SUGAR AND CAROTENE CONTENTS OF CARROTS AS INFLUENCED BY VARIETY, SOIL TYPE AND STORAGE

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

WERNER JACOB LIPTON

1953

This is to certify that the

thesis entitled

Sugar and Carotene Contents of Carrots As Influenced by Variety, Soil Type and Storage

presented by

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has been accepted towards fulfillment of the requirements for

M. S. degree in Horticulture

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Date May 27, 1953

O-169

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By

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A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Horticulture

Year 1953

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation for the support and encouragement received from Dr. Robert L. Carolus and Dr. Donald H. Dewey and for their guidance and active assistance throughout the course of this investigation.

Special thanks are due to Dr. E. J. Benne and his staff of the Agricultural Chemistry Department who made available laboratory space and furnished valuable advice. The writer is also indebted to Dr. C. L. Bedford of the Food Technology Department for his helpful suggestions.

This study was partially supported from Research and Marketing Act Funds (Project 68) and by the Kroger Company, Cincinnati 2, Ohio.

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INTRODUCTION

The carrot is an important vegetable. It is easily grown, highly palatable and provides several of the important nutritional requirements of the human diet. Two constituents that are generously furnished are sugars, which are an important source of energy, and carotene, which is a precursor of vitamin A which is generally considered to be essential for proper development of the epithelial tissues.

The popularity of carrots in the diet gives rise to a year-round demand. The supply available during the winter months in Michigan is either shipped in from regions favorable to fall and winter production or locally grown and held in storage. Many consumers seem to prefer the "garden-fresh" appearance of carrots from fall and winter production areas so that the demand for the locally grown stored product has been reduced.

Michigan produced, stored carrots are grown on both muck and mineral soils. The quality of the carrots from these two sources may vary considerably. It has seemed desirable, therefore, to compare the sugar and carotene contents of shipped-in "garden-fresh" carrots with stored carrots of several varieties grown on both muck and mineral soil.

The available information concerning the quality of northern-grown carrots is not very helpful, mainly, because investigators have not obtained uniform results and have frequently arrived at dissimilar conclusions. The disagreements center around the question of possible increases or decreases in sugar and carotene content, and it has been noted that the disagreements center on the methods of presenting the data. Both the sugar and carotene contents may be extremely variable for a given lot of carrots depending upon whether or not the data are based on their fresh weight at analysis, on their dry weight, or on their original fresh weight. One solution is to express the data on all three bases of calculation. This should aid in differentiating between actual and apparent changes in sugar and carotene content which occur in carrots during storage.

REVIEW OF LITERATURE

The changes in sugar and carotene content of carrots which occur during storage have been studied rather extensively, but the results have been variable and the conclusions somewhat indefinite. These variations may have been due to differences in the objectives of the studies, in the procedures of analysis or in the method of presentation of results. Variable environmental conditions may also have contributed to the divergence of the results reported.

Sugar in Carrots

The chemical transformations of sugars during storage are important because they directly affect the edible quality of the carrots. These changes were investigated as early as 1927 by Hasselbring. He reported, as cited by Platenius (1934), that some sucrose and polysaccharides in carrots stored at temperatures of 32° to 34° F and 39° to 40° F changed to reducing sugars during the first ten weeks of storage, but later reached an equilibrium. Platenius (1934), investigating these changes further, found that sucrose in carrots undergoes a reversible reaction during storage; there being a transformation to reducing sugars early in the storage period and the reverse taking place later during storage.

He was not successful in differentiating between glucose and fructose by employing the osazone method for the detection of fructose and therefore concluded that the reducing sugar was principally glucose. Werner (1941) was also of this opinion as a result of tests with the variety Chantenay, but he did not present evidence to support this theory. More recent sutdies by Rygg (1945) show that nearly equal amounts of glucose and fructose occur in the reducing sugars of Imperator and Danvers carrots stored for as long as 15 days. He obtained positive results with the Flueckiger test, as well as the Jackson and Mathews, and osazone tests, but he casts doubt upon the validity of the last named method. It seems likely that the variations in results obtained in these cases were due to differences in the chemical methods employed rather than to differences in varieties and storage conditions. The findings of Rygg appear to be logical provided the hydrolysis of sucrose in carrots follows the generally accepted pattern of one molecule of glucose and one of fructose from each molecule of sucrose.

The changes in total sugar content of carrots in storage are of primary significance because they determine to a large extent the edible quality of carrots. Platenius (1934) concluded that the total amount of sugars changed little during five months of storage when the results were based on dry weight. It is noteworthy, however, that his final readings of sugar content were at least 5 percent higher than the initial determinations at all temperatures below 50° F. In the same paper, Platenius contended that differences as great as 2 percent in water content or dry weight are unlikely to affect the quality of carrots materially. There is doubt that these changes in dry weight *per se* would affect the quality appreciably; however, for carrots having a dry weight of about 12 percent, a 2 percent difference in dry matter would considerably affect the sugar values based on the dry weight. This can be shown as follows: carrots with 11.77 percent dry matter and a sugar content of 6.15 percent on the fresh-weight basis actually contain 52.25 percent sugar on the dry-weight basis, however, if the dry matter content were either 2 percent smaller or 2 percent greater, the figures become 62.95 percent and 44.66 percent sugar, respectively. Thus, carrots relatively high in sugars and dry matter would appear to be of lower quality than carrots of the same or a lower sugar content coupled with a lower dry weight. It is therefore doubtful if data based on dry weight, especially with reference to sugar, form a reliable basis for an evaluation of edible quality. Data based on the fresh weight at analysis would appear to be more valid.

Denny, Thornton and Schroeder (1944) found that carrots (variety not specified) lost sucrose and gained glucose during storage of 16 days at 5° C and under high humidity. They did not summarize the total amounts of sugar at the beginning and end of their determinations. When this is done, their data show that the total sugar content remained practically unchanged. The authors did not state the basis for the calculations of sugar content, but it appears that the data were based on the fresh weight at the time of analysis. Since some respiration and transpiration likely occurred under their test conditions, it is possible that the sugar changes reported were apparent rather than actual.

Carotene in Carrots

There has been considerable interest in the carotene of carrots because of its close relationship to vitamin A. Consequently, its synthesis in the growing root as well as its fate in the stored product has been the subject of many investigations. The age of the plant has been reported as an important factor determining the amount of carotene in carrots. The studies of Barnes (1936), Smith *et al.* (1944), Hansen (1945), Brown (1947) and Lantz (1947) show that carotene increased consistently as the growing season progressed. Their data show that the conclusions were valid for the carotene content calculated on either the fresh or dry weight basis. A slightly smaller increase was noted toward the end of the growing season, however, on the dry weight basis. This levelling-off tendency was attributed by Smith *et al.* to the increase in dry weight toward the end of the growing season.

The growing temperatures influence the carotene content of carrots and in regard to this, Barnes (1936) reported that carrots developed their best color at 60° to 70° F and less color was evident at temperatures above and below this range. Hansen (1945) found that carrots grown in the coastal region of Oregon and at altitudes of 4200 feet were slightly higher in carotene than the roots from intermediate regions and he ascribed this difference to the cooler climate of the former areas. Smith et al. (1944) noted that carrots grown in the south row of experimental plots in the fall in Arizona were higher in carotene content than those grown in the north row. They believed this difference was due to variations in soil temperature although no data were given to substantiate this view.

Soil moisture seems to affect the carotene content of the roots considerably, but the effects may be dependent upon the method of expressing the carotene content. For example, Barnes (1936) reported that roots from high moisture plots were lower in carotene content than those from low moisture plots if the results were based on fresh weight. These differences were not evident, however, when results were based on dry weight. Miller (1934) had previously observed color differences and concluded that high moisture adversely affects carotene formation. Lantz (1949) compared data of two years with different amounts of irrigation each year and had found that the higher moisture had a detrimental effect upon the carotene content of carrots. It is unlikely that data from different years are sufficient evidence to conclude that the water supply was the primary factor.

The findings of various workers show great variation in the changes in carotene which may take place during storage, ranging from increased amounts through no changes to decreases. Increases were obtained by Brown (1947) with the carotene values based on dry weight and by McKillican (1948) with reference to both the original fresh weight and the dry weight. Kelley et al. (1950) state that the carotene content increased 2 to 11 percent in outdoor storage for one month, whereas after two additional months of storage under similar conditions, there was a 12 percent decrease. Their data were calculated on the fresh weight at analysis. Rygg (1952), after storing carrots for 15 days, obtained increased carotene values when the calculations were based on fresh weight at analysis. Earlier, the same author (1949) observed a consistent increase in the carotenoids of carrots stored one month when the carotene content was calculated on the original fresh weight. He further showed that the increase was more rapid at room temperature than at lower temperatures and that the increase in older carrots was less than in younger roots. The maximum increase occurred during the first few days after harvest when conditions for good aeration were provided. In contrast, Taylor and Russel (1938) found better retention of carotene in alfalfa at low temperatures with the exclusion of air. Ezell et al. (1948, 1952) determined absolute increases of carotene in sweet potatoes upon storage. Garcia (1944) has suggested, without presenting any supporting data, that the increases in carotene of carrots during storage may be caused by moisture changes, or by actual synthesis of carotene or some other substance determined as carotene in the chemical analyses.

