Frost Injury Systemic in Sweet Potatoes

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Frost has long been believed to impair the storage quality of sweet potatoes unless harvested shortly after the foliage is killed. Several hypotheses, but few data, have been submitted to explain the impairment or even to substantiate the injury if the soil temperature remains fairly warm. In the present studies, sweet potato vines were injured by various means, and the storage roots from injured and noninjured vines were compared. Injuring the tops by frosting or other means apparently caused systemic injury to the whole plant as evidenced by less carotenoid synthesis during storage.

This is the eleventh and final report in this series on pre- and postharvest factors that affect storage quality of sweet potatoes (Ezell and Wilcox, 1946, 1948, 1952, 1954, 1958; Ezell *et al.*, 1952, 1956, 1959, 1948; Wilcox and Ezell, 1951). In an earlier study (Ezell *et al.*, 1952), sweet potatoes harvested 5 to 11 days after frost killed the foliage, either failed completely or showed greatly reduced ability to synthesize carotenoid pigments during storage. This supports a widely held belief that frost impairs the storage quality of sweet potatoes unless harvested shortly thereafter.

Several hypotheses have been proposed to explain how injury to the vine affects the storage roots. Beattie (1908) ascribed the injury to the frozen sap passing into the storage roots, and recommended cutting the frosted vines to prevent its passage. He furnished no data, but this diagnosis and treatment, or some variation thereof, were accepted for many years (Harter, 1916; Miller, 1919; Taylor, 1936; Thompson, 1923, 1929; Ware, 1937; Work and Carew, 1955).

Hasselbring (1918) reported an increase in the moisture content of sweet potatoes after frost, and ascribed frost injury to excess moisture accumulation after transpiration from the leaves ceased. The hypothesis was not generally accepted, as evidenced by continued recommendations for vine cutting.

Kimbrough (1944) reported no benefits from severing the frosted vines, and Deonier *et al.* (1950) concluded that, as practiced, the procedure might cause injury.

The chilling-before-harvest hypothesis evolved over a period of years. Harter and Whitney (1926) reported that sweet potato plants held at 50° F. gradually turned yellow and died. This temperature also was found to be too low for long-term storage of the harvested roots. Lauritzen (1931) reported that short periods at low temperatures caused the roots to decay at higher temperatures even though no injury was evident immediately after chilling. Lutz (1945) reported that the keeping quality of freshly harvested Porto Rico sweet potatoes was reduced after 2 days at 32° F., 4 days at 40° F., or 10 to 21 days at 50° F. Sweet potatoes apparently are injured before harvest if allowed to remain in the ground at temperatures known to injure harvested roots, but low temperatures without frost are not generally considered harmful and may even be regarded as beneficial by retarding growth and hastening maturity, a term sometimes applied to sweet potatoes to indicate slow or inactive growth at time of harvest. Results during this series of studies tend to support the slow growth hypothesis and suggest that roots from slow-growing vines are higher in carotenoids and more tolerant of low temperatures after harvest.

Materials and Methods

Orange Little Stem and Yellow Jersey sweet potatoes were grown on a Chillum sandy loam at the Plant Industry Station, Beltsville, Md. To study the effect of frost injury and related phenomena on the storage quality of the sweet potatoes, the vines were injured by various means, and after 5 to 11 days' delay, the roots were harvested, cured, and stored under uniform and standard procedures. The roots from the treated plants were compared with roots from adjoining untreated controls or with controls receiving comparable treatments except for the factor under study.

The general postharvest handling and analytical procedures were as described previously (Ezell and Wilcox, 1948). At harvest the roots were washed and weighed individually, and the weight was recorded thereon with an indelible pencil. They were reweighed after storage, and the carotenoid contents calculated to harvest weight to show quantitative changes during the postharvest period. Roots for storage were cured at 85° F. and high humidity for 8 days, and then were stored at 60° F. in a constant-temperature room with a relative humidity of 85% or above.

