Hardcore Development in Sweetpotatoes A Response to Chilling and its Remission as Influenced by Cultivar, Curing Temperatures, and Time and Duration of Chilling

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ABSTRACT

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The physiogenic disorder, hardcore, can be induced in Centennial and Jewel sweetpotatoes (*Ipomoea batatas*) by chilling the roots at 1.5 to 10 C. Centennial sweetpotato roots cured at 27 C developed much less hardcore following chilling than did fleshy roots cured at ambient temperatures (about 15.5 C). Centennial sweetpotatoes cured at 27 C and chilled early in their storage life (November) possess the ability to recover from hardcore, whereas similar fleshy roots chilled later (March) demonstrated only slight recovery capacity. Centennial sweetpotatoes cured at ambient temperatures, and exposed to chilling temperatures in January and March, exhibited some corrective capacity in January. Although the susceptible Centennial cultivar exhibited little or no such capacity in March, Jewel sweetpotatoes still recovered from hardcore at that late date. The development or disappearance of the hardcore symptom appeared to be related to modification of the pectic substances of the root tissue, in particular, protopectin.

Additional key words: chilling, curing, injury, pectin modification.

Hardcore of sweetpotatoes, a market disorder in which areas within the sweetpotato remain hard after boiling, was first reported by Ceponis and Butterfield in 1972 (3) and identified as a physiogenic disorder induced by exposure to cold by Daines et al. (4). Since hardcore may influence adversely the marketability of sweetpotatoes, obtaining an understanding of parameters that are reponsible for its occurrence, disappearance, or prevention provided the basis for this investigation. In addition, attention has been given to comparing responses of Centennial (susceptible) and Jewel (probably resistant) fleshy roots to chilling, as well as to biochemical changes in the roots that might contribute to or accompany hardcore development.

MATERIALS AND METHODS

Hardcore development in sweetpotato roots.—The sweetpotatoes used in these experiments were grown in North Carolina, harvested 11 October 1973, and stored in New Jersey. Fleshy roots were used without curing, cured for 1 week at 27 C or 3 weeks at 15.5 C. Following curing they were held at 13 C until used. The remaining sweetpotatoes were cured at ambient temperatures (15.5 - 18.5 C) in a storage house with the thermostat set at 13 C, where they were held until used.

All treatments consisted of four 5.5 kg (0.25 bushel) lots, and all sweetpotatoes were boiled for 45 minutes, cooled, and crushed by hand to detect hardcore in the crushed roots.

To determine the effects of chilling on harvested, uncured sweetpotatoes, Centennial sweetpotatoes [four 22 kg (1.0 bushel) lots] were exposed to one of five temperatures: 1.5, 4.5, 7, 10, or 13.5 C. After 1, 3, 6, and 9 days, one 22 kg lot from each temperature was removed, held at 21 C for 2 weeks, boiled, and examined for hardcore.

A second experiment was conducted with Centennial roots to determine the time required for the hardcore symptom to develop after chilling at various temperatures. Two studies were completed in this experiment, the first in mid-November, the second in mid-January. The Centennial sweetpotatoes for the first study were cured at 27 C for 1 week prior to storage at 13 C. Twenty-eight 22 kg lots were chilled at 1.5, 4.5, or 7 C for 1, 3, 6, or 9 days. After each chilling period seven 22 kg lots were removed from each temperature and six of these were stored at 21 C for 1, 3, 5, 7, 9, or 14 days. Immediately after chilling, and at the end of each storage period, three 22 kg lots (one from each chilling temperature) were examined for hardcore.

A like number of Centennial sweetpotatoes cured at ambient temperatures were similarly treated in the second study (January).

To investigate the effects of good and poor curing practices on the incidence of hardcore in chilled sweetpotatoes, roots were cured at 27 and 15.5 C. Four 22 kg lots from each curing temperature were chilled at 4.5 C for 6 days. After being chilled, they were held at 21 C and a 22 kg lot was boiled and examined for hardcore after 3, 5, 9, and 14 days.

