# Relationship of Chilling to Development of Hardcore in Sweetpotatoes

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## ABSTRACT

A condition we have called "hardcore", which develops in the fleshy roots of sweetpotato (*Ipomoea batatas*) after exposure to chilling, was common in the cultivar Centennial, but was rare in cultivar Jewel. Exposure of Centennial sweetpotatoes from selected, field run, and virus-free plants to chilling temp just before, or during the harvest, storage, marketing, or use periods was effective in eliciting this response among fleshy roots from all sources used. Sweetpotatoes cured at 27 C (80 F) developed less hardcore than did fleshy roots cured at 15 C (60 F), following the same chilling and holding exposures.

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*Additional key words:* physiological disorder, market disorder.

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An internal disorder of sweetpotatoes in which the cooked fleshy roots contained hard tissue was first noticed in 1968 and was described by Ceponis and Butterfield in 1972 (1) as hard areas that failed to soften during cooking. Such areas may occur as hard central cores or firm outer cylinders or, in extreme cases, the entire fleshy root may be firm. These hard areas may be of any shape or size, but are usually lengthened in the long axis of the sweetpotato. If a sweetpotato is halved and one half boiled to detect hard areas, the corresponding area in the uncooked half may be slightly darker than surrounding tissue.

Low temperature or chilling injury was considered a possible cause, but this symptom is unlike any other (3, 4, 5, 6) attributed to exposure to cold. Association with the cold winter months was shown by Ceponis and Butterfield (1) who reported that this disorder was most common in samples collected in retail stores in the New York area after January. Up to 15 percent of moist-type sweetpotatoes collected during this period were affected in varying degrees. Although sweetpotatoes often could not be identified as to a cultivar, roots of Centennial that were identified exhibited this disorder.

Our studies have been directed toward determining the cause and, hopefully, the control of this disorder. They include consideration of the possible role of a virus (2), pathogenic organisms, or environmental factors.

## A. SWEETPOTATOES PRODUCED IN NORTH CAROLINA

*Materials and Methods.*—Sweetpotatoes (cultivars Centennial and Jewel) harvested on 8 and 28 September and 24 October were purchased from a North Carolina grower and shipped on 8 October and 19 November to Rutgers University and Belle Mead, New Jersey. On arrival, those [13 crates of each cultivar, $3.9 \times 10^{-2}$ m$^3$ (1-1/9 bu.) capacity] from the 8 September harvest were cured at 27 C for 10 days and then held at 13 C (56 F) until used. Similar amounts of sweetpotatoes from the other two harvest dates were cured at 27 C, 21 C (70 F), and 15 C for 10, 20, and 30 days respectively, after which they were held at 13 C.

The roots were examined for hardcore twice monthly, October through March. Each examination involved one-quarter of a crate of sweetpotatoes from each of four crates. The examination consisted of cutting each fleshy root in half longitudinally, boiling one half of each root

for 30 min, cooling, and examining for hardcore. Each replication was boiled separately. Where hard areas were found in the cooked half, the uncooked half was used for cultural studies to determine whether an organism might be associated with this condition. The media used to detect fungi and bacteria were potato-dextrose and nutrient agar.

Since Ceponis and Butterfield reported (1) that hardcore appeared during the cold months, the possible relationship of chilling to hardcore symptoms was studied by the following experiments:

Ten crates of sweetpotatoes from each cultivar received from North Carolina were chilled at 6 C (42 F) for 2 days prior to their curing. Of these six crates (two from each of the three harvest dates) of each cultivar, Centennial and Jewel, were cured for 10 days at 27 C, and then stored at 13 C. In addition, two crates from each cultivar taken from each of the last two harvest dates were placed, after chilling, at 15 C for 30 days, after which they were held at 13 C until examined for hardcore.

In February, six crates from each cultivar (two from each of the three harvest dates) that had been cured at 27 C and four from each cultivar (two from each of the last two harvest dates) that had been cured at 15 C, were put in 1 C (34 F) rooms for 3 days, and all were returned to 13 C until boiled.

As the storage experiments with sweetpotatoes from North Carolina were being completed, the remaining Centennial sweetpotatoes were exposed to 1 C for 7 days, and then held 3 wk at 13 C before boiling. This period was selected to represent the near-maximum time that might elapse during shipping, marketing, and use, and to allow maximum hardcore to develop.

*Results.*—Hardcore symptoms were not found in sweetpotatoes that had not been chilled. Over 4,000 Centennial and 5,000 Jewel roots were examined on 11 cooking dates which extended from October through March. Of the Centennial roots held for 2 days at 6 C before curing and storage (Table 1), only a few roots (6 in 559 examined) had hardcore and the hard areas were small.