The evidence for the absence of a change or the loss of carotene is not as strong as the evidence for increased amounts. Werner (1941), in experiments similar to those of Brown, McKillican and Kelly and using the fresh weight at analysis as the basis, reported that there were no changes in the amount of carotene until the carrots sprouted late in spring when a slight decrease occurred. The two varieties tested, Chantenay and Nantes, behaved similarly when stored in moist sand at 38° to 40° F, but the latter variety was always lower in carotene content than the former. The high moisture conditions apparently decreased water loss to a minimum and therefore no noticeable concentration of carotene took place. Lee and Tapley (1947) report that the variety Chantenay dropped slightly in carotene value toward spring, whereas, the carotene content of Nantes remained practically constant. Their data were based on the fresh weight at the time of analysis and agree quite closely with those of Werner in that Chantenay was always higher in carotene content than Nantes. The above results indicate that the decomposition or transformation of carotene proceeded at a rate equal to that of the water loss. If this were not true, the carotene would become concentrated as water was lost and an apparent increase in carotene would be evident. The results obtained by Lantz (1949) with Imperator carrots are presented several ways in order to distinguish between actual and apparent changes in carotene content. They are based on the fresh weight at anlaysis, on the dry weight and on the original fresh weight. When based on fresh weight at analysis, an increase in carotene of 46 percent was recorded, whereas, calculated to the dry weight, the gain amounted to 28 percent. On the original fresh weight basis the increase was only 6 percent, an amount not considered significant by the author.

The carotene changes in stored vegetables are probably different than those taking place in a growing plant but the basic mechanism of the changes is likely similar for both. Some of the theories advanced in respect to growing plants are noteworthy and their application to the storage changes should be considered. Rygg (1949) stated that phytofluene, a phosphorescent pigment, may be a precursor of carotene in plants. He based this idea upon the studies of Bonner _et al_. (1946) and Zechmeister and Sandoval (1946). His review of the studies of Roberts and Southwick (1948) caused him to suggest that vitamin A may be a precursor as well as a derivative of carotene which seems to imply that he believes vitamin A to be a constituent of plants.

Substantiation of the theories of Roberts and Southwick and Rygg would help explain the differences in results reported by other authors regarding the changes in carotene content of stored carrots. A breakdown of carotene to vitamin A in carrot roots could result in a lower carotene content without adversely affecting the nutritive value.

METHODS AND MATERIALS

Nutritional quality was determined by a quantitative analysis of sugar and carotene contents. These were expressed on three bases: (1) fresh weight of the carrot sample at the time of analysis, (2) dry weight of a comparable sample taken at the time of analysis and held in a hot air oven at 100° F for 24 hours, and (3) fresh weight of the carrots at the time they were selected for storage. The last method of expression, subsequently called "content based on original fresh weight", was used for stored carrots and was calculated by dividing the product of the carotene content in micrograms per gram of fresh weight and the weight of the lot of carrots at analysis by the weight of the lot prior to storage. Results based on this method of calculation are not affected by the weight loss of the roots during storage.

The experimental lots of carrots weighed 650 to 1000 grams when fresh, depending upon treatment and time of analysis. They were weighed to the nearest gram and allowance was made for weight changes of the container when necessary. The roots were prepared for analysis by quartering lengthwise and one quarter of each root was used. They were then macerated in a food grinder and samples were taken for carotene and sugar analysis and for dry weight determinations.

The carotene was extracted by the barium hydroxide method described in Methods of Analysis of the Association of Official Agricultural Chemists (1950) and evaluated on a Cenco-Sheard-Sanford photoelectric colorimeter equipped with a No. 554 H.R. Lantern Blue Corning glass filter. The percent light transmission was converted to micrograms of carotene per gram of tissue by means of a standard table previously prepared by the Agricultural Chemistry Department. Carotene was expressed as micrograms per gram rather than as milligrams per 100 grams in order to simplify the statistical calculations.

The total sugar content, expressed as invert sugar, was determined by the Lane-Eynon General Volumetric Method described in the Methods of Analysis of the Association of Official Agricultural Chemists (1950).

The preliminary tests conducted in the spring of 1952 were designed to compare the quality of carrots grown and stored in Michigan with the quality of roots shipped from Texas and California. Similar carrots were also used to determine whether or not packaging the roots in perforated polyethylene bags has any effect upon their sugar or carotene content.

The locally grown carrots were purchased from a wholesaler near Grand Rapids, Michigan. The roots, variety Supreme Half Long, had been grown on muck and had been held in storage for five months. The Texas-grown carrots were of the Imperator type and were shipped in mesh bags of 50 pounds capacity and were obtained from the same wholesaler. The bunched California carrots were also of the Imperator type and were obtained at food stores in East Lansing. Several brands were chosen in order to obtain a respresentative sample of the bunched carrots available to consumers at that time.

The carrots were stored for as long as two months at 32° F in covered bushel baskets lined with paper to minimize water loss. Four random samples of about 500 grams were taken at varying intervals from each of the three lots and weighed to the nearest gram. Half of these were packaged in perforated polyethylene bags, which were closed by placing a rubber band around the previously twisted top of the bag. The remainder were placed in No. 10 tin cans lined with cheesecloth and covered with a four-fold layer of the same material to prevent desiccation. The packaged samples were stored at 55° F for five days to simulate the holding conditions existing in many stores. The carrots were checked for weight loss and analyzed for sugar and carotene content upon removal from storage.

The trials during the 1952 growing and storage season were designed to study the effects of pre-harvest cultural treatments and post-harvest storage treatments on their sugar and carotene contents. Growing conditions were varied to compare the effect of muck and mineral soils and to determine the influence of maturity upon the quality of the roots as affected by harvesting at two six-week intervals. The structure of some of the mineral soil plots was altered by an application of Krilium in order to ascertain whether or not the soil conditioner changed the soil structure sufficiently to affect the quality of the carrots.

The post-harvest studies consisted of experiments of two and of fourteen weeks duration. The former trials were intended to determine the effect of removing the tops at the time of harvest upon the sugar and carotene content of the roots during a brief holding period. The latter experiment was designed to measure the quantitative changes in sugar and carotene content of carrots throughout the storage period.

The carrots were grown on both the muck experimental plots and on a Hillsdale sandy loam soil on the horticulture farm. Three varieties, Nantes, Imperator and Supreme Half Long, were chosen as representing three types of carrots. The Nantes variety matures early and has an orange, blunt, cylindrical root and small foliage. The variety Imperator has orange, tapering roots, large foliage and is a mid-season variety that is used extensively for bunching. Supreme Half Long is a variety belonging to the Danvers type and adapted for culture on muck soil. The roots are short-tapered with an orange flesh and large foliage. The carrots were planted in both areas according to commercial practice in soil of average fertility. The carrots on the organic soil were planted May 10 and harvested August 4 and

September 16. The carrots grown on the mineral soil were seeded May 17 and harvested August 11 and September 23. The carrots for the soil-conditioner trials were seeded May 27 after 1200 pounds "Krilium" per acre, type B, had been rotatilled into the soil and were pulled October 1. Part of each of the Krilium-treated plots was irrigated to maintain the soil moisture above 50 percent of field capacity. A total of three inches of water was applied during the season.

Carrots of marketable size, with a diameter of one inch or more at the neck, and free of disease and anatomical abnormalities were selected for storage and chemical analysis.

Upon harvesting, the carrots were washed, dried with cheesecloth, taken to the laboratory, weighed, and placed in Kraft paper bags for storage. The tops of the bags were folded and closed with staples and eight 1/4-inch holes were punched in the bags to facilitate gas exchange. The trimmed tops of the carrots were enclosed with the roots to provide similar atmospheric conditions for both treatments; this resulted in a total weight of about 1000 grams. The weights of the tops and roots were recorded separately for the topped carrots.

The topped and non-topped roots were analyzed for weight loss, sugar and carotene content after storage for two weeks at 40° F, the temperature approximating that occurring during the transit of produce in refrigerator

ears. Due to limitations in the facilities for the carotene determinations, the analyses of the two replicates were separated by 48 hours.

The carrots used in the storage experiments of fourteen weeks duration were selected from the roots of the second harvest. Carrots of all three varieties grown on muck and mineral soil were included in the trials. They were cleaned and packaged according to the procedure outlined earlier except that the tops were not included and then stored at 40° F and a relative humidity of 60 percent. The quantitative analyses for sugar, carotene, and dry matter contents were conducted at monthly intervals throughout the storage period.

Statistical Methods

The data obtained from the various treatments were analyzed statistically as a factorial experiment. Interactions above the first order were combined with the error term.

RESULTS

Preliminary Experiments

The experiments conducted in the spring of 1952 showed that pre-packaging had no appreciable effect on either the sugar or carotene contents. Seven lots of roots from each of three sources were packaged in perforated polyethylene bags and held for five days at 55° F. They had an average sugar content of 6.49 percent and an average carotene content of 115 micrograms per gram as compared to 6.35 percent sugar and 114 micrograms of carotene per gram for the unpacked lots. The latter carrots were held for the same period and at the same temperature. These results were based on the fresh weight at analysis. The weight loss for both lots was less than one percent and therefore of no practical significance. Pre-packaging, as shown in Table 1, affected the dry matter content of the roots significantly. The packaged lots contained 11.84 percent dry matter and the non-packaged lots 12.16 percent.

In these tests, the source of the carrots significantly influenced their sugar and carotene values. Locally, muck-soil grown carrots analyzed in March after five months storage contained 5.41 percent sugar, whereas the roots shipped in bulk from Texas contained 6.68 percent sugar and the bunched lots from California and Arizona contained

TABLE 1

INFLUENCE OF PACKAGING AND SOURCE ON THE SUGAR, CAROTENE AND DRY MATTER CONTENT OF CARROTS*

	Percent sugar	Carotene ug/g	Percent dry matter
	Treatment (Avg. 21 samples)		
Packaged	6.35	115	11.84
Non-packaged	6.49	114	12.16
L.S.D. 5%	NS	NS	0.28
	Source (Avg. 14 samples)		
Michigan	5.41	107	10.9
Texas	6.68	131	12.5
Calif. & Ariz.	7.18	105	12.6
L.S.D. 5%	--	7	0.4
1%	0.39	9	0.5

*The Michigan grown carrots were of the variety Supreme Half Long and the shipped carrots of the variety Imperator. The packaging material was polyethtlene bags. All values based on fresh weight at analysis.