An experiment was conducted to further test the influence of proper curing on susceptibility to hardcore, and to test the report (4) that roots of the cultivar Jewel remained free of hardcore after exposure to chilling temperatures and prolonged storage whereas those of Centennial did not.

Four 22 kg lots of Centennial and four of Jewel cultivars cured at 27 C were exposed to 1.5 C for 6 days early in the storage period (November). Late in the storage period (March), four 22 kg lots of Centennial and four of Jewel cured at 27 C, and four of Centennial and four of Jewel cured at ambient temperatures, were exposed to a chilling temperature of 1.5 C for 6 days. Immediately after chilling and after holding at 21 C for 3, 5, 9, or 14 days, one 22 kg lot of each cultivar was examined for hardcore.

Biochemical alterations in chilled fleshy roots.—Roots from the January and March chilling experiments were analyzed to determine whether changes in pectic fractions and pectic enzymes accompanied the development of hardcore in sweetpotato roots. Specifically, analyses were made of the alcohol-insoluble solids (AIS), oxalate-soluble pectin, protopectin, and pectinmethylesterase (PME) from samples of roots from various chilling treatments. Fractions were prepared by procedures outlined by Ahmed and Scott (1) and Baumgardner and Scott (2).

1) *Sampling.*—Longitudinal sections (~1 cm) were sampled from eight to twelve uncooked root halves; the other half of each root was cooked and examined for hardcore. The sections were cut into slices about 1 mm thick and immediately frozen in liquid nitrogen. The slices were fractured to a frozen powder by blending in a stainless steel Waring Blendor for eight 15-second intervals and stored in sealed polyethylene containers at −20 to −30 C.

2) *Analysis for alcohol-insoluble solids.*—Samples for alcohol-insoluble solids (AIS) analyses were prepared by boiling 50 g of frozen sweetpotato powder in 150 ml of 95% ethanol for 3 minutes; samples were cooled and the alcohol was discarded. The residue was blended with 200 ml of 95% ethanol for 3 minutes at high speed in a Waring Blendor. The blend was filtered on a coarse sintered glass funnel, and the residue was washed with 75 ml of 95% ethanol and dried at 70 C overnight. The dried residue was weighed and ground to pass a 125-μm sieve.

3) *Analysis for oxalate-soluble pectin.*—A 500 mg sample of AIS was placed in a 250-ml Erlenmeyer flask, 100 ml of 0.5% ammonium oxalate was added, and flask was shaken at about 60 rpm at room temperature (20-24 C) for 3 hours. The suspension was washed from the flask and filtered with suction through No. 1 Whatman filter paper on a Büchner funnel. The tared filter paper was then dried for 16 hours at 70 C and the extraction loss calculated.

4) *Analysis for protopectin.*—A 500 mg sample of AIS was placed in a 250-ml Erlenmeyer flask containing 50 ml of 0.5% ethylene diaminetetraacetic acid. The pH was adjusted to 11.5 with 20% sodium hydroxide, and the flask was shaken for 30 minutes. The pH was then lowered to 5.5 with acetic acid and 0.5 ml of pectinase (Nova Industries, Copenhagen, Denmark) was added. The suspension was shaken at 60 rpm on a rotary shaker for 1 hour at room temperature. The digested samples were filtered, dried, and weighed as described above for soluble pectin. In addition, preliminary trials showed that other sources of pectic enzymes (Worthington, Wallenstein, Miles-Servac), and an electrophoretically pure sample of pectin lyase (supplied by James

TABLE 1. Effects of chilling temperatures and duration during the early storage period (November) on hardcore development in Centennial sweetpotatoes cured at 27 C