In the sweetpotatoes that were chilled for 3 days at 1 C in February, incidence of the disorder, and size of the affected areas, greatly increased (Table 2). Fifty-eight (9.3%) of the 621 Centennial roots examined and 4 of 758 roots of Jewel (0.5%) were affected.

In the final experiment with Centennial and Jewel sweetpotatoes from North Carolina, hardcore was found in all lots and a portion of the data is reported in Table 3. Of 529 Centennial roots, 205 (38.6%) developed hardcore; of the 642 Jewel sweetpotatoes 5 (0.8%) showed the same symptom. The incidence of hardcore in all of the chilling experiments was higher with roots cured at 15 C than with roots cured at 27 C.

TABLE 1. Incidence of hardcore in Centennial[a] sweetpotatoes chilled at 6 C for 2 days before storage[b]

| Harvest date | Curing temp (C) | Roots examined (no.) | Showing hardcore | |
|---|---|---|---|---|
| | | | (no.) | (%) |
| 8 Sept | 27 (80 F) | 155 | 3 | 1.9 |
| 28 Sept | 15 (60 F) | 114 | 2 | 1.8 |
| | 27 | 96 | 1 | 1.0 |
| 24 Oct | 15 | 101 | 0 | 0 |
| | 27 | 93 | 0 | 0 |

[a]Jewel sweetpotatoes receiving the same temperatures as the Centennials tabulated above were all free of hardcore.
[b]Sweetpotatoes cured for 10 days at 27 C and 30 days at 15 C. The holding temperature was 13 C.

TABLE 2. Incidence of hardcore in Centennial[a] sweetpotatoes chilled at 1 C for 3 days early in February

| Harvest date | Curing temp (C) | Roots examined (no.) | Roots showing hardcore (%)[b] |
|---|---|---|---|
| 8 Sept | 27 (80 F) | 125 | 1.5 A |
| 28 Sept | 15 (60 F) | 104 | 33.6 B |
| | 27 | 159 | 2.4 A |
| 24 Oct | 15 | 104 | 15.5 B |
| | 27 | 129 | 1.5 A |

[a]Four out of 758 Jewel sweetpotatoes treated as the Centennials tabulated above showed slight symptoms of hardcore.
[b]Treatments followed by the same letter do not differ at $P = 0.05$ according to Duncan's multiple range test.

TABLE 3. Incidence of hardcore in Centennial sweetpotatoes near the end of the storage period following chilling at 1 C for 7 days

| Harvest date | Curing temp (C)[a] | Total sweetpotatoes showing hardcore | |
|---|---|---|---|
| | | (no.) | (%)[b] |
| 8 Sept | 27 (80 F) | 49 | 27.4 CDEF |
| 28 Sept | 15 (60 F) | 25 | 93.7 A |
| | 21 (70 F) | 20 | 79.8 A |
| | 27 | 21 | 33.2 BCDEF |
| 24 Oct | 15 | 34 | 55.7 B |
| | 21 | 72 | 17.1 EF |
| | 27 | 69 | 32.8 BCDEF |

[a]Curing period, 27 C - 10 days; 21 C - 20 days; and 15 C - 30 days.
[b]Treatments followed by the same letter do not differ at $P = 0.05$ according to Duncan's multiple range test.

## B. SWEETPOTATOES PRODUCED FROM HARDCORE AND VIRUS-FREE SPROUTS

*Materials and Methods.*—During the spring before the above storage experiments were begun, Centennial sweetpotatoes suspected of having hardcore were cut in half longitudinally, one of the halves boiled, and the other half of those showing hardcore were dipped and bedded in sand. The dipping suspension contained a mixture of DCNA (2, 6-dichloro-4-nitroaniline); and benomyl. The resulting sprouts were grown in the greenhouse for one year, one to a $1.14 \times 10^{-2}$ m$^3$ (3-gal) container filled with 2:1 mixture of steam-sterilized sand and soil. In addition, a few virus-free Centennial plants were grown, as described above, in a screened area.

Fifteen of the Centennial plants coming from fleshy roots showing hardcore were used in a preharvest soil-