7.18 percent (Figure I). The differences between the three lots are significant at the one percent level. In comparisons conducted in the fall and winter of 1952, Arizona-grown bunch carrots obtained from local food stores contained 6.81 percent sugar, whereas locally grown roots of the same type (Imperator) which were grown on mineral soil and stored for two weeks, contained 6.93 percent sugar. California carrots, purchased November 12, and Michigan carrots which had been stored ten weeks contained 6.09 percent and 8.49 percent sugar, respectively. Both lots were of the Imperator type and of marketable quality. The above results were based on the fresh weight of two samples of the roots at the time of analysis.

The carotene analyses show that the carrots shipped from Texas contained 131 ug/g of fresh weight, whereas, muck-grown carrots from Michigan contained 107 ug/g and the California and Arizona bunched carrots contained 105 ug/g. The only significant differences occurred between the Texas-grown carrots and the other two lots. In October, the variety Imperator grown in Michigan on mineral soil contained 131 ug/g and the Arizona-bunched carrots contained 61 ug/g of carotene per gram. These results were not evaluated statistically due to the small number of determinations made. The carotene content of the California-bunched carrots obtained in December was not determined.

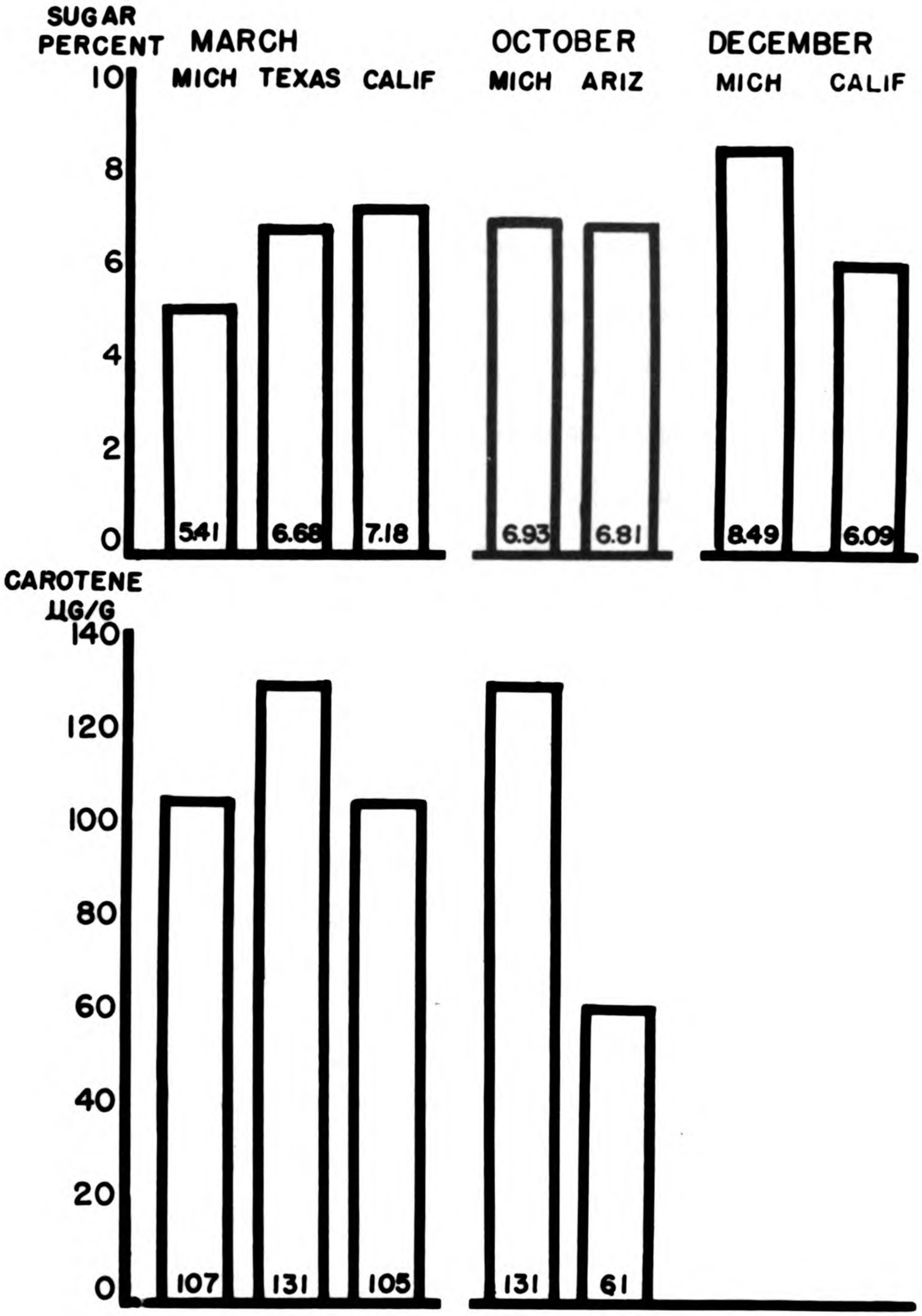

Figure I.. The effect of source on the sugar and carotene content of carrots.

(Average of 14 (March) and 2 (Oct., Dec.) samples based on fresh weight at analysis)

Tests with Carrots Grown on Mineral and Muck Soils in 1952

In the results reported below, only data for main effects and first order interactions are given.

Sugars

Field experiments: The total sugar content of carrots from a factorial experiment comparing three varieties (Nantes, Imperator and Supreme Half Long) grown on two soils (muck and mineral), each harvested at two dates (August 4, 1952, and September 16, 1952, on muck and August 11, 1952, and September 23, 1952 on mineral soil), and stored for two weeks topped and non-topped, was determined in duplicate (96 samples). Table 2 indicates the effect of soil, variety, harvest date, variety x soil and harvest x soil interactions, all of which were statistically significant, on the sugar content of the roots. There was no significance for storage period, for topping or for variety x harvest interaction or for any interaction with storage period or topping.

Carrots grown on mineral soil, based on an average of three varieties harvested at two different stages of growth, contained 31.3 percent more sugar on a fresh weight basis and 10.7 percent more sugar on a dry weight basis than those grown on muck soil.

The varieties were of variable sugar content and ranked differently depending upon the method of expressing the sugars. Imperator was highest on a fresh weight basis, but

TABLE 2

THE INFLUENCE OF SOIL TYPE, VARIETY AND AGE OF ROOT ON THE SUGAR CONTENT OF CARROTS

	Fresh weight (percent)		Dry weight (percent)	
Soil (Avg. 48 samples)				
Muck	4.32		42.56	
Mineral	5.67		47.12	
L.S.D. 1%	0.20		1.26	
Variety (Avg. 32 samples)				
Nantes	4.81		46.48	
Imperator	5.18		43.47	
Supreme Half Long	5.00		44.58	
L.S.D. 5%	0.19		1.16	
1%	0.25		1.54	
Age (Avg. 48 samples)				
Early harvest*	4.65		43.41	
Late harvest*	5.34		46.28	
L.S.D. 1%	0.20		1.26	
	Muck	Mineral	Muck	Mineral
Variety x Soil (Avg. 16 samples)				
Nantes	4.32	5.29	44.71	48.24
Imperator	4.05	6.30	39.45	47.49
Supreme Half Long	4.58	5.42	43.53	45.63
L.S.D. 5%	0.27		1.64	
1%	0.35		2.18	
Age x Soil (Avg. 24 samples)				
Early harvest*	4.12	5.18	41.88	44.94
Late harvest*	4.51	6.16	43.25	49.30
L.S.D. 5%	—		1.34	
1%	0.29		1.78	

*Harvest dates: Muck August 4, 1952; September 16, 1952
Mineral August 11, 1952; September 23, 1952

lowest on a dry weight basis. The reverse was true for Nantes while Supreme Half Long was intermediate in both cases.

The three varieties responded differently on the two soils. On the fresh weight basis the Imperator variety had a significantly higher sugar content on the mineral soil and a significantly lower sugar content on the muck soil than the other two varieties. Based on the dry weight the Imperator variety also contained significantly less sugar than the other two varieties when grown on the muck soil, but was intermediate when grown on the mineral soil.

Although all three varieties of carrots increased in average sugar content with age on both soils, the increase on mineral soil was of considerably greater magnitude than on muck soil (Table 2).

Removal of the tops of carrots at the time of harvest was of no significant or appreciable effect upon the sugar content of roots held in storage two weeks. The topped roots contained 4.92 percent sugar and the non-topped ones 5.06 percent sugar when based on the fresh weight, whereas the sugar contents based on the dry weight amounted to 44.5 percent and 45.19 percent, respectively.

<u>Storage experiments</u>: The sugar content of carrots from a factorially designed storage experiment comparing three varieties (Nantes, Imperator and Supreme Half Long) grown on two soils (muck and mineral) and sampled at five intervals (at harvest, after two, six, ten and fourteen

weeks of storage) was determined in duplicate (60 samples). Table 3 shows the effects of storage period, soil, and the interaction storage period x soil, on the sugar content of the roots. The differences found between varieties due to growing conditions were maintained during storage. During storage, the sugar content increased 45 percent on the fresh weight basis, but only 14 percent on the dry weight basis, while a 6.7 percent decrease was found on the original fresh weight basis. These results are shown graphically in Figure II.

The analyses indicated that the storage behavior of carrots, in respect to the sugar content, was influenced by soil type. On the basis of the fresh weight at sampling, carrots grown on muck soil appear to gain in sweetness to a greater extent in storage than those grown on mineral soil. However, the sugar content in mineral soil-grown carrots remained higher than in muck soil-grown carrots throughout the storage period. It is significant that on the original fresh weight basis the carrots from both soils decreased in sugar content during the storage period by similar amounts. On the dry weight basis, the muck soil-grown carrots increased during the early portion of the storage period and decreased toward the terminal storage interval while the carrots from the mineral soil increased during the entire storage period (Figure III).