Each sample for carotenoid analysis consisted of 10 replicates of five roots each. The replicates were analyzed in duplicate for carotene and total carotenoids by the Wall and Kelley method (1943). The results of the duplicates were averaged, and the amount reported is the average of the 10 replicates.

Moisture was determined by drying the macerated tissue at 158° F. in air for 24 hours, and under vacuum for an additional 24 hours. Analysis of variance was used to determine the significance of the differences.

Samples were analyzed at harvest and after storage. A previous study (Ezell and Wilcox, 1948) showed an absolute increase in carotenoids during curing and storage. A later study (Ezell *et al.*, 1952) demonstrated that a failure or a reduction in rate of carotenoid synthesis

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during storage was a sensitive indicator of physiological injury to sweet potatoes. This method of determining injury was used in the present study. A significant decrease in the rate of accumulation of carotenoid pigments in roots from treated plants, as compared to the controls, is interpreted as an indication of injury, and nonsignificant change as no injury. Methods that need to be clearly associated with the specific treatment to assure proper evaluation of the results are included with the results.

Experimental

Injury to Vines. To determine if vine injury per se or the types of injury would affect the behavior of the storage roots, sweet potato vines were injured by frosting with solid carbon dioxide applied directly to the foliage, by flaming with a weed burner, and by spraying with different herbicides (Table I). Adequate precautions were taken to prevent direct injury to the storage roots. To exclude possible effects of low root temperatures, the treatments were applied and the storage roots harvested while the soil was still warm.

In the first season, the postharvest increase in carotenoid pigments in Orange Little Stem sweet potatoes from noninjured vines averaged about three times that in roots from injured vines (Table I). In Yellow Jersey, the increase was about twice that from injured vines, and the differences were significant (1% level) in every treatment. At harvest the moisture content often appeared higher in roots from injured than from noninjured plants, but moisture was determined in only two replicates per sample, too few for statistical evaluation. Roots from injured vines also lost more weight during storage than roots from noninjured vines; the difference was statistically greater in 11 of the 14 comparisons.

Although carotenoids in roots from the injured vines increased less than in roots from noninjured vines, they did increase. The question then arose, was the difference in amounts synthesized due to the injury or to the time of harvest? In the second season, controls B were taken at the time the injured plants were harvested in addition to controls A taken at the time of injury.

In general, roots from injured plants again accumulated less carotenoid pigments during storage than roots from noninjured plants (Table I). In Orange Little Stem, five of the eight controls increased in total carotenoids enough to be statistically significant at the 1% level, one at 5%, one no significant change, and one was lost because of decay. Of the nine lots from injured plants, carotenoids in only one increased enough to be statistically significant, and this increase was about half that in the control. The Yellow Jersey increased in carotenoids during storage, with the greater increases in roots from the noninjured plants. Controls B, harvested when the injured plants were harvested, synthesized more carotenoids in storage than roots from the injured plants; somewhat less than controls A in Orange Little Stem, but about the same in Yellow Jersey. The smaller amount of synthesis in roots from injured vines must therefore be considered as evidence of injury to the roots, not because of the time of harvest.

Table I. Effects of Vine Injury on Carotene and Total Carotenoid Pigments of Sweet Potatoes

