

Effects of Wilting, Drought, and Temperature Upon Rotting of Sugar Beets During Storage¹

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Storage of sugar beets, *Beta vulgaris* L., in large piles at receiving stations between time of harvest and processing is a common practice in most sugar beet regions of the United States. Such storage ranges from a few days to 3 or 4 months and is advantageous both to growers and processors, but its usefulness is limited seriously by loss of sugar through the natural process of beet respiration and by rotting caused by microorganisms. In some storage piles the former type of loss predominates. In others, rotting caused by microorganisms is by far the more important. These organisms break down the normal cell structure of the roots, utilizing the sugar for their own growth and respiration and producing heat which, together with that evolved by the respiration of the beets, tends to raise pile temperature and thus accelerate both beet respiration and rate of rotting. This vicious cycle leads frequently to excessively high temperature, resulting in such rapid rotting that large sections of a pile are rendered unfit for use within a few days or weeks. In fact, in more than one instance, an entire pile of thousands of tons has been totally lost in this way.

Rotting of sugar beets during storage is influenced by a wide variety of factors. High storage temperature has long been recognized as a serious hazard, and freezing of roots between time of lifting and piling is generally regarded as an extremely important factor predisposing them to attack by microorganisms. Larmer (4)³ found that poor soil fertility—especially shortage of phosphorus—has a detrimental effect on keeping quality. Inadequate moisture during the growing season also was found to be conducive to rot. Tompkins and Nuckols (5, 6) showed that hook injury made during harvest contributes to the development of rot and that low topping also is detrimental. Some years ago it was observed by the writer that storage rot losses were more severe among mother beet roots which had become wilted in the field after lifting than among roots which were stored promptly. A similar observation was made by Stout and Fort (1) in connection with respiration studies, and such a tendency has been suspected by sugar company agriculturists in recent years.

The experimental work reported in this paper was begun at Fort Collins, Colorado, in 1948 for the purpose of obtaining more detailed in-

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³ Numbers in parentheses refer to literature cited.

formation regarding the importance of some of the factors listed above insofar as rot loss is concerned. Data pertaining to certain other factors are presented by the author in contemporary papers (2, 3).

STORAGE METHODS

Samples of sugar beet roots were hand topped, avoiding hook injury, and stored in shallow wooden boxes in 2 insulated rooms held at 65° F. and 45° F. ($\pm 2^\circ$ F.). Continuous forced ventilation was provided, the air in each room was circulated constantly, and relative humidity was maintained at a level high enough to prevent excessive evaporative loss in weight of healthy roots. Average relative humidity was approximately 93 percent in each room during the 1948-49 storage season and about 97 to 98 percent

Table 1.—Effects of pre-storage drying upon keeping quality of sugar beet roots stored for 13 and 19 weeks at 65° F. and 45° F., respectively; results given as averages of duplicate samples of 18-19 roots each. Fort Collins, Colorado, 1948-49.

Drying period in sunlight	Loss in weight during drying period	Loss in weight during storage		Weight of rotted tissue at end of storage	
	Percent	65° F. Percent	45° F. Percent	65° F. Percent	45° F. Percent
½ hr. (check)	11.7	2.8	11.8	4.3
1 day	6.0	12.9	0.9	31.9	11.4
2 days	9.9	18.7	2.6	65.6	27.3
4 days	15.4	26.1	3.5	87.5	34.2
L. S. D. (5-percent point)				11.7	6.3

during the following season. Atmospheric carbon dioxide determinations made periodically during the first storage season indicated that the maximum concentration reached in either room was less than 0.5 percent.

The percentage of rot in each sample was determined at the end of storage by separating and weighing the rotted and healthy tissue. Storage periods during the fall and winter of 1948-49 were approximately 3 and 4½ months for the 65° and 45° rooms, respectively. In the 1949-50 season, rot determinations were made for both rooms 2 months after harvest, in order to permit temperature comparisons; also at the end of storage periods of approximately the same length as those of the first year. Of the 1949-50 results, only the 2-months' storage data were obtained in time to be included in this paper.

WILTING OF ROOTS AFTER HARVEST 1948-49

On October 20, 1948, 16 comparable samples of freshly harvested sugar beet roots of a commercial variety—18 to 19 roots per sample—were washed, drained, weighed, and divided into 4 groups of 4 samples each, which were then dried out of doors in direct sunlight for ½ hour (check), 1 day, 2 days, and 4 days, respectively. Weather was relatively dry and sunny. The samples were covered at night to prevent freezing, reweighed after drying, and divided between the 2 storage rooms—2 samples per room for each treatment. Rot weighings were made after approximately 13 weeks' storage at 65° and 19 weeks at 45°.