Chilling		Hardcore (mean percent)							
		Storage time (days) at 21 C following chilling[a]							
Temp (C)	Time (days)	0	1	3	5	7	9	14	av[c]
. . .	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.5	1	0.0	30.2	88.7	0.0	4.7	23.8	0.0	21.1
	3	9.9	70.8	36.2	33.9	11.5	9.4	0.0	24.5
	6	6.3	68.6	67.3	36.7	37.4	44.7	2.0	37.6
	9	0.0	48.0	57.0	70.6	24.7	31.1	10.0	34.6
	av[b]	4.0	54.4	62.5	35.3	19.6	27.3	3.0	29.4[d]
4.5	1	0.0	0.0	3.2	0.0	2.9	3.6	0.0	1.4
	3	0.0	38.8	8.7	0.0	11.1	5.4	0.0	9.1
	6	0.0	2.0	5.5	21.7	7.3	6.9	0.0	6.2
	9	6.4	0.0	0.0	1.9	1.7	1.9	0.0	1.7
	av[b]	1.6	10.2	4.4	5.9	5.7	4.5	0.0	4.6
7.0	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3	0.0	1.9	0.0	0.0	1.4	0.0	0.0	0.5
	6	0.0	3.6	0.0	1.7	1.7	0.0	0.0	1.0
	9	0.0	3.9	0.0	0.0	1.8	0.0	0.0	0.8
	av[b]	0.0	2.4	0.0	0.4	1.2	0.0	0.0	0.6

[a]To compare mean percent hardcore in the body of the table: LSD ($P = 0.05$) = 9.4; ($P = 0.01$) = 12.3.

[b]To compare mean percent hardcore between storage times at 21 C for each chilling temperature: LSD ($P=0.05$) = 4.7; ($P=0.01$) = 6.1.

[c]To compare mean percent hardcore between chilling times within each chilling temperature: LSD ($P=0.05$) = 3.5; ($P=0.01$) = 4.6.

[d]To compare mean percent hardcore between chilling temperatures: LSD ($P = 0.05$) = 1.8; ($P = 0.01$) = 2.3.

Macmillan, Department of Biochemistry and Microbiology, Rutgers University) and longer digestion times with the Nova enzymes gave similar solublization of AIS as the procedure described above.

5) *Analysis for pectinmethylesterase (PME).*—A 25 g sample of root powder was blended with 150 ml of isolation medium containing sodium phosphate (0.01M, pH 7.5) and sodium chloride (0.15 M) for 3 minutes at 4 C. A 2 ml portion of the homogenate was added to 23 ml of assay mix containing 0.75% pectin NF (Sigma Chemical Co.), 0.15 M sodium chloride at 25 C. The mixture was maintained at pH 7.5 by titration with 0.05M sodium hydroxide. PME activity was expressed as milli-equivalents of ester bonds hydrolyzed per minute per gram of sweetpotato.

RESULTS

Hardcore development in sweetpotato roots.—Freshly harvested Centennial sweetpotatoes placed at chilling temperatures of 1.5, 4.5, 7, 10, and 13.5 C for 1, 3, 6, and 9 days, and then held at 21 C for 2 weeks were free of hardcore except for some roots chilled at 1.5 C for 3, 6, and 9 days. At these severe exposures 3 days chilling resulted in 24.5%; 6 days chilling, 70%; and 9 days, 42.5%, of the fleshy roots showing hardcore.

The experiments with Centennial sweetpotatoes cured at 27 C and chilled in mid-November showed hardcore development during the chilling period at temperatures of 1.5 and 4.5 C (Table 1) but not at 7.0 C. At 1.5 C, hardcore was present in fleshy roots chilled for 3 and 6 days, whereas at 4.5 C hardcore was found in the sweetpotatoes chilled for 9 days. The average values for hardcore development, as influenced by the length of time the sweetpotatoes were held at 21 C following chilling at 1.5 C [LSD = 6.1 ($P < 0.01$)], indicate that maximum amount of hardcore developed during the first 3 days after chilling, and declined significantly thereafter, with little or no hardcore remaining by the 14th day. The data in the body of the table [LSD = 9.4, 12.3; ($P = 0.05$ and 0.01, respectively)] indicate that although maximum hardcore developed early in the chilled sweetpotatoes, the maximum development seemed to be delayed somewhat in the prolonged chilling treatments, and recovery was also delayed. Chilling the fleshy roots of the Centennial cultivar at a temperature of 4.5 C (Table 1) resulted in only three treatments having a significant increase in hardcore over unchilled sweetpotatoes, whereas no significant increase in hardcore was found in fleshy roots chilled at 7 C. However, some hardcore did develop in sweetpotatoes chilled at 4.5 and 7 C, whereas no hardcore has been found in unchilled fleshy roots.