Treatments	Orange Little Stem								Yellow Jersey							
	Carotene			Total Carotenoids					Carotene			Total Carotenoids				
	At harvest, mg./100 g.	After storage, mg./100 g.	Difference, %	At harvest, mg./100 g.	After storage, mg./100 g.	Difference, %	Moisture at harvest, %	Loss in weight, %	At harvest, mg./100 g.	After storage, mg./100 g.	Difference, %	At harvest, mg./100 g.	After storage, mg./100 g.	Difference, %	Moisture at harvest, %	Loss in weight, %
								First Season								
Control A[a]	6.17	7.55^b	22.4	7.09	8.40^b	18.5	76.5	8.8	0.11	0.62^b	464	0.57	1.47^b	158	72.9	10.8
Frosted lightly	7.04	7.63^b	8.4	8.04	8.31	3.4	75.7	10.9	0.18	0.28^b	53	0.72	1.04^b	44	73.6	11.0
Control A	6.50	7.37^b	13.4	8.13	8.26	1.6	77.1	10.6	0.27	0.63^b	133	0.81	1.58^b	95	71.1	10.1
Frosted severely	6.89	7.66^b	11.2	7.93	8.42^c	6.2	77.3	11.3	0.27	0.44^b	63	0.83	1.17^b	41	73.2	10.2
Control A	5.37	7.55^b	40.6	6.04	8.33^b	37.9	75.3	10.2	0.11	0.62^b	464	0.57	1.47^b	158	72.9	10.8
Flamed lightly	7.37	7.86	6.6	7.95	9.23^b	16.1	76.9	11.2	0.14	0.45^b	221	0.66	1.33^b	102	71.8	11.9
Control A	7.19	8.39^b	16.7	8.14	9.20^b	13.0	76.1	9.8	0.27	0.57^b	111	0.82	1.45^b	77	70.9	10.8
Flamed severely	6.85	7.21	5.3	7.95	8.16	2.6	77.3	13.8	0.23	0.42^b	83	0.77	1.17^b	52	72.3	13.0

Control A	5.70	8.07[b]	41.6	6.35	8.77[b]	38.1	77.6	10.1	0.17	0.66[b]	288	0.68	1.53[b]	125	71.1	9.5
Sulfuric acid spray	6.16	6.44	4.5	7.08	7.07	−0.1	78.7	11.0	0.18	0.39[b]	117	0.68	1.18[b]	74	73.9	11.4
Control A	6.02	6.65[b]	10.5	6.48	7.75[b]	19.6	77.9	8.2	0.15	0.65[b]	333	0.67	1.65[b]	146	71.3	10.1
Potassium cyanate spray	6.13	6.67[b]	8.8	6.72	7.28[b]	8.3	79.0	11.0	0.17	0.30[b]	76	0.68	1.00[b]	47	73.6	12.6
Control A	6.02	6.65[b]	10.5	6.48	7.75[b]	19.6	77.9	8.2	0.15	0.65[b]	333	0.67	1.65[b]	146	71.3	10.1
Alkanolamine salt of 4,6-dinitro-*o*-*sec*-butylphenol (DNBP) spray	5.51	6.15[b]	11.6	6.14	6.64[b]	8.1	79.9	10.7	0.15	0.31[b]	107	0.62	1.05[b]	69	74.4	11.0
Average increase controls			22.2			21.2					304			129		
Average increase treated			8.1			6.4					103			61		
							Second Season									
Control A	2.53	...	...	3.17	...	...	71.7	...	0.10	0.37[b]	270	0.52	1.06[b]	104	72.7	19.0
Control B[d]	2.78	3.07[c]	10.4	3.48	3.75[c]	7.8	71.5	11.9	0.08	0.46[b]	475	0.51	1.18[b]	131	73.2	20.0
Frosted	2.63	2.76	4.9	3.44	3.46	0.6	72.3	13.7	0.10	0.37[b]	270	0.58	1.06[b]	82	72.2	19.8
Frosted and irrigated	2.68	2.82	5.2	3.44	3.54	2.9	71.8	13.7	0.10	0.36[b]	260	0.59	1.07[b]	81	72.7	19.2
Frosted and feeder roots cut	2.99	2.95	−1.3	3.72	3.64	−2.1	71.3	13.2	0.09	0.34[b]	278	0.56	1.02[b]	82	72.2	18.8
Control A	2.85	3.33[b]	16.8	3.56	3.96[b]	11.2	71.8	14.6	0.07	0.44[b]	529	0.48	1.08[b]	125	74.4	...
Control B	2.80	3.04	8.6	3.56	3.66	2.8	72.3	12.4	0.07	0.34[b]	386	0.44	0.94[b]	114	74.6	19.4
Flamed and irrigated	3.21	3.51[c]	9.3	3.92	4.09	4.3	71.6	14.3	0.07	0.27[b]	286	0.46	0.87[b]	89	75.8	20.6
Flamed and feeder roots cut	3.00	3.07	2.3	3.68	3.67	−0.3	72.6	13.2	0.07	0.26[b]	271	0.44	0.89[b]	102	75.2	17.4
Control A	2.64	3.26[b]	23.5	3.48	3.91[b]	12.4	72.6	13.2	0.06	0.33[b]	450	0.41	0.98[b]	139	75.4	22.7
Control B	3.19	3.52[b]	10.3	3.85	4.18[b]	8.6	72.0	12.1	0.08	0.40[b]	400	0.44[b]	1.05[b]	139	75.7	21.2
Sulfuric acid spray and irrigated	2.53	2.70	6.7	3.22	3.34	3.7	73.3	14.4	0.07	0.46[b]	557	0.36	1.06[b]	194	76.1	23.7
Sulfuric acid spray and feeder roots cut	3.03	2.94	−3.0	3.68	3.60	−2.2	71.2	14.1	0.08	0.30[b]	275	0.45	0.88[b]	96	76.3	20.2
Control A	2.36	2.74[b]	16.1	2.97	3.39[b]	14.1	73.5	12.0	0.08	0.31[b]	288	0.49	0.97[b]	98	74.6	19.1
Control B	2.53	3.00[b]	18.6	3.21	3.70[b]	15.3	72.6	11.2	0.11	0.37[b]	236	0.48[b]	1.05[b]	119	75.2	15.6
Healthy vines severed and irrigated	2.62	3.02[b]	15.3	3.39	3.62[b]	6.8	73.0	16.0	0.09	0.24[b]	166	0.47	0.80[b]	70	75.6	20.6
Healthy vines severed and feeder roots cut	2.74	2.75	0.4	3.42	3.36	−1.8	74.1	15.8	0.09	0.22[b]	144	0.46	0.79[b]	72	76.3	22.1
Average increase controls A			18.8			12.6					384			116		
Average increase controls B			12.0			8.6					374			126		
Average increase treated			4.4			1.3					279			96		