TABLE 4. Influence of preharvest temp on hardcore development in Centennial sweetpotatoes of plants grown from virus-free or hardcore-containing roots

| Temp (C) | Duration of chilling | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 4 days | | | | 12 days | | | |
| | Virus-free source | | Hardcore source | | Virus-free source | | Hardcore source | |
| | Fleshy roots (no.) | Roots showing hardcore (%) | Fleshy roots (no.) | Roots showing hardcore (%) | Fleshy roots (no.) | Roots showing hardcore (%) | Fleshy roots (no.) | Roots showing hardcore (%) |
| 2 (35 F) | 19 | 42.1 | 20 | 30.0 | 29 | 93.0 | 12 | 100.0 |
| 4 (40 F) | 16 | 0.0 | 22 | 0.0 | 16 | 75.0 | 15 | 66.7 |
| 7 (45 F) | 26 | 0.0 | 21 | 0.0 | 19 | 95.0 | 18 | 83.0 |
| 10 (50 F) | 26 | 0.0 | 30 | 0.0 | 25 | 0.0 | 26 | 4.0 |
| 21 (70 F) | 25 | 0.0 | 20 | 0.0 | 11 | 0.0 | 18 | 0.0 |

chilling experiment. Of these, five plants were held in a dark chamber at 21 C and 10 plants were placed in a similar chamber at 3 C (37 F) for 2 wk. Then all plants were harvested and the fleshy roots dipped in a DCNA-benomyl mixture. The 24 fleshy roots from the plants held at 21 C, and 20 roots from five of the plants exposed to 3 C, were placed in the 21 C chamber for 1 wk, while 18 roots from the remaining five plants were returned to the 3 C chamber; and the temp gradually raised to 13 C during the next 7 days. The sweetpotatoes from each treatment were examined for hardcore.

In a second experiment with plants produced from Centennial roots showing hardcore, 18 sweetpotatoes from three plants grown in a greenhouse were harvested, dipped in a DCNA-benomyl mixture, chilled at 3 C for 2 wk, then stored 4 days at 21 C. Eight of the 18 roots showed decayed areas and were discarded. The remaining 10 roots were examined for hardcore. In addition, in a prestorage experiment, 18 roots harvested from hardcore plants were cut in half and one half of each root boiled immediately. The remaining halves were chilled for 4 days at 3-4 C (37-40 F) and examined for hardcore.

A third experiment involved 31 fleshy roots from 10 Centennial plants grown in a greenhouse from hardcore sweetpotato roots. These roots were cured at 15 C for 3 wk, then held at 13 C for 3 wk, chilled at 1 C for 1 wk, and then held 2 wk at 13 C before examination for hardcore.

Virus-free Centennial plants (meristem source) were multiplied by cuttings and planted, one to a $1.90 \times 10^{-2}$ m$^3$ (5-gal) container. In the fall, before harvest, the virus-free plants and plants produced from hardcore roots were exposed to 3 C and 21 C for 4 and 12 days. The fleshy roots were harvested, stored for 7 days at 21 C and boiled and crushed to detect hardcore. The source plants were indexed for virus prior to taking cuttings and the individual plants used in the experiment were indexed just before chilling. Indexing was accomplished by cleft-grafting stem tissue from the sweetpotato plants onto plants of *Ipomoea setosa* L. and examining for foliar symptoms after 4 wk.

*Results.*—In the preharvest soil-chilling experiment, all 38 sweetpotatoes harvested from the Centennial plants that were held 2 wk at 3 C, regardless of the subsequent treatment, exhibited hardcore that involved the entire fleshy roots; no hard areas were found in the 24 fleshy roots of plants exposed only to 21 C during the 2 wk before harvest.

In the second experiment, all of the 10 Centennial sweetpotato roots that were chilled at 3 C immediately after harvest and then held 4 days at 21 C also showed hard, unsoftened tissue that involved the entire sweetpotato after boiling. In the prestorage experiment, none of the 15 roots that were cut in half and boiled or held at 3-4 C for 4 days and then boiled showed hardcore symptoms.

In the third experiment, where the roots were stored 6 wk before being chilled at 1 C, 10 of the 31 sweetpotatoes examined contained hard areas.

The preharvest chilling experiment, with Centennial roots produced from hardcore and virus-free plants (Table 4), showed that hardcore was as prevalent in virus-free sweetpotatoes as in those produced from a hardcore source.

DISCUSSION.—The results of these experiments suggest the following conclusions:

(i) The Centennial sweetpotato shows much more hardcore on boiling than does the Jewel sweetpotato after both have been exposed to the same chilling environments.

(ii) Hardcore is a physiological response of the fleshy roots to chilling. No evidence was found that suggests an association of fungi, bacteria, or viruses with the occurrence of hardcore.

(iii) In these experiments hardcore did not develop unless fleshy sweetpotato roots were exposed to 6 C or less for at least 2 days.

(iv) Centennial sweetpotatoes cured at 27 C developed less hardcore (L.S.D. 23.3 and 12.2, $P < 0.05$) than those that were cured or dried at 15 C.

(v) Chilling Centennial sweetpotatoes at any time from before harvest and through marketing and use may induce hardcore.

To prevent development of hardcore, Centennial

sweetpotatoes should not be exposed to chilling temp, either in the soil before harvest or during harvesting, storage, or marketing. Good curing practices (curing in warm, humid rooms) also should help prevent hardcore development.

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