The results as presented in Table 1 and Figure 1 show a very striking trend from relatively little rot for roots dried $\frac{1}{2}$ hour to 7 or 8 times as much rot for roots which had lost 15.4 percent of their weight during 4 days' pre-storage drying. Each successive increase in drying time, beyond the $\frac{1}{2}$ hour given the check treatment, was accompanied by a statistically significant increase in percentage rot at both temperatures.

1949-50

On October 12, 1949, a similar experiment was begun using 40 samples of 18 roots each. Weather was dry and sunny on the whole, and the samples were handled in about the same way as in the preceding experiment with one important difference. After 2 months' storage each sample was weighed and divided as nearly as possible into two 9-root samples equivalent in

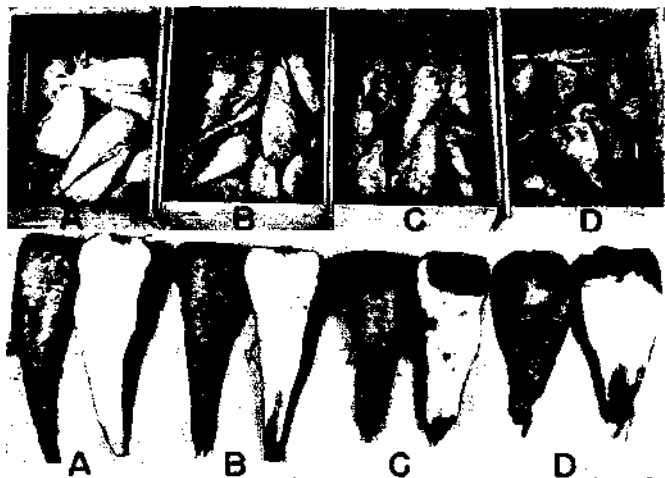


Figure 1. Sugar beet roots showing effects of pre-storage drying upon keeping quality. A, Dried $\frac{1}{2}$ hour; B, Dried 1 day; C, Dried 2 days; D, Dried 4 days. Top—samples after 3 months' storage at 65° F. Bottom—representative roots from samples stored 4 months at 45° F.

apparent amount of rot. One was used for immediate determination of percentage rot and the other was returned to storage for later rot determination.

The data obtained after 2 months' storage are given in Table 2. These results confirm the findings of the preceding experiment insofar as the disastrous effects of field wilting are concerned. In addition they show consistent contrasts between storage rooms with average percentage rot in the

65° room amounting to approximately 7 times that occurring at 45°. Since storage conditions in the two rooms were very nearly identical, except for temperature, that factor is considered as largely responsible, basically, for the difference in percentage rot.

DROUGHT

1948-49

In a field near Ault, Colorado, in 1948, a long 8-row strip of a commercial variety which had been well watered until August 27 or 28 was divided into 6 sections, in each of which rows 4 and 7 were used as a pair of plots. In section 1, the furrow on each side of row 7 was irrigated on September 13 and October 5, row 4 receiving no irrigation after August 27 or 28. In section 2, row 4 was irrigated, number 7 remaining dry, and this same alternating system was used throughout the other 4 sections. Weather was dry from the time of the last general irrigation until after harvest. At harvest (October 12) the soil was quite moist in the series of "wet" plots and very dry in the other series. In the dry plot in sections 4, 5, and 6, foliage was somewhat wilted and a small percentage of the roots were rather flaccid. In the other 3 sections drought effect appeared to be much less severe and

Table 2.—Comparison of keeping quality of sugar beets dried after harvest for varying periods and stored for 2 months at 65° F. and 45° F. Percentage-rot data are given as averages, each based on five 9-root samples; other storage data are averages from five 18-root samples each. Fort Collins, Colorado, 1949.

Drying period in sunlight	Loss in weight during drying period	Loss in weight during storage		Weight of rotted tissue at end of storage	
	Percent	65° F.	45° F.	65° F.	45° F.
1 hr. (check)		5.9	4.7	2.3	0.5
1 day	2.9	8.5	4.3	15.2	2.1
2 days	8.1	8.9	3.5	30.5	5.2
4 days	13.2	13.5	4.2	52.5	6.8
L. S. D. (5-percent point)				9.9	1.7
General mean				25.0	3.65

no flaccid roots were found. Seventy five consecutive roots were dug carefully by hand in each plot and divided into 3 comparable samples of 25 roots each. After being washed and weighed, sample 1 was analyzed for sucrose percentage and samples 2 and 3 were stored at 65° and 45°, respectively.

With harvest performance of the wet treatment taken as 100 percent, the dry treatment results were as follows: average weight per root 92.3, percentage sucrose 106.3, and gross sucrose per root 98.8. These figures indicate an appreciable but largely compensating effect of drought upon root size and sucrose percentage, with negligible effect upon yield of gross sucrose.

As shown in the summary of storage results (Table 3), the average percentage rot for the dry plots was significantly greater than that obtained for the wet plots—data from both temperatures combined.