[a] Control A—sample harvested when plants treated. [b] Difference between at harvest and after storage significant at 1% level. [c] Difference between at harvest and after storage significant at 5% level. [d] Control B—sample harvested when treated plants harvested.

Roots from the injured plants sometimes showed a higher carotene content at harvest than at time of injury. In some instances, the differences were sufficient to compensate for the slower rate of accumulation during storage. Injury is known to cause temporary stimulation in other plant functions, notably respiration, and may well be the cause for this increase. This preharvest increase does not diminish the significance of the post-harvest slowdown, as a high carotene content at harvest normally does not impede synthesis during storage (Ezell and Wilcox, 1958). Conditions that result in high concentrations at harvest may be expected to continue during storage if no injury is involved.

In the second season, the treatments were extended to test the various hypotheses as to how the injury is effected. Beattie's hypothesis (1908) of transfer of frozen sap from frostbitten vines, and his recommended treatment, were discredited when injury occurred after chilling the roots without frosting the vines (results reported below) and became untenable when injury to the storage roots comparable to frost injury resulted from cutting healthy vines, and delaying harvest for the specified 5 to 11 days.

Moisture was determined on each of the 10 replicates used for carotenoid determinations in this second season and often significant increases in moisture did not occur. Of the 18 lots from injured plants only eight (3 at the 1% level, and five at 5%) had significantly higher moisture at harvest than at time of injury (controls A). Neither irrigating nor withholding irrigation and cutting the feeder roots of injured vines consistently affected the moisture content at harvest. This suggests that the increases in moisture noted may be coincidental and without special significance, perhaps a loss of solids through increased respiration rather than additional moisture uptake. Cutting the feeder roots appears to have caused some additional injury, as Orange Little Stem showed a slight decrease in carotenoids during storage when the feeder roots were cut.