Soil conditioner and irrigation tests: The results of the tests involving the application of 1200 pounds of Krilium

TABLE 3

THE INFLUENCE OF STORAGE PERIOD AND SOIL TYPE ON THE SUGAR CONTENT OF CARROTS

	Fresh weight (percent)	Original fresh weight (percent)	Dry weight (percent)
Storage period (Avg. 12 samples)			
At harvest	5.22	5.19	45.6
2 weeks	5.37	5.18	47.1
6 weeks	6.65	5.15	50.6
10 weeks	7.49	5.28	53.8
14 weeks	7.58	4.84	52.1
L.S.D. 5%	0.37	0.27	2.3
1%	0.49	0.37	3.1
Soil (Avg. 30 samples)			
Muck	5.44	4.28	46.6
Mineral	7.48	5.98	53.1
L.S.D. 1%	0.31	0.23	1.9

	Fresh weight (percent)		Original fresh weight (percent)		Dry weight (percent)	
	Muck	Mineral	Muck	Mineral	Muck	Mineral
Storage period x Soil (Avg. 6 samples)						
At harvest	4.21	6.22	4.17	6.20	41.5	49.7
2 weeks	4.58	6.16	4.37	5.98	44.3	49.8
6 weeks	5.77	7.53	4.44	5.86	50.0	51.2
10 weeks	6.45	8.53	4.38	6.18	50.2	57.5
14 weeks	6.20	8.95	4.02	5.67	46.8	57.3
L.S.D. 5%	0.52		0.39		3.2	
1%	0.70		0.52		4.3	

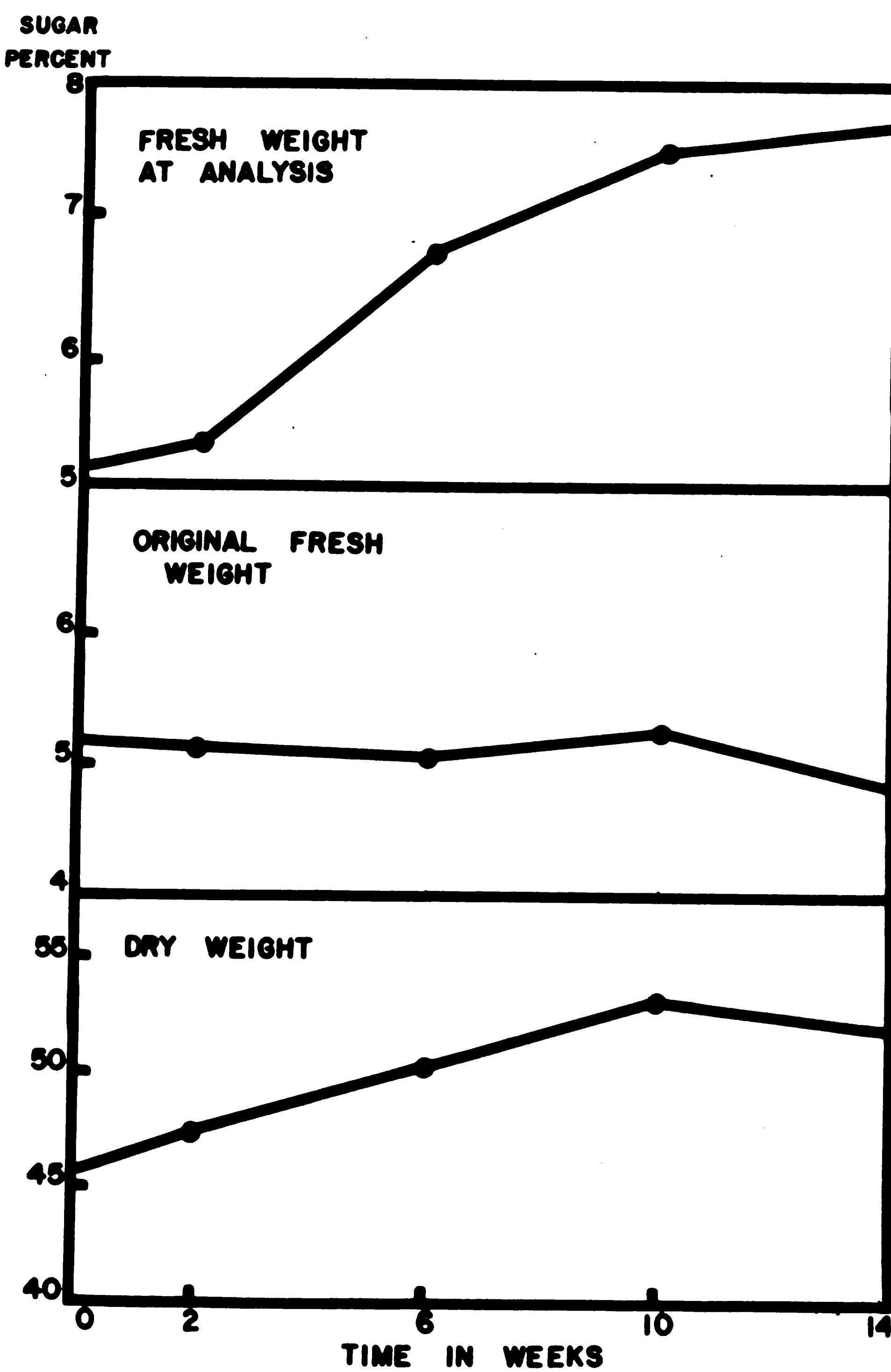

Figure II. . Influence of storage period on sugar content of carrots.

(Average of 12 samples)

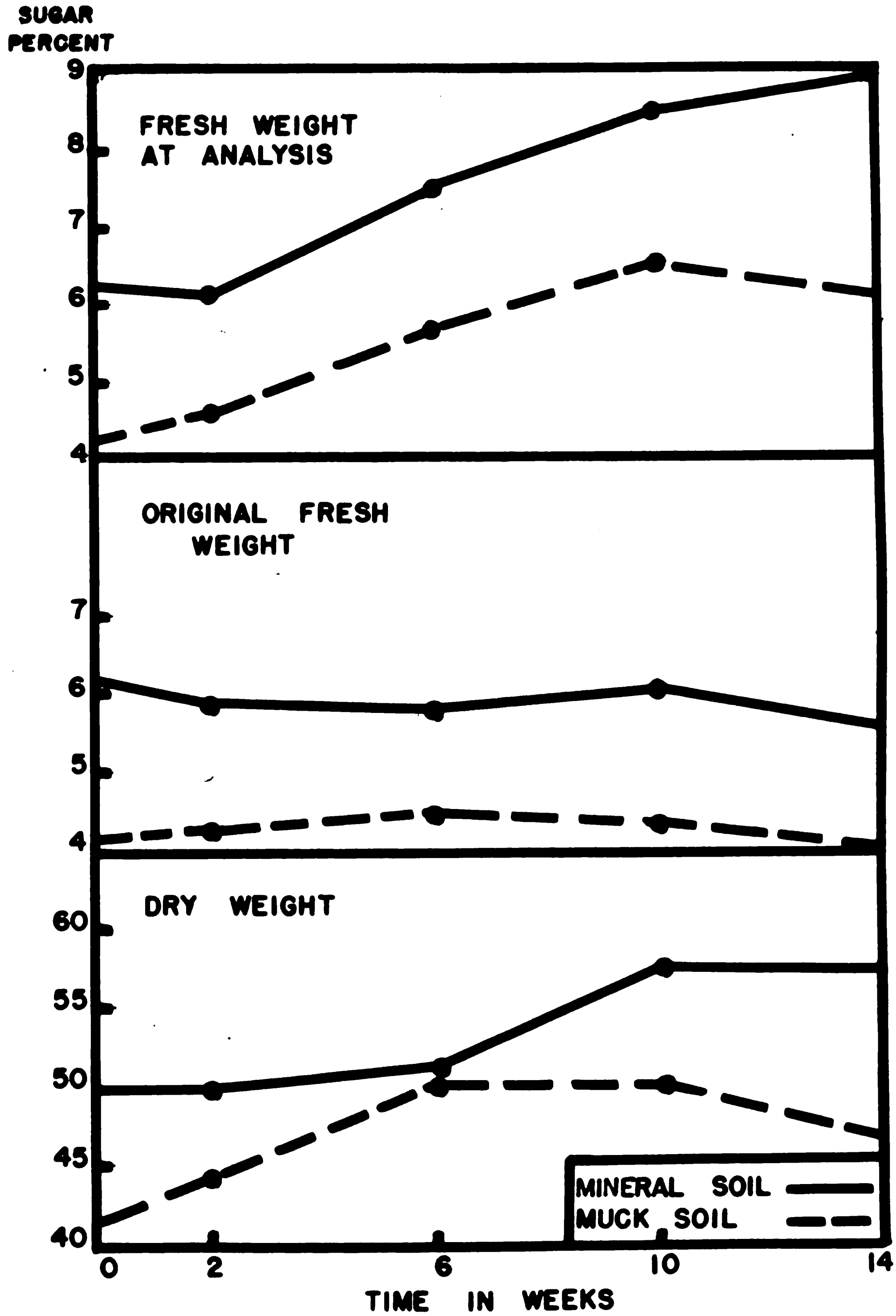

Figure III. Influence of storage period and soil type on sugar content of carrots.

(Average of 6 samples)

and supplemental irrigation were not analyzed statistically. The carrots grown on the plots treated with Krilium contained 6.70 percent sugar on the fresh weight basis, whereas those grown on the non-treated plots contained 7.31 percent. When based on the dry weight the corresponding values were 57.6 percent and 60.1 percent. The effect of irrigation was beneficial in that the roots from the irrigated plots contained 7.18 percent sugar versus 6.83 percent for those from the non-irrigated plots when based on the fresh weight. On the dry weight, however, the sugar contents were 58.3 percent and 59.4 percent, respectively. The results are presented in Table 4.