Improperly cured (ambient temperatures) Centennial sweetpotatoes chilled during January exhibited a higher incidence of hardcore at all chilling temperatures (Table 2) than did properly cured fleshy roots chilled during November (Table 1). Hardcore development in fleshy roots exposed to 10 C in January was similar to that developed from exposure to 7.0 C in November.

The average incidence of hardcore, as influenced by storage time in days at 21 C following chilling, usually

TABLE 2. Effects of chilling temperatures and duration (January) on hardcore development in Centennial sweetpotatoes cured at ambient temperatures

Chilling		Hardcore (mean percent)							
		Storage time (days) at 21 C following chilling [a]							
Temp (C)	Time (days)	0	1	3	5	7	9	14	av[c]
. . .	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.5	1	0.0	64.4	63.1	91.0	63.1	51.9	2.6	48.0
	3	0.0	85.1	90.5	85.7	90.7	69.5	38.1	65.6
	6	25.6	94.6	96.3	94.5	94.5	96.7	37.7	77.1
	9	7.4	86.7	88.4	85.2	86.8	85.1	63.9	77.9
	av[b]	8.3	82.7	84.6	89.1	83.8	75.8	35.6	65.7[d]
4.5	1	0.0	29.8	51.9	50.6	42.9	61.7	0.0	33.8
	3	0.0	85.1	90.5	85.7	90.7	69.5	11.4	61.8
	6	25.3	96.7	100.0	97.0	85.6	89.2	15.3	72.7
	9	48.5	83.8	88.4	60.6	78.4	80.2	7.6	63.9
	av[b]	18.5	73.8	82.7	73.5	74.4	75.1	8.6	58.1
7.0	1	0.0	14.0	26.2	14.0	17.4	14.8	0.0	12.0
	3	7.4	58.7	70.6	42.6	56.8	73.3	0.0	44.2
	6	64.2	53.4	72.9	92.0	64.9	90.8	14.3	64.6
	9	62.1	72.3	83.1	85.8	66.6	74.5	1.5	63.7
	av[b]	33.4	49.6	63.2	58.6	51.4	63.3	3.9	46.2
10.0	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3	0.0	0.0	3.4	0.0	8.6	0.0	0.0	1.7
	6	2.9	0.0	12.3	0.0	1.3	0.0	0.0	2.4
	9	0.0	0.0	4.2	0.0	1.6	14.5	0.0	4.7
	av[b]	0.7	0.0	5.0	0.0	2.9	3.6	0.0	2.2

[a]To compare mean percent hardcore in the body of the table: LSD ($P = 0.05$) 12.3; ($P = 0.01$) = 16.1.

[b]To compare mean percent hardcore between storage times at 21 C for each chilling temperature: LSD ($P=0.05$) = 6.1; ($P=0.01$) = 8.1.

[c]To compare mean percent hardcore between chilling times within each chilling temperature: LSD ($P=0.05$) = 4.6; ($P=0.01$) = 6.1.

[d]To compare mean percent hardcore between chilling temperatures: LSD ($P = 0.05$) = 1.8; ($P = 0.01$) = 2.3.

reached a maximum in 1 day and did not exhibit significant [LSD = 8.1, ($P < 0.01$)] remission of hardcore until after the ninth day. The data also indicate that the average incidence of hardcore increased [LSD = 6.1, ($P < 0.01$)] with the length of the chilling period up to 6 days, for chilling temperatures of 1.5, 4.5, and 7 C. At a chilling temperature of 10.0 C hardcore increased with the length of the chilling period, but the increases were barely significant [LSD = 4.6, ($P < 0.05$)]. The data in the body of Table 2 [LSD = 16.1, ($P < 0.01$)] reveal little evidence of remission of hardcore symptoms until after the ninth day.