Since sweet potatoes from the injured vines were not subjected to chilling temperatures at any time, and since controls B and the roots from the injured vines were subjected to the same temperatures, chilling before harvest could not have been the reason for the injury in these cases. Thus none of the three hypotheses most widely cited adequately explains how the injury is effected.

The carotene content in the first season averaged more than twice that in the second season; the controls varied widely within a season, but these differences and variations were reported earlier (Ezell and Wilcox, 1958) and are believed normal for sweet potatoes. For this reason, a specific control is applicable for a specific test and that test only. The conditions affecting the behavior of the roots are too varied and unpredictable to permit interchanging or substitution of controls.

Preharvest Chilling. To study the effects of chilling the roots without frosting the tops, whole plants with storage roots attached were transferred in bushel baskets from the field to a 40° F. storage room. By watering with 40° F. water, the soil throughout the baskets was near 40° F. the next morning. Controls, similarly transferred and treated at 60° F., were used to compensate for injury resulting from the transfer. After 3 days at these temperatures, the roots were harvested, cured, and stored in the usual manner. Table II shows that while both varieties synthesized carotenoids after transfer, synthesis was significantly less in the chilled roots.

In the second season, to facilitate the transfer of plants, each vine was trained to a narrow strip to prevent intertwining with other plants. This resulted in stunted growth with so few storage roots that all available plants were required for the 40° and 60° F. samples. No samples were analyzed at time of transfer. Only Yellow Jersey was transferred and samples were held at 40° and 60° F. as before for 8 days. In the first season, when the plants were held 3 days at 40° F., the carotene content after storage was 86% of the 60° F. control; in the second season and held 8 days, the carotene content was about 33% of the 60° F. control. These results indicate that low temperatures may cause injury without frosting the vines, and furnishes evidence that frozen sap flowing from the vines into the storage root is not the manner of impairment in frost injury.

While the limited exposure to 40° F. did not visibly injure the vines, 40° F. is well below the 50° F. reported as causing injury to sweet potato plants (Harter and Whitney, 1926). To test further the chilling-before-harvest hypothesis, possible vine chilling needed to be eliminated. To chill the roots only, whole plants were transferred to a greenhouse held at 70° F. or above. The vines were supported above the soil, and the baskets insulated with paper. The soil surface was kept covered with melting ice, which seeped through the soil, chilling the roots. The transferred controls were kept moistened with tap water. However, the transferred plants could not absorb moisture as rapidly as it was lost. After 7 days, foliage from the ice-treated plants was withered, with brownish areas on many leaves, as were the tap water controls, but to a lesser degree. The roots were then harvested, cured, and stored. Field controls were harvested, cured, and stored at time of transfer to furnish information on amount of injury resulting from the transfer.

After storage the Orange Little Stem roots harvested directly from the field had increased in carotene and total carotenoids by 16 and 9%, respectively (Table II, Second Season). Those subjected to the greenhouse treatments contained less carotenoid pigments after storage than when removed from the field. This variety is more subject to injury than Yellow Jersey, and sometimes showed slight losses, while Yellow Jersey increased significantly (Table I, Second Season). The injury to the plants resulting from the transfer, and their inability to take up enough water to supply the plant's needs at the higher temperatures, apparently caused more injury than when held at lower temperatures and where the transpiration losses were less. The Yellow Jersey ice-treated lot contained 75% more carotene, the tap water control 242% more, and the field control 592% more, than when removed from the field. Total carotenoids similarly increased by 39, 96, and 168%; the greater the injury the less the increase.