Carotene

Field experiments: The carotene content was determined on the same lots of carrots used for the sugar determinations. Table 5 shows the influence of soil type, variety, time of harvest, variety x soil, time of harvest x soil and variety x time of harvest upon the carotene content of the roots. No significance was found for storage period, for topping or for any interactions involving these factors. A comparison of 48 lots of mineral with 48 lots of muck-grown carrots, on the fresh weight basis, indicates that mineral-grown carrots contain 27.6 percent more carotene than carrots grown on muck soil. Varietal differences showed that the Nantes variety was significantly lower in carotene than the other two varieties. It is of interest that mature

TABLE 4

THE EFFECT OF APPLICATION OF A SOIL CONDITIONER AND IRRIGATION ON THE SUGAR, CAROTENE AND DRY MATTER CONTENT OF CARROTS

	Check	Krilium*	Average
	Percent sugar (Fresh weight)		
Check	7.06	6.60	6.83
Irrigated**	7.56	6.79	7.18
Average	7.31	6.70	
	Percent sugar (Dry weight)		
Check	60.7	58.1	59.4
Irrigated	59.5	57.0	58.3
Average	60.1	57.6	
	Micrograms per gram carotene (Fresh weight)		
Check	95	90	93
Irrigated	101	103	102
Average	98	97	
	Micrograms per gram carotene (Dry weight)		
Check	813	792	803
Irrigated	795	865	830
Average	804	829	
	Percent dry weight		
Check	11.63	11.36	11.50
Irrigated	12.71	11.91	12.31
Average	12.17	11.64	

*1200 pounds per acre

**3 inches during season

Main effects: Averages of two samples

TABLE 5

THE INFLUENCE OF SOIL TYPE, VARIETY AND AGE OF ROOT ON THE CAROTENE CONTENT OF CARROTS

	Fresh weight (ug/g)	Dry weight (ug/g)
	Soil (Avg. 48 samples)	
Muck	76	747
Mineral	97	796
L.S.D. 1%	5	NS
	Variety (Avg. 32 samples)	
Nantes	77	738
Imperator	90	754
Supreme Half Long	92	820
L.S.D. 5%	4	NS
1%	6	--
	Age (Avg. 48 samples)	
Early harvest*	70	656
Late harvest*	102	886
L.S.D. 1%	5	106

	Muck	Mineral
	Variety x Soil (Avg. 16 samples)	
Nantes	70	84
Imperator	73	107
Supreme Half Long	85	99
L.S.D. 5%	6	
1%	8	
	Age x Soil (Avg. 24 samples)	
Early harvest*	64	76
Late harvest*	88	117
L.S.D. 1%	7	

	Early harvest	Late harvest
	Variety x Age (Avg. 16 samples)	
Nantes	66	88
Imperator	70	110
Supreme Half Long	75	109
L.S.D. 5%	6	
1%	8	

*Harvest dates: Muck August 4, 1952; September 16, 1952
Mineral August 11, 1952; September 23, 1952

roots harvested in September contained 45.7 percent more carotene than those harvested in August at an immature stage.

The Imperator variety contained markedly more carotene on the mineral than on the muck soil and, in general, the accumulation of carotene was enhanced more as the carrots matured on mineral soil than on muck soil. Although the three varieties of carrots were similar in carotene content during the immature stage, they differed as they matured in that Nantes showed a lower increase between harvests than the other two varieties.

The chemical analyses showed that the carotene content of the roots of the three varieties of carrots was not affected significantly by the removal of the tops at the time of harvest. Both the topped and the non-topped roots contained 86 ug/g of carotene. The values based on dry weight were 775 ug/g and 768 ug/g, respectively, for topped and non-topped carrots.

Storage experiments: The carrot samples described earlier were also analyzed for carotene. It is shown in Table 6 and in Figures IV and V that the storage period, the variety and the storage period x variety interaction influenced the carotene content significantly. The soil on which the carrots were grown had no effect upon the fluctuations of their carotene content in storage. On the basis of the fresh weight, there was an apparent increase early in storage, but an actual decline occurred on the basis of original fresh weight or dry weight during the

TABLE 6

THE INFLUENCE OF STORAGE PERIOD AND VARIETY ON THE CAROTENE CONTENT OF CARROTS

	Fresh weight (ug/g)			Original fresh weight (ug/g)			Dry weight (ug/g)		
	N	I	SHL	N	I	SHL	N	I	SHL
Time (Avg. 12 samples)									
At harvest		99			98			857	
2 weeks		106			102			931	
6 weeks		123			95			934	
10 weeks		126			89			896	
14 weeks		116			74			800	
L.S.D. 5%		9			8			64	
1%		12			11			85	
Variety (Avg. 20 samples)									
Nantes		101			81			832	
Imperator		115			95			854	
Supreme Half Long		127			100			965	
L.S.D. 5%		-			7			-	
1%		9			9			20	
Time x Variety (Avg. 4 samples)									
At harvest	84	110	102	84	110	102	784	910	877
2 weeks	99	112	108	94	110	103	899	922	971
6 weeks	107	127	135	80	101	105	866	889	1048
10 weeks	111	116	152	79	84	103	845	826	1017
14 weeks	104	108	137	67	70	87	768	721	912
L.S.D. 5%		15			13			110	
1%		20			18			148	

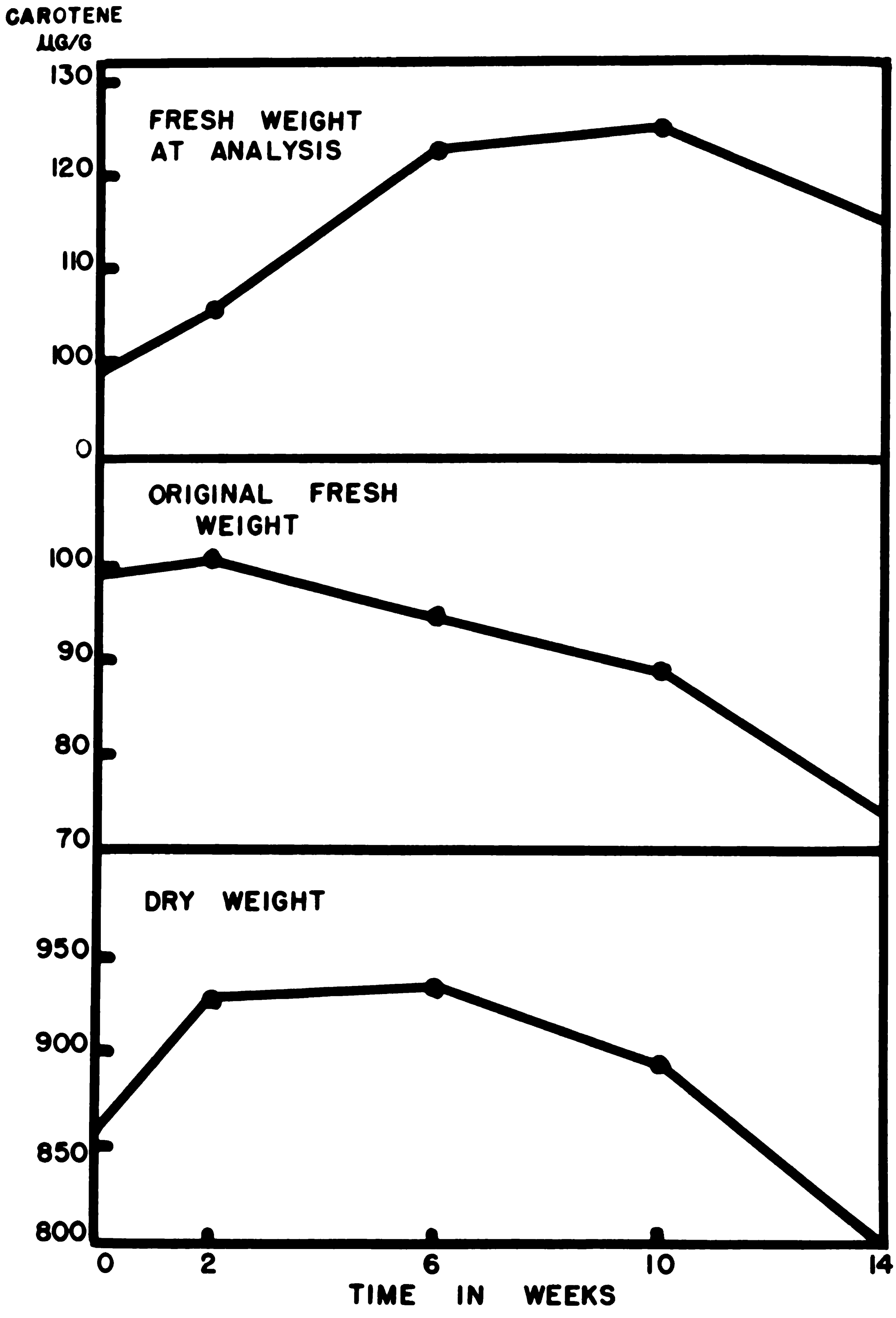

Figure IV. Influence of storage period on the carotene content of carrots.