Analysis of the data in Table 2 reveals the average percentage of hardcore in fleshy roots chilled at all temperatures for 1 day was 23.5; 3 days, 43.3; 6 days, 54.2; 9 days, 51.1. The average percentages of hardcore in fleshy roots chilled at 1.5 C was 65.7; 4.5 C, 51.1; 7 C, 46.2; and 10 C, 2.2; and unchilled check fleshy roots, 0.0. These data show that the length of the chilling period and the temperature used in the chilling significantly influenced [LSD = 3.0, ($P < 0.01$)] the incidence of hardcore.

A comparison of the mean percentages for hardcore for the indicated chilling temperatures (grand totals for chilling temperatures) indicated highly significant differences [LSD = 2.3, ($P < 0.05$) and 3.0, ($P < 0.01$)] between the chilling temperatures used. The fleshy roots in Table 2 chilled at 10 C did not show hardcore until the chilling period was of 3 or more days duration, and then its occurrence was light. Unchilled fleshy roots (4) have, without exception, remained free of hardcore. A value of 2.2% hardcore for that temperature was not statistically significant; however, had the analysis compared hardcore development in fleshy roots chilled at 10 C for 3, 6, and 9 days with hardcore development in unchilled sweetpotatoes, significance would have been indicated.

The results of an experiment designed to compare the influence of cultivar, curing temperatures, chilling temperatures, and dates of the exposures are tabulated in Table 3. An analysis of the data summarized in this table shows clearly that the Jewel cultivar is significantly [LSD = 10.5, ($P < 0.01$)] less susceptible to hardcore development, and its capacity to recover is greater and is retained longer in the storage period than it is in Centennial. In fact, even poorly cured Jewel roots exhibited substantial recovery from hardcore that resulted from chilling in March. Properly cured Centennial fleshy roots, chilled at 1.5 C for 6 days in November, exhibited fair recovery from hardcore, whereas similar fleshy roots chilled in March showed poor recovery. Data in Table 3 show that improperly cured Centennial roots, chilled at 1.5 and 4.5 C in March, exhibited little or no capacity to recover from hardcore. In addition, the average value (45.1%) for properly cured Centennial fleshy roots showing hardcore from chilling in March was significantly greater [LSD = 5.2, ($P < 0.01$)] than that (33.1%) for similarly cured and chilled fleshy roots in November. This also held for the Jewel cultivar, as an average of 15.1% exhibited hardcore in March and 8.3% in November. Curing temperature likewise had a significant [LSD = 5.2, ($P < 0.01$)] effect on the percentage of fleshy roots developing hardcore. Centennial sweetpotatoes cured at 27 C and chilled at 1.5 C for 6 days in March developed an average percent hardcore for all four record-taking dates of 45.1, whereas improperly cured fleshy roots of the Centennial cultivar exhibited an average of 77.1. The Centennial fleshy roots cured at 27 C and chilled at 4.5 C for six days, developed an average for the four hardcore reading dates of 5.2%, whereas Centennial roots cured (dried) at the poor curing temperature of 15.5 C and chilled at 4.5 C showed an average of 50.8% hardcore.

Biochemical alterations in chilled fleshy sweetpotato roots.—1) *Alcohol-insoluble solids (AIS).*—Centennial roots stored at 13 C for 3 months showed relatively small fluctuation in AIS [9.8 - 13.4% fresh weight basis (fwb)], soluble pectin (39-44% of AIS; 4.3 - 5.3% fwb) and protopectin (27-34% of AIS; 3.3 - 3.6% fwb). However, roots chilled at temperatures where hardcore developed (Table 2) exhibited a pronounced increase in AIS (as high as 22.8% fwb), a consistent decrease in soluble pectin expressed as percentage of root tissue (2.2 - 6.3 fwb) and a consistent increase in the protopectin content of the root (as high as 12.0% fwb). These data for roots chilled at 1.5

TABLE 3. Hardcore development in Centennial and Jewel sweetpotatoes chilled in November and March after exposure to different curing conditions