Table II. **Effects of Chilling Sweet Potato Roots without Frosting the Tops on Carotene and Total Carotenoid Pigments**

Variety and Treatment	Carotene		Total Carotenoids	
	Mg./100 g.	Change, %	Mg./100 g.	Change, %
First season				
Orange Little Stem				
Field control at time of transfer	6.94		7.91	
60° F. control after curing and storing	7.76[a]	11.8	8.50[a]	7.4
40° F. chilled after curing and storing	7.33[b]	5.6[c]	7.88	−0.4[c]
Yellow Jersey				
Field control at time of transfer	0.23		0.79	
60° F. control after curing and storing	0.44[a]	91.3	1.25[a]	58.2
40° F. chilled after curing and storing	0.38[a]	65.2[c]	1.07[a]	35.4[c]
Second season				
Yellow Jersey				
60° F. control after curing and storing	1.48		2.28	
40° F. chilled after curing and storing	0.48[c]		0.97[c]	
Orange Little Stem				
Field control at time of transfer	2.80		3.65	
Field control after curing and storing	3.24[a]	15.7	3.99[a]	9.3
Tap water control after curing and storing	2.56[b]	−8.6	3.14[a]	−14.0
Melted ice treated after curing and storing	2.64	−5.7	3.19[a]	−12.6
Yellow Jersey				
Field control at time of transfer	0.12		0.57	
Field control after curing and storing	0.83[a]	592	1.53[a]	168
Tap water control after curing and storing	0.41[a]	242	1.12[a]	96
Melted ice treated after curing and storing	0.21[a]	75[d]	0.79[a]	39[d]

[a] Difference between when transferred and after storage significant at 1% level.
[b] Difference between when transferred and after storage significant at 5% level.
[c] Rate of change between 60° and 40° F. lots significant at 1% level.
[d] Rate of change between tap water and melted ice lots significant at 1% level.

An attempt also was made to chill sweet potatoes in the field without disturbing the plants or chilling the vines, to compare the effect of low root temperatures when the vines were and were not injured by frost. Open-bottomed V-shaped troughs were placed directly over the rows; melting ice in the troughs supplied cold water for cooling. The temperature of the soil beneath the troughs ranged from 40° to 47° F. during the 9 days of treatment preceding harvest, compared with 50° to 70° F. for the controls in adjacent rows.

The results indicated that the temperatures were not low enough to cause injury under existing conditions. The treatments caused no significant difference in Yellow Jersey. In the Orange Little Stem, which seems to be more responsive to changes in environmental conditions, the carotene and total carotenoids were significantly higher in the treated lot, both at harvest and after storage thus supporting the belief that slow or inactive growth—i.e., well matured roots—is conducive to better storage quality.

Rapid *vs.* Slow Vine Growth at Harvest. Sweet potatoes have no definite period of growth and under favorable conditions may continue to grow for years. One supposedly grown in a greenhouse for 4 years, and weighing approximately 125 pounds, was exhibited at the Saint Louis Exposition in 1904. However, textbooks and other publications often specify well matured roots at harvest, apparently meaning slow or inactive growth, as a prerequisite for good storage quality. Few data to support this generalization are available. To supply pertinent information, sweet potatoes from adjoining plots were harvested and chilled before curing. One plot was irrigated, growing rapidly, and the foliage dark green at harvest. The other plot was not irrigated, the feeder roots along each side of the row were cut, and the moisture uptake was further restricted by lifting the vines to prevent adventitious roots forming. The foliage of these plants was yellow green at harvest. Samples of approximately 60 roots each from the two plots were subjected to 32° and 40° F. for different periods before curing. The roots were transferred immediately after chilling to 85° F. for curing and then stored at 60° F. Nonchilled roots were used as controls.