(Average of 12 samples)

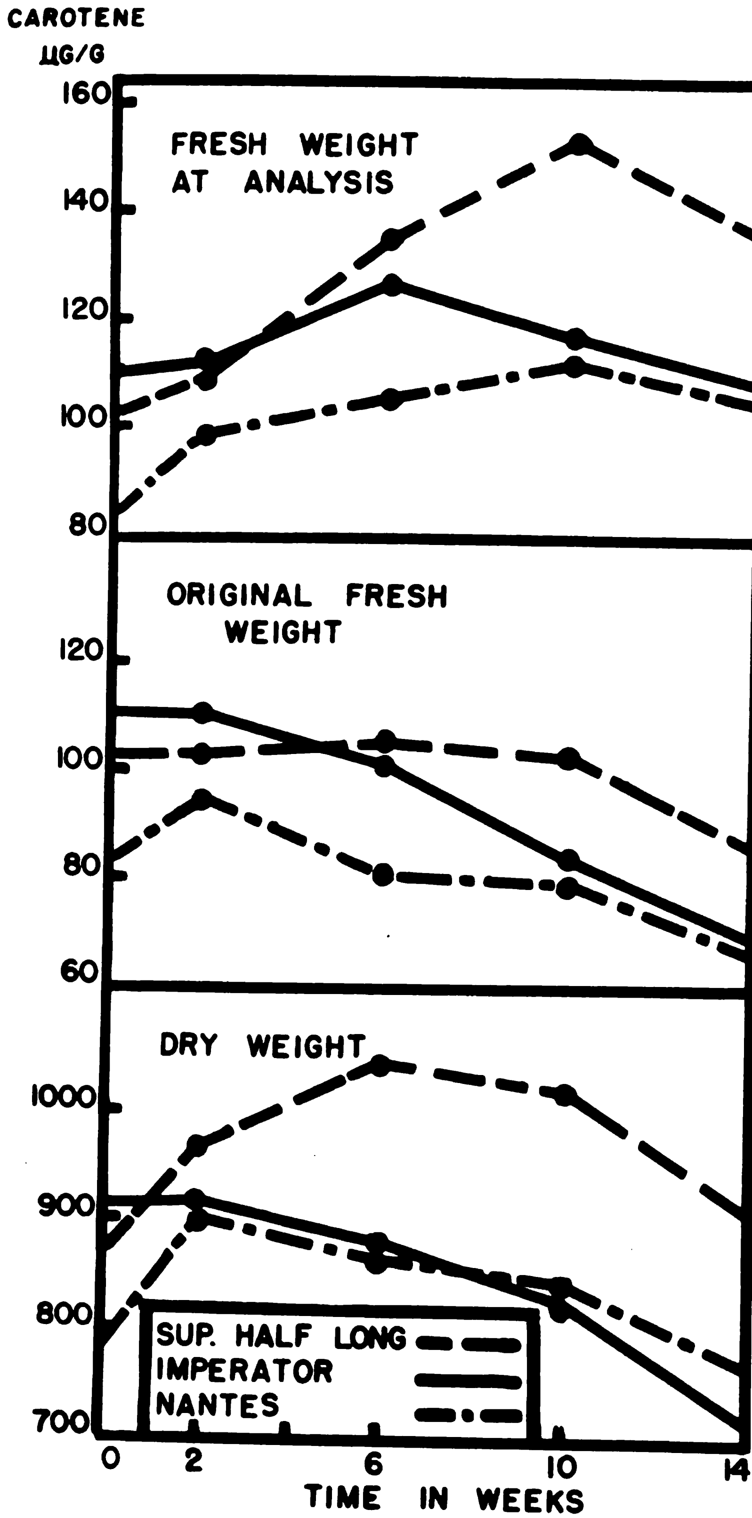

Figure V. . Influence of storage period and variety on the carotene content of carrots.

(Average of 6 samples)

later portion of the storage period. It is noteworthy that the variety Supreme Half Long maintained a significantly higher carotene content in storage than the other two varieties.

The interaction of storage period x variety shows that the variety Supreme Half Long increased more in carotene early in storage and declined less during the final four weeks of storage than either one of the other two varieties. Therefore, the variety Supreme Half Long had the highest carotene content at the end of the storage period although it had been intermediate at the time of harvest.

Soil conditioner and irrigation tests: On the fresh weight basis, the application of Krilium had little influence upon the carotene content of the carrots, while on the dry weight basis, it resulted in an increase of 25 ug/g. Irrigation, however, caused increases both on the fresh and on the dry weight basis amounting to 9 ug/g and 27 ug/g, respectively (Table 4).

Dry Weight

Field experiments: The dry matter content of the lots of carrots cited earlier was influenced significantly by soil type, variety, time of harvest and variety x soil. The data presented in Table 7 show that the dry weight of mineral-grown carrots was higher than that of muck-grown carrots and that the variety Imperator was highest in dry weight. The six-week interval between harvests also caused

TABLE 7

THE INFLUENCE OF SOIL TYPE, VARIETY AND AGE OF ROOT ON THE DRY WEIGHT OF CARROTS

Soil (Avg. 48 samples)		
Muck	10.11	
Mineral	12.02	
L.S.D. 1%	0.27	
Variety (Avg. 32 samples)		
Nantes	10.29	
Imperator	11.73	
Supreme Half Long	11.18	
L.S.D. 1%	0.33	
Age (Avg. 48 samples)		
Early harvest	10.66	
Late harvest	11.46	
L.S.D. 1%	0.27	

	Muck	Mineral
Variety x Soil (Avg. 16 samples)		
Nantes	9.62	10.96
Imperator	10.19	13.26
Supreme Half Long	10.52	11.83
L.S.D. 5%	0.35	
1%	0.47	

an increase in dry weight. An interesting observation was that on muck soil the variety Supreme Half Long was highest in dry matter, but on mineral soil the variety Imperator was highest.

Storage experiments: The dry weight data of the stored roots showed that while all varieties increased during storage, the variety Supreme Half Long gained the greatest amount (Table 8 and Figure VI).

Soil conditioner and irrigation tests: Applications of 1200 pounds of Krilium and supplementary irrigation caused variations in dry matter content of the roots. While carrots from the Krilium-treated plots contained 11.64 percent dry matter, those from the untreated plots contained 12.17 percent. Surprisingly, irrigation caused an increase in the dry matter content from 11.50 percent to 12.31 percent (Table 4).

Weight Loss

Storage experiments: The storage interval was the only factor which affected the weight loss significantly (Table 9 and Figure VI). The influences of variety, soil and their interactions were not significant. The data, which were based on the weight of the individual lots at the beginning of the storage period, show that the decrease in weight during the first two weeks of storage was less than 10 percent of the total loss which amounted to 35.8 percent.

TABLE 8

THE INFLUENCE OF STORAGE PERIOD AND VARIETY ON THE DRY WEIGHT OF CARROTS

Time (Avg. 12 samples)	
At harvest	11.39
2 weeks	11.39
6 weeks	13.17
10 weeks	13.94
14 weeks	14.44
L.S.D. 5%	0.48
1%	0.64
Variety (Avg. 20 samples)	
Nantes	12.09
Imperator	13.45
Supreme Half Long	13.04
L.S.D. 5%	0.37
1%	0.50

	N	I	SHL
Time x Variety (Avg. 4 samples)			
At harvest	10.68	11.92	11.58
2 weeks	10.89	12.16	11.06
6 weeks	12.35	14.27	12.89
10 weeks	13.12	13.98	14.74
14 weeks	13.40	14.95	14.97
L.S.D. 5%		0.83	
1%		1.11	

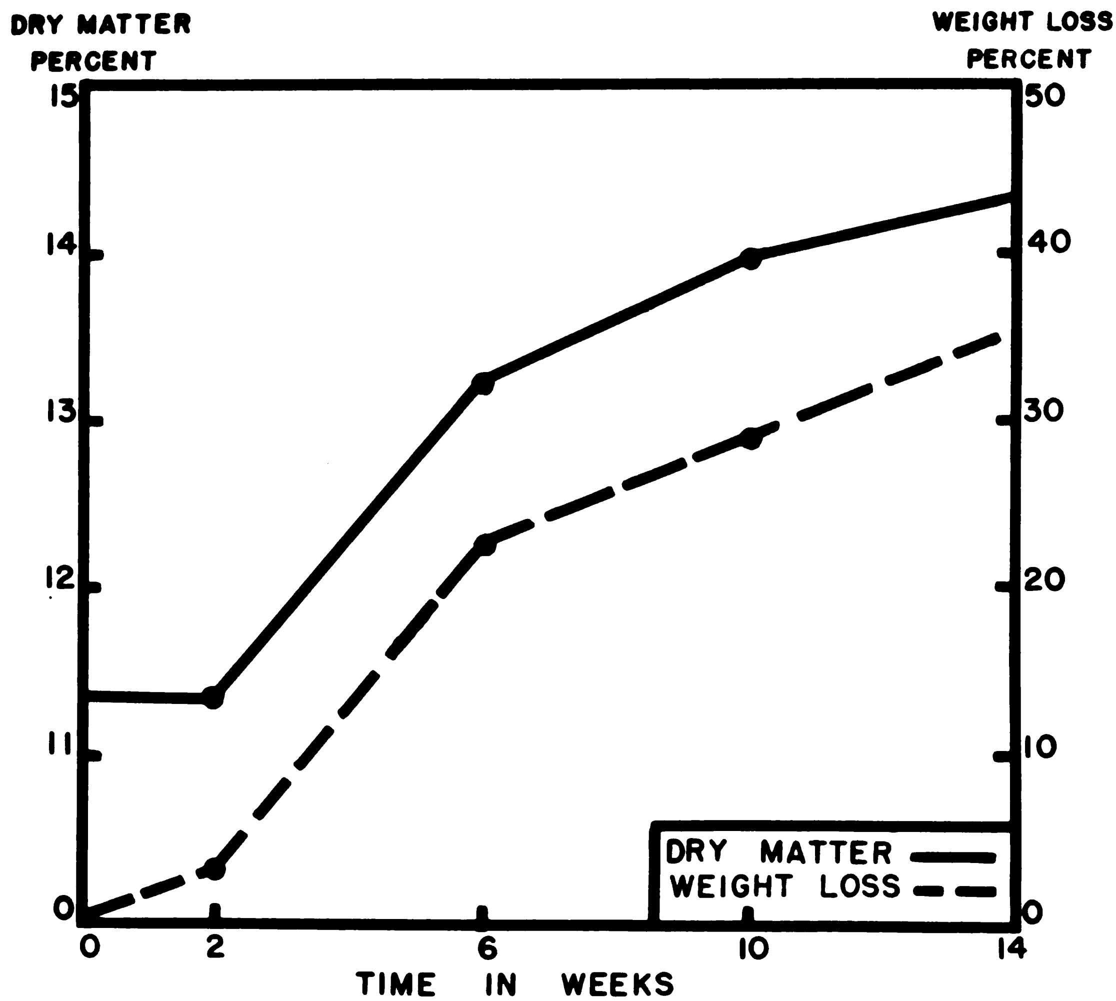

Figure VI.. Influence of storage period on the dry matter content and weight loss of carrots.