Cultivar	Curing temp (C)	Chilling temp[a] (C)	Hardcore (mean percent) Storage time (days) at 21 C following chilling[b] 3	5	9	14
			November			
Centennial	27	1.5	67.3	35.0	30.1	0.0
Jewel	27	1.5	25.3	7.2	0.7	0.0
			March			
Centennial	27	1.5	50.2	46.8	51.9	31.8
Centennial	Ambient temp	1.5	64.7	58.0	95.0	90.8
Jewel	27	1.5	37.4	14.3	8.9	0.0
Jewel	Ambient temp	1.5	51.9	16.6	12.8	1.9
Centennial	27	4.5	2.8	7.6	6.1	4.5
Centennial	15.5	4.5	47.5	50.0	60.8	45.1

[a]Chilling time was 6 days.
[b]Level of significance for least significant difference. To compare mean percentages of hardcore. LSD ($P = 0.05$) = 7.9, LSD ($P = 0.01$) = 10.5.

TABLE 4. Effects of chilling on alcohol-insoluble solids of Centennial sweetpotatoes

Chilling time (days)	Storage time (days at 21 C)	Hardcore (%)	Proportion of fresh weight of root (%)		
			AIS[a]	Soluble pectin	Protopectin
1.5 C					
1	0	0.0	11.4	4.2	4.3
1	1	62.2	13.6	3.7	6.9
1	3	63.8	16.2	4.0	12.0
1	5	91.0	17.6	3.3	9.6
1	7	63.6	18.2	4.4	9.0
3	1	93.1	17.4	2.8	10.5
3	9	69.1	17.6	4.2	8.1
6	3	96.3	10.0	2.8	5.6
6	5	95.4	11.0	2.2	6.4
6	7	95.0	16.4	3.4	8.4
6	9	96.8	16.8	4.5	7.7
9	0	8.5	11.0	3.1	4.9
9	3	95.3	17.0	4.1	9.3
9	5	83.1	17.4	3.6	9.5
9	7	93.3	22.8	5.0	8.8
9	9	100.0	20.0	4.8	7.4
4.5 C					
1	0	0.0	9.2	3.7	3.1
1	1	29.9	19.2	3.8	6.6
1	3	51.7	17.2	3.6	9.4
3	3	93.6	17.6	4.4	7.4
3	9	80.9	16.4	4.0	7.5
6	3	97.1	10.6	2.9	4.7
6	5	95.7	10.8	3.2	5.4
6	7	85.7	17.4	4.7	7.1
6	9	88.8	16.6	4.4	8.2
9	0	44.3	10.6	2.7	6.1
9	3	89.0	18.0	4.1	9.6
9	5	77.9	19.2	6.3	7.3
9	7	60.0	21.6	5.3	7.7
9	9	95.2	19.8	4.8	7.4

[a]AIS = alcohol-insoluble solids.

TABLE 5. Effects of chilling on the alcohol-insoluble solids of Jewel sweetpotatoes

Chilling time (days at 1.5 C)	Storage time [days at 21 C (70 F)]	Hardcore (%)	Proportion of fresh weight of root (%)		
			AIS[a]	Soluble pectin	Protopectin
0	0	. . .	13.8	3.8	3.9
6	1	34.0	18.8	3.9	6.5
6	2	66.9	18.3	4.1	6.1
6	5	15.9	18.4	4.0	5.5
6	6	12.1	18.4	4.2	5.1
6	7	29.5	18.5	4.7	5.0
6	8	18.1	17.7	4.2	4.5

[a]AIS = alcohol-insoluble solids.

TABLE 6. Pectinmethylesterase activity[a] of Centennial and Jewel sweetpotatoes after chilling

Cultivar	Chilling time (days at 1.5 C)	Storage time [days at 35 C (70 F)]	Hardcore (%)	PME (me $\times 10^{-3}$)
Centennial	0	0	. . .	4.2[a]
	6	1	73.1	4.0
	6	2	100.0	4.1
	6	9	94.7	4.2
Jewel	0	0	. . .	4.6
	6	1	34.0	4.6
	6	2	66.9	4.5
	6	8	18.1	4.6

[a]The number of milliequivalents of ester bonds hydrolyzed per minute per gram of sweetpotato tissue at pH 7.5, 25 C, and with 0.15 M NaCl, when acting on 0.75% pectin solutions. Controls stored at 13 C after harvest.