After storage, so many of the chilled Orange Little Stem sweet potatoes were decaying that too few sound roots remained for adequate samples. Little decay developed in Yellow Jersey during the 7-months storage. Table III shows that exposures of 6 hours or more at 32° F., or 24 hours or more at 40° F. (the minimum exposures tested) reduced carotenoid synthesis in storage. By averaging the carotenoid contents of the treated samples in each lot (rapid-growing and slow-growing), and reporting the averages as a percentage of the nonchilled controls, the effects of the rate of growth on injury can be seen readily, the lower the percentage the greater the injury. Synthesis of carotenoids in roots from the rapidly growing plants was depressed appreciably more than in roots from the slow-growing plants,

Table III. Effect of Growth Rate at Harvest on Susceptibility of Yellow Jersey Sweet Potatoes to Chilling Injury as Indicated by Postharvest Synthesis of Carotenoid Pigments

Treatment	Chilling Period, Hours	Carotene Mg./100 G.		Total Carotenoids Mg./100 G.	
		Rapid-growing	Slow-growing	Rapid-growing	Slow-growing
Control at harvest	...	0.07	0.09	0.47	0.55
Control after storage	...	0.48	0.38	1.21	1.07
Roots chilled at 32° F., cured, and stored 7 months	6	0.38[a]	...	1.08[a]	...
	12	0.39[a]	0.35	1.02[a]	0.96[a]
	24	0.45	0.27[a]	1.07[a]	0.95[a]
	36	0.27[a]	0.28[a]	0.88[a]	0.92[a]
	48	0.27[a]	0.33[a]	0.84[a]	0.94[a]
	60	0.32[a]	0.32[a]	0.93[a]	0.96[a]
	72	0.28[a]	0.24[a]	0.89[a]	0.81[a]
	84	0.23[a]	0.23[a]	0.77[a]	0.84[a]
	96	0.29[a]	0.25[a]	0.87[a]	0.86[a]
Percentage of control, average		66.6	74.7	76.7	84.6
Roots chilled at 40° F., cured, and stored 7 months	24	0.34[a]	0.36	0.99[a]	1.02
	48	0.30[a]	0.31[b]	0.98[a]	0.97[b]
	60	0.24[a]	0.33	0.86[a]	0.99
	72	0.27[a]	0.34	0.86[a]	1.00
	84	0.33[a]	0.25[a]	0.94[a]	0.86[a]
	96	0.33[a]	0.30[a]	0.92[a]	0.89[a]
	108	0.28[a]	0.29[a]	0.85[a]	0.90[a]
	120	0.30[a]	0.31[a]	0.92[a]	0.93[a]
	168	0.26[a]	0.29[a]	0.79[a]	0.88[a]
Percentage of control, average		61.3	81.3	74.5	87.7

[a] Reduction significant at 1% level. [b] Reduction significant at 5% level.

and the superiority of well matured roots is substantiated. Although the roots from the rapidly growing plants were lower in carotenoids at harvest than those from the slow-growing plants, the difference was more than equalized during storage as indicated by the unchilled controls. Normally, high carotenoid content at harvest is no deterrent to synthesis during storage (Ezell and Wilcox, 1958). The slower rate of increase during storage in roots from the slow-growing plants probably resulted from injury caused by cutting the feeder roots to ensure slow growth. That such treatment may cause injury is indicated in Table I, where slight decreases in carotenoids in Orange Little Stem sometimes occurred during storage when the feeder roots were cut.

Sweet Potatoes Harvested after Frost. After a very light frost on October 4, vines in one plot were severed at the base of the plants about sunup to prevent injury to the roots, as recommended by Beattie (1908). However, so little damage to the foliage resulted, that detectable injury to the roots seemed unlikely. Consequently, harvest was delayed awaiting greater injury to the plants. On October 21 the air temperature dropped to 22° F., the surface soil was frozen, and vines from another plot were severed at the base of the plant. A third plot was left undisturbed. Sweet potatoes were harvested from each plot 6, 13, and 22 days later. At the last harvest so many of the Yellow Jersey roots were decaying that all nondecaying roots were reserved for the storage tests.