1949-50

A randomized-block field experiment with 8 treatments, 6 replications, and 6-row, 40-foot plots was laid out in 1949 in a field of a commercial

sugar beet variety near Wellington, Colorado. All plots were watered alike until August 29-30, the time of the last general irrigation. Thereafter, check plots received no more irrigations, and Treatments W1 and W2 were irrigated once and twice, respectively. Weather was very dry after the last general irrigation, and by harvest time foliage in check plots wilted considerably in midday. There was relatively little wilting in plots of W1 and

Table 3.—Effects of moderate drought late in the season upon storage rot of sugar beets; results given as 6-plot averages. Fort Collins, Colorado, 1948-49.

Storage temperature C.F.	Storage period Days	Wt. of rotted tissue at end of storage	
		Well irrigated Percent	Soil dry at end of season Percent
65	96	33.9	43.3
45	139	14.4	28.8
Analysis by Student's method (both temperatures combined):			
Mean difference		11.87 ¹	
t		2.30	
P		< .05	

¹ A significant difference, based on the 5-percent point.

none in W2. Roots were somewhat less turgid in check plots than in plots of the other 2 treatments. The effect of drought upon harvest performance in check plots, based on results obtained for the W2 treatment, was about like that recorded for the preceding experiment. Yields of gross sucrose of 2.187, 2.096, and 2.223 tons per acre for check, W1, and W2 treatments, respectively, did not differ significantly.

Four samples of 25 roots each were obtained from each plot on October 3 for storage comparisons. Border effect was eliminated and special care was taken to avoid puller injury. Adhering soil was removed by hand insofar as practicable without apparent injury to the tap roots, and the samples were placed in storage at once without washing, and containing approximately 1.2, 1.9, and 1.9 percent soil for the check, W1, and W2 treatments, respectively. The 4 samples from each plot were divided between the 65° and 45° storage rooms.

After 2 months' storage, the percentage rot was determined for one sample per plot in each room, adhering soil disregarded. The summarized results (Table 4) fail to show significant effects of drought upon rot development. Temperature effects are shown strikingly, average percentage

Table 4.—Comparison of storage rot development among sugar beets matured under differing soil moisture conditions and stored for 2 months at 65° F. and 45° F.; results presented as 6-plot averages. Fort Collins, Colorado, 1949.

Treatment number	Irrigations after Aug. 29-30 ¹ Number	Wt. of rotted tissue at end of storage	
		65° F. Percent	45° F. Percent
Check	0	9.54	0.55
W1	1	7.92	0.69
W2	2	7.85	0.44
I. S. D. (5-percent point)		9.72	0.49
General mean		8.44	0.56

¹ All plots irrigated alike up to and including August 29-30.

rot of 8.44 for the 65° room amounting to 15 times that occurring at 45°. Figure 2 is presented in an attempt to illustrate representative types of rotting occurring at the 2 temperatures, irrigation treatment disregarded—roots taken from supplementary samples which had been washed before being stored.

The above results indicate that, under some conditions, moderate drought late in the season tends toward greater susceptibility to storage rot. These



Figure 2. Exterior and interior view of sugar beet roots after 72 days' storage, showing effects of temperature on development of storage rot. Top, 65° F.; bottom, 45° F. Photographed by Beet Sugar Development Foundation, December 14, 1949.

findings are in agreement with the results obtained by Larmer (4) from an experiment in which low-moisture plots were irrigated only 3 times throughout a dry season as contrasted with plots irrigated every 2 weeks from June 14 to September 15, inclusive.

SUMMARY

Samples of topped sugar beet roots were stored for periods ranging from 2 to $4\frac{1}{2}$ months, approximately, under conditions of high humidity, forced ventilation, and continuous circulation of air, with 2 temperature

levels—65° F. and 45° F., approximately. At the end of storage the percentage of rot in each sample was determined by separating and weighing the rotted and healthy tissue.

Two years' results from replicated experiments showed conclusively that wilting of washed roots out of doors in dry, sunny weather has very disastrous effects upon keeping quality. Percentage rot was relatively low in check samples (dried ½ to 1 hour), becoming progressively greater for 1, 2, and 4 days' drying and, for the latter exposure, ranging from 7 to 23 times that obtained for the checks.

In 1 year's results the average percentage rot found, after 3 to 4½ months' storage, in samples taken from plots in which moderate drought conditions had existed late in the season, was significantly greater than that occurring in samples from well watered plots. In the following year the differences between similar treatments, in percentage rot, were negligible at the end of 2 months' storage.

Influence of storage temperature upon rotting was shown strikingly by results obtained from 2 large sets of root samples, each set divided between 2 storage rooms and held for 2 months with relative humidity averaging approximately 97-98 percent. Average rot percentages for the 2 groups of samples stored in the 45° room were 3.65 and 0.56, whereas the comparable percentages for 65° storage were approximately 7 and 15 times as great, respectively.

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