C and 4.5 C are summarized in Table 4.

2) *Oxalate-soluble pectin.*—The soluble pectin fraction of roots increased with hardcore development with certain storage conditions (e.g., 1.5 C for 9 days followed by holding at 21 C storage), but did not do so under other conditions of storage (e.g., 4.5 C for 1 day followed by holding at 21 C).

3) *Protopectin.*—The protopectin content increased with hardcore development in most cases (Table 4-6). Jewel sweetpotatoes, which exhibited a remission of hardcore during holding at 21 C (Table 3), showed a parallel decrease in the protopectin fraction (Table 5). The protopectin content did not change stoichiometrically with the incidence of hardcore. This may relate to the fact that incidence rather than severity of hardcore was measured in the storage experiments.

DISCUSSION

The experiments with uncured Centennial roots indicate that sweetpotatoes may develop hardcore from exposure to severe chilling during the period between harvest and curing that is not corrected in a 2-week period at 21 C. Although hardcore was not found after the 2-week holding period, in fleshy roots chilled to 4.5, 7, 10, or 13.5 C for 1 to 9 days, or at 1.5 C for 1 day, it seems likely that symptoms did occur earlier in the holding period in some of the treatments, but had disappeared by the end of the experiment. These data suggest that hardcore resulting from chilling during the harvest period will disappear during the curing and holding period.

The experiments using Centennial and Jewel sweetpotatoes indicate that as the storage season progresses the incidence of hardcore from chilling increases, and especially in Centennial the capacity for symptom remission during a 14-day holding period following chilling is seriously reduced and even lost. It also appears from the data that the hardcore response to chilling is initiated late in the storage period, by higher temperature than is the case early in the storage period. The report (4) that curing temperatures have a marked effect upon hardcore response is corroborated by experiments reported here. Fleshy roots cured at favorable temperatures show less hardcore than do poorly cured ones (ambient or low curing temperatures). The poorly cured sweetpotatoes also exhibit a reduced capacity to recover from hardcore as compared with properly cured ones. The differences in response to chilling between the Centennial and Jewel cultivars are marked. At all portions of the storage season that were investigated, Centennial developed significantly [LSD = 10.5, ($P<0.01$)] more hardcore than did Jewel. In addition, Jewel exhibited a much greater capacity to overcome hardcore symptoms. This was especially true late in the storage season and with improperly cured fleshy roots.

The difficulty of protecting Centennial sweetpotatoes against hardcore development is indicated by the occurrence of symptoms in a high percentage of poorly cured fleshy roots following exposures in January to 4.5 or 7 C for 1 day or 10 C for 2 days. These temperatures are common in northern market areas, which indicate the need to protect hardcore-susceptible cultivars against chilling.

In our biochemical studies the protopectin fraction measured represents a modified form of pectic substances since results were very similar when electrophoretically pure pectin lyase (free of cellulase, hemicellulase, and α-1, 4-glucanase) was substituted for the crude Nova pectinase preparation.

We also have observed that various commercial pectinase preparations, as well as the purified pectin lyase, softened and separated the cells of raw and cooked slices of sweetpotato exhibiting hardcore. Other enzyme preparations, including proteases (pronase, trypsin, ficin) amylases (α-amylase, β-amylase, glucoamylase), cellulase, hemicellulase, and lipase did not soften hardcore tissue. Areas of roots which exhibited hardcore stained the same with phloroglucinol as hardcore-free controls; apparently hardening is not caused by gross lignification. Root slices exhibiting hardcore that were cooked in 50mM EDTA did not soften. Moreover, slices of root cooked in medium containing up to 0.4 M $CaCl_2$ did not develop hardcore, although the texture was firm. Also, there was no apparent change in pectinmethylesterase activity during chilling of Centennial and Jewel sweetpotatoes (Table 6). These observations appear to exclude calcium pectate formation as the mechanism of hardening.

The data, although inconclusive, suggest that hardcore is related to a modification of the middle lamella substances associated with pectin.

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