This unusually low preharvest temperature caused some unexpected results. In all three plots and in both varieties some samples taken after storage were significantly higher in carotenoids than those taken at harvest (Table IV). Earlier results with less severe temperatures (Ezell *et al.*, 1952), showed little if any increase in storage in roots harvested several days after frost killed the foliage. These increases, however, probably are more apparent than real. Appreciable and increasing decay occurred in roots as the season advanced. Earlier results (Ezell and Wilcox, 1958) indicate that roots from slow-growing plants tend to be higher in carotenoid pigments than from the more rapidly growing ones. Also results presented above under Rapid *vs.* Slow Vine Growth indicate that sweet potatoes from more rapidly growing plants are more subject to chilling injury than are those from slow-growing plants. Only sweet potatoes showing no decay were used for analysis. Roots receiving the least injury (slow growing, high-carotenoid content) would normally survive longer than the more severely injured ones (rapid growing, low-carotenoid content). Assuming the above to hold in the present tests, sweet potatoes with the lower carotenoid content, the ones growing rapidly, would be more severely injured by the cold, and would decay more

Table IV. Carotenoids in Sweet Potatoes Harvested after Frost

	Days Delayed after Frost											
	6 Carotene, Mg./100 G.		13 Carotene, Mg./100 G.		22 Carotene, Mg./100 G.		6 Total Carotenoids, Mg./100 G.		13 Total Carotenoids, Mg./100 G.		22 Total Carotenoids, Mg./100 G.	
Variety and Treatment	At harvest	After storage[a]	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage	At harvest	After storage
Orange Little Stem												
Vines severed 17 days before killing frost	2.55	2.82	2.92	3.02	2.60	2.68	3.33	3.26	3.53	3.58	3.29	3.15
Vines severed day of killing frost	2.47	2.97	2.99	3.07	2.77	2.74	3.33	3.46	3.59	3.65	3.53	3.29[b]
Vines attracted	2.39	2.98	2.89	3.20[a]	2.28	2.30	2.93	3.47[a]	3.48	3.72[b]	2.84	2.82
Yellow Jersey												
Vines severed 17 days before killing frost	0.06	0.15	0.06	0.23[a]	...	0.33	0.40	0.62[a]	0.40	0.73[a]	...	0.88
Vines severed day of killing frost	0.06	0.23	0.08	0.45[a]	...	0.32	0.40	0.72[a]	0.47	1.08[a]	...	0.80
Vines attached	0.07	0.14	0.07	0.21[a]	...	0.28	0.40	0.59[a]	0.45	0.70[a]	...	0.82

[a] Difference after storage significant at 1% level. [b] Difference after storage significant at 5% level.

readily. Thus decay would progressively eliminate roots with the lower carotenoid content from the samples analyzed. The higher values after storage might thus arise, not from actual increases in carotenoids in storage, but from the greater proportion of high-carotenoid roots in the samples analyzed.

After remaining in the soil several days following the heavy frost, many sweet potatoes that superficially appeared sound were found on close examination after washing to have minute decayed spots. When promptly cured under favorable conditions, most of these spots developed no further in storage. Prompt curing would thus seem of prime importance if vines are inadvertently frosted.

Discussion

The injuries notwithstanding, decay during storage was generally low throughout this study. This may be ascribed to careful hand handling and strict control of the storage conditions. Under commercial procedures decay probably would have reduced the supply of roots below the minimum for adequate samples in many cases.

The consistency with which any type of injury to sweet potato vines adversely affected the behavior of the storage roots would indicate that injury to the vine was systemic regardless of how injured. This work thus supports the belief that frost impairs the storage quality of sweet potatoes, furnishes a logical explanation of how the injury is effected, and emphasizes the need to keep the interval between vine injury and root harvest minimal in the harvesting of sweet potatoes where the vines are removed or injured as a preliminary to the harvest operation.

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