solution. The latter amounts to 11.1% of the carotenoids recovered (rather than 0.012% as Sherman and Koehn reported for xanthophyll) and is comparable with that in our samples, individual ones of which sometimes ran as high as 90% carotene. Since they recovered only 82% of the carotenoids originally present, the composition of the remainder is unknown. However, it seems likely that a relatively high percentage of non-carotene carotenoids may have been included in the unrecovered fraction. In Sherman and Koehn's preparation of crystalline carotene the first two or three extracts crystallized were contaminated with and inseparable from sterols; later extracts were essentially free from them. The sterols, in common with many of the non-carotene carotenoids, contain hydroxyl groupings in the molecule while carotene does not. This suggests

that the conditions which resulted in complete separation and removal of the sterols might also have been more favorable for removal of non-carotene carotenoids. If true, the non-carotene carotenoids of this fraction might well be sufficient to bring the total non-carotene pigments well within the averages found in our studies instead of in the lower range.

Other workers have also reported non-carotene pigments in Porto Rico sweetpotatoes. MATLACK (**15**) separated the pigments by shaking a petroleum ether extract repeatedly with 85% alcohol and identified violaxanthin from the alcohol phase. The recrystallized pigments of the ether solution showed four bands when chromatographed; the lower and predominant band he identified as beta-carotene, but the others were not identified. CALLISON *et al.* (**2**) working with cooked Porto Rico sweetpotatoes, reported that beta-carotene was the only biologically active carotenoid present and constituted 81.8% of the yellow pigments. MILLER *et al.* (**17**) reported very high ratios of carotene to total pigments; depth of color of the flesh had little effect on their ratios. Since approximately one-fourth of their samples showed 1 to 8% more carotene than total carotenoids some error must have been involved in their results.

Storage of sweetpotatoes at 60° F is much more favorable to carotene production and preservation than the lower temperatures. This temperature is somewhat higher than generally recommended for sweetpotato storage. Perhaps the most common recommendation is, or was until recently, 50 to 55° F. However, recent studies (**3**) have shown 50° F to be definitely unfavorable and 55° F much superior to 50° F in reducing decay. During these studies extending over the past several years a 60° F constant storage temperature has been quite satisfactory, and when both 55 and 60° F temperatures have been used the latter has been as good or slightly superior in reducing decay and preserving the original appearance and general condition of the roots. Sprouting, even when the roots were held until late July, has not been a serious problem. Previous evidence of chilling injury to sweetpotatoes stored at 50° F has been the greater susceptibility of the roots to pathogenic organisms. Now the failure to synthesize carotenoid pigments and the tendency for the carotenoids to decrease in amounts may be added as effects of chilling.

Summary

The carotene, total carotenoids, ascorbic acid, and moisture content, and the weights of Yellow Jersey, Nancy Hall, Porto Rico (Unit I Strain), and Orange Little Stem sweetpotatoes were determined at harvest, after curing, and at intervals during storage at 50, 55, 60, and 70° F.

Storage temperature and variety are major factors in determining the behavior of the carotenoid pigments during storage.

Nancy Hall sweetpotatoes decreased in carotene and total carotenoid pigments during storage at all temperatures. The other varieties studied tended to decrease in carotene and total pigments when stored at 50° F. At

55° F there was little change while at 60° F and 70° F the increases were appreciable and of nutritional significance.

The ascorbic acid content of sweetpotatoes was not greatly affected by storage temperatures, the tendency in general being for it to decrease fairly rapidly during the first two to three months in storage and to approach a common level before the storage season was over. The average ascorbic acid content after two to three months in storage was about one half to two thirds that at harvest.

The temperature of storage had little effect on the moisture content of sweetpotatoes. When held at 85% relative humidity losses in weight were least at 60° F, slightly greater at 55° F, and still greater at 50 and 70° F.

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