(Average of 12 samples)

TABLE 9

THE INFLUENCE OF STORAGE PERIOD, VARIETY AND SOIL TYPE ON THE WEIGHT LOSS OF CARROTS

Time (Avg. 12 samples)	
2 weeks after harvest	3.2
6 weeks after harvest	22.6
10 weeks after harvest	29.6
14 weeks after harvest	35.8
L.S.D. 1%	3.8
Variety (Avg. 16 samples)	
Nantes	23.2
Imperator	22.0
Supreme Half Long	23.2
L.S.D.	NS
Soil (Avg. 24 samples)	
Muck	23.4
Mineral	22.2
L.S.D.	NS

DISCUSSION

The results of these experiments showed that variety, soil type, age of roots, and length of storage period differentially influenced the accumulation and behavior of sugar, carotene and dry matter in carrots.

Implications of Basing Sugar and Carotene Contents on Three Methods of Calculation

These experiments demonstrate that the method of calculation and the expression of data are important in the interpretation of results. If they are to be of practical application, in that the sugar and carotene contents are to afford a comparison of the edible and nutritional value of the carrots at time of consumption, they should be based on the fresh weight at analysis. This method of expression reflects the nutritional value per unit of weight which is the usual basis of purchase by the consumer.

The original fresh weight is indirectly valuable because it permits the evaluation of changes in the sugar and carotene contents of stored carrots independent of the changes of other constituents. Moreover, it provides a means for distinguishing the changes in sugar and carotene content which are actual rather than merely apparent. The actual changes would result from the synthesis or destruction of the sugars and carotene, whereas, the apparent changes would result from changes in other materials that affect the weight of the samples.

The data based on the dry weight, although of little value in detecting quality, are of value in determining how the sugar and carotene contents of the carrots vary in relation to the changes in other constituents, and in showing how changes in the water content affect the sugar and carotene contents. The water content is important to carrot quality because of its influence upon crispness, texture and the appearance of the product. The amount of water present may also have an important role in the physiological changes occurring in stored carrots, particularly in connection with the transformations of sugars and carotene. Data based on the original fresh weight and the dry weight are needed to study the actual physiological changes taking place in stored carrots, even though they provide little information concerning the apparent variations in the constituents.

The sweetness of carrots is primarily a function of the total sugar content and a positive correlation of flavor and soluble solids as measured by the refractometer has been reported by Brown (1944) for carrots. The kind of sugar present also plays a role in sweetness and considerable conversion of sugars may take place in carrots. The data of Platenius (1934), for example, indicate that the ratio of glucose to sucrose on the dry weight basis increases for a period of two months after harvest and remains fairly constant before it decreases after four months of storage. Similar changes in the glucose to sucrose ratio have been reported by Werner (1941) on the fresh weight at analysis. Glucose is about 74 percent as sweet as sucrose and a shift toward glucose would result in a reduction in sweetness. However, the formation of simple sugars from polysaccharides and their concentration due to transpiration losses may proceed at a more rapid rate than the change from sucrose to glucose. If this is the case, the carrots would increase in sweetness in storage. Furthermore, if the findings of Rygg (1945) are correct in that fructose is present in carrots it is possible that the fructose to sucrose ratio also increases during storage. The greater sweetening power of fructose (about 173 percent of sucrose) would then offset the possible loss in sweetness caused by an increase in glucose.

Effect of Source on Quality

Quality comparisons showed that stored, Michigan-grown carrots were equal and sometimes superior in quality, as expressed by sugar and carotene contents, to freshly harvested and shipped roots. While these results were based on the fresh weight at analysis, similar comparisons undertaken by Platenius (1934) were based on the dry weight. Although it was previously pointed out that comparisons of quality based on dry matter data are not always valid, Platenius' results indicate that southern-bunched carrots were generally lower in sugar content than carrots grown and stored in New York state. The lack of effect of prepackaging upon the sugar content agrees with the findings of Rygg (1952), but the results for carotene in the present tests are not strictly comparable with those of Rygg since he determined total carotenoids rather than carotene. Rygg found the carotenoids to increase during two weeks of storage, whereas, in these trials, no changes in the carotene content were noted.

Variations in Composition Related to Soil Type

The type of soil is important since carrots grown on muck soil were generally lower in both sugar and carotene than carrots grown on mineral soil. These differences in sugar content amounted to 30 percent on the fresh weight basis, but to only 10 percent on the dry weight basis. Furthermore, the dry matter content of the carrots grown on the muck was 20 percent lower than the dry matter content of the roots grown on the mineral soil. These results indicate that the rate of accumulation of the sugars proceeds more rapidly in the carrots grown on the muck than in the carrots grown on the mineral soil when it is related to their respective dry weights. The same relationship holds for the carotene content on the fresh weight basis since the difference between the two lots of carrots was about 30 percent, whereas, it was only about one-fifth as large when based on the dry weight.

The behavior of the Imperator variety differed markedly from the other two varieties in respect to soil type. This interaction of soil and variety was very marked in respect to sugar content and of significance in respect to carotene content. It appears therefore, that the Imperator variety possesses a narrower range of favorable soil conditions than Nantes or Supreme Half Long.

It is difficult to offer an explanation for the fact that the quality, based on sugar and carotene, of carrots grown on muck soil was consistently lower than that of carrots grown on mineral soil. However, it is feasible that the level of fertility, particularly nitrogen, of the muck soil, though favorable for good growth, may have been too high for the development of a high sugar and carotene. It is also conceivable that the nitrogen-potassium ratio was too high for optimum accumulation of storage materials. Soil temperatures unfavorably high for the best development of both carotene and sugars during the period of growth may also explain the relatively low quality of carrots grown on muck. This effect of temperature on carotene development has been shown by Barnes (1936) and by Hansen (1945).

Improvements in the sugar and carotene content of muck-grown carrots may be attained by growing a variety better adapted to this type of culture than the varieties tested here. Supreme Half Long, a Danvers type, has been recommended by seedsmen for muck soil plantings and its reasonably satisfactory performance on muck in these trials would make it a logical starting point for such a breeding program. Moreover, nutritional studies may offer a means of improving the quality of muck soil-grown carrots by establishing a nutrient element balance favorable to the formation of carotene and sugars.

Variations Due to Variety

The changes in ranks in sugar content of the three varieties caused by the two methods of calculation illustrate the importance of selecting the proper basis for comparing the results. It proved to be more important in considering sugars than carotene in this instance since the three varieties ranked similarly in carotene content both on the fresh and dry weight basis. These differences lead to the belief that sugar accumulation is relatively independent of total dry matter accumulation, while carotene production is governed by total dry matter accumulation. The data also indicate that a low dry matter content, a low sugar content and a low carotene content are associated when the analyses for the latter two constituents are based on the fresh weight. Similar conclusions can be drawn from the data presented by Yamaguchi et al. (1952).

Variations Due to Age of Roots

The six weeks interval between the two harvests resulted in increased sugar and carotene contents, but the relative increases of the two substances differed. Sugars, on the fresh weight basis, increased only one-third as much as carotene during this time. It would, therefore, appear that carotene formation occurs primarily toward the end of the growing season while the sugars accumulate earlier in the season or continuously during the growing period. From the viewpoint of sweetness and succulence, high edible quality would be reached earlier than high nutritional quality when both sugar and carotene are considered. A similar pattern of quality development has been reported by Yamaguchi *et al*. (1952).

Influence of the Storage Period on the Sugar Content

The results of these experiments demonstrate that the sweetness of carrots varies with the length of the storage period and the variety. The increases in sugars which occurred during ten weeks of storage were probably due to the concentration of sugars in the carrots because of the water loss. The nearly constant level of total sugars when calculated to the original fresh weight leads to the inference that the total sugar content did not undergo any marked changes until late in the storage period. This is contrary to the expected pattern because the soluble sugars are consumed in respiration and would ordinarily decrease during storage. Since they did not decrease in total amount, the respired sugars were probably replaced by the hydrolysis of polysaccharides. Such a transformation in carrots has been reported by Platenius (1934). The gains in sugar content on the dry weight basis suggest that the increase in sugar content due to a loss in water and the conversion from polysaccharides proceeded at a more rapid rate than the increase of the dry matter caused by losses in water alone. The rate of sugar accumulation was slower than the rate of dry matter increase only during the final storage interval and showed up as a loss in sugars when calculated to the dry weight. This decrease in sugar was probably due to either an increased rate of respiration or to a reduced rate of hydrolysis of polysaccharides, rather than to a sudden and rapid concentration of the dry matter due to water losses. This assumption seems justified because the decrease in sugar (1.7 percent) was more than three times the magnitude of the increase in dry matter (0.50 percent) during the same period of time. Platenius (1934) suggested that the lack of change in sugar content in his tests was caused by a balance between respiration and the hydrolysis of polysaccharides. Since the changes in sugar for carrots from muck and mineral soil vary only in magnitude and never in direction during the storage period, the explanations for the variations in sugar content as a whole apply equally well to the carrots from both soils.

