

Effect of Low and Fluctuating Temperatures on the Storage Life