Influence of the Storage Period on the Carotene Content

The decreases in carotene content which occurred throughout the major portion of the storage season, especially when based on the original fresh weight and on the dry weight, indicate that carotene is broken down during storage. The increases in carotene noted on the fresh weight basis early in storage very likely were due to losses in water and not to the synthesis of carotene while the decrease in carotene observed later was related to breakdown of carotene. A decrease in carotene caused by an uptake of water by the roots, as may occur under conditions of high relative humidity, is precluded in these tests because the carrots lost weight during the entire storage period.

Nantes attained its highest carotene value after ten weeks of storage, whereas, the other varieties reached their peaks earlier. The results for Nantes are not in agreement with Werner (1941) and Lee and Tapley (1947) as they found this variety to remain practically constant in carotene content when based on the fresh weight at analysis throughout storage periods of seven and five months duration, respectively. The decline in carotene content which set in after six weeks of storage for Imperator is at variance with the results obtained by Lantz (1949) who determined that increases in carotene for this variety, based on the fresh weight, continued throughout a storage period of seventeen weeks. However, these changes in carotene agree with those reported by Kelley et al. (1950) who found increases during storage on the fresh weight for one month and decreases during storage periods of three months.

It would appear from the results for Nantes, on the fresh weight basis, that a relatively low original carotene content was followed by an early and relatively minor increase in carotene in storage. Carrots with a relatively high carotene content, such as Supreme Half Long, showed a large increase (fresh weight) in carotene during storage and this increase was extended over a longer time period than those of a lower carotene content.

It is possible that this differential increase is the result of the presence of a greater amount of precursor in the varieties with a large carotene content than in those with a lower carotene content.

The increases in the carotene content found on the basis of fresh weight calculations were not evident when the data are calculated on the original fresh weight. Instead, the carotene showed a continuous decrease which became more rapid as the storage period lengthened. The results on this basis confirm only those obtained by Kelley et al. (1950). Werner (1941) has also reported a slight decrease in carotene during storage, but it occurred when the roots started to sprout in the spring. The storage temperature for the tests reported in this paper (40° F) was approximately the same as for the experiments reviewed and therefore not likely responsible for the differences. It is possibly that unlike relative humidities were responsible for the variations. Carotene is destroyed oxidatively (Griffith, 1949; Bonner, 1950) and, therefore, a high relative humidity would retard the destruction of carotene and a low relative humidity, as used in the present experiments, would accelerate it. This may be disputed, however, since the internal atmosphere of the carrots is usually assumed to be almost saturated with water vapor regardless of the moisture conditions of the external atmosphere.

The increases in carotene, based on the dry weight, which occurred early in storage were also observed by Brown (1947) who reported an increase in carotene content during thirty days of storage, while McKillican (1948) found increases to occur throughout a storage period of about six months. The increases early in storage, evident by all three methods of calculation, may have been a result of the development of carotene immediately after harvest from precursor substances already present, so that the carotene became a relatively larger proportion of the dry matter than at harvest.

The larger and more consistent decreases in carotene, on the original fresh weight basis, of the Nantes and Imperator varieties as compared to Supreme Half Long leads to the belief that the carotene in Nantes and Imperator, which are fine-textured carrots, breaks down earlier and more rapidly than it does in Supreme Half Long.

The increase in carotene on the dry weight basis for the variety Supreme Half Long which concurred with an increase in dry matter, and which is not reflected on the original fresh weight basis cannot be explained on the basis of available data.

The presently accepted theories offer no obvious explanations for the differences between the results of these experiments, which may have been influenced by a low relative humidity, and those conducted by other workers regarding changes in carotene content of stored carrots. If it may be assumed that vitamin A occurs in plants, as was indicated by Roberts and Southwick (1948) and suggested by Rygg (1949), the differences are explainable. If carotene and vitamin A are interchangeable in the roots of carrots, it is conceivable that under certain storage conditions vitamin A is formed from carotene and that the reverse process would take place under a different set of environmental conditions. Kelley _et al_. (1950), who found a decrease in carotene content in carrots which were stored outdoors in straw, very likely had conditions of comparatively low relative humidity. If so, it is possible that the conditions which favored water loss also favored the destruction of carotene. Any hydrolysis of carotene to vitamin A would require two moles of water for each mole of carotene which was hydrolyzed. Should low humidity contribute to a generally unstable condition of the roots, it is conceivable that a portion of the water in the carrots may be used for the hydrolysis of carotene. The new compounds, vitamin A, would escape detection in the analysis for carotene and a low carotene content would result. Such a change, however, would not affect the nutritional value of the carrots.

The limit of storage life for these carrots was about ten weeks as judged by their sugar and carotene content. After this time, the sugar and carotene either decreased or showed only a minor increase regardless of the variety or basis of calculation which is evidence for a physiological breakdown. Higher relative humidities than those prevailing in these tests would extend the storage period considerably and probably account for the acceptable storage periods of 12 and 17 weeks duration reported by Platenius (1934) and Lantz (1949), respectively.

Influence of the Storage Period on the Dry Matter Content

The parallel relationship of the gain in dry matter and the losses in weight through the storage period is in agreement with the findings of Platenius (1934). The weight loss of stored carrots is primarily a loss in water by transpiration rather than a loss in dry matter by respiration, for if the losses were primarily caused by respiration, the increase in dry matter would proceed more slowly than the loss of weight.

The water losses had no apparent effect upon the crispness of the stored carrots used in the analyses since only roots of marketable quality were analyzed. The water losses of the carrots as a whole were greater than normal, however, because of the conditions of low relative humidity employed in these trials.

Weight losses in storage are economically important and should be considerably less than the 30 percent recorded in these experiments. Platenius found the losses were about 7 percent during three months of storage at 40° F and 93 to 98 percent relative humidity.

Influence of the Soil Conditioner and Irrigation on Sugar and Carotene Accumulation

The adverse effect of Krilium applications upon the accumulation of storage materials may be due to improved aeration afforded by the soil conditioner. It possibly brought about a higher rate of respiration in the roots and tops which interfered with the accumulation of carbohydrates. Nitrification, due to good aeration, may also have contributed to the low sugar accumulation by creating an unfavorable nitrogen-potassium ratio. The benefit derived from irrigation may have been caused by the same factors in that aeration was adequate for the proper development of sugars, but low enough to prevent excessive use of carbohydrates by respiration. The data for the carrots grown under irrigation further indicate that only those analyses based on the fresh weight are valid bases for the judgement of quality because the increase in sugar due to irrigation was evident on the fresh weight and not on the dry weight basis.

SUMMARY

The sugar, carotene and dry matter contents of three varieties of carrots (Nantes, Imperator, Supreme Half Long) grown on two types of soils (muck and mineral) and harvested at two dates (August 4, 1952 and September 11, 1952 on muck and August 11, 1952 and September 23, 1952 on mineral soil) were determined in duplicate in a factorially designed experiment. While the above factors were found to exert varying effects upon the three constituents, topping and storage for two weeks had no discernible influence.

Under the conditions of this study carrots grown on muck soil were generally found to be lower in sugar, carotene and dry matter than the carrots grown on mineral soil. Delaying harvest for six weeks yielded increased sugar, carotene and dry matter contents for all three varieties grown on both soils. In general, the variety Imperator was highest in quality, Supreme Half Long was intermediate and Nantes was lowest. Supreme Half Long, a Danvers type, seemed best adapted to use for the production of a quality product on muck soil.

Quality comparisons, based on sugar and carotene content, of stored Michigan carrots (variety Supreme Half Long) and carrots shipped from California, Texas or Arizona (Imperator type) showed that the locally-grown carrots were

equal and sometimes superior to the shipped product.

The application of a chemical soil conditioner (1200 pounds per acre of Krilium, type B) to the mineral soil caused a decrease in sugar content but was of no apparent effect upon the carotene content of the roots. Irrigation (three inches during the growing season) resulted in higher concentrations of both sugar and carotene in the roots.

The effects of length of storage (2, 6, 10 and 14 weeks), variety (Nantes, Imperator, Supreme Half Long) and soil type (muck and mineral) on the sugar, carotene and dry matter content of carrots were studied in a factorially designed experiment. The roots were stored in paper bags at 40° F and about 60 percent relative humidity. The fresh weight at the time of analysis was employed as a basis for studying the apparent changes of these constituents and for the evaluation of the edible and nutritional quality of the carrots. The actual quantitative changes were evaluated by calculating the data to the original fresh weight and to the dry weight. The results of the storage tests according to the three methods of presentation are summarized as follows:

	Fresh weight at analysis	Original fresh weight	Dry weight
Sugar	Increased during entire storage period	No important changes for 10 weeks then decreased significantly	Increased significantly for 10 weeks then decreased slightly
Carotene	Increased for 10 weeks, then decreased significantly	Decreased during entire storage period	Increased for six weeks than decreased significantly

The fluctuations in the sugar content of stored carrots were in accord with the generally accepted theories concerning the conversion of polysacchardies to monosaccharides and the hydrolysis of sucrose to glucose and fructose. The possible influence of these changes on sweetness were discussed. The changes in the carotene content were attributed to a general physiological breakdown of the carrots. The disagreement between the results obtained in these investigations and those of other workers indicate a need for further studies of carotene changes.

The following conclusions are drawn from these experiments:

1. While the production of carrots with a high sugar and carotene content is more difficult on muck soil than on mineral soil, studies on the nutrition and breeding of carrots may aid in resolving these difficulties..

2. Removing the tops at harvest and subsequent prepackaging of the roots can be recommended since they tend to enhance, rather than destroy, the market quality of carrots.

3. The results of storage experiments should be based on more than one method of calculation if they are to furnish information about actual and apparent changes in the constituents under investigation.

4. Evaluations of quality based on the fresh weight at anlaysis may differ from those based on the original fresh weight and dry weight. The fresh weight at analysis

would appear to be the most reliable basis for consumer needs.

5. Carrots can be stored for at least ten weeks at 40° F without any loss in quality as indicated by their sugar and carotene contents. The crispness of the carrots would be better preserved under storage conditions of a higher relative humidity than used in these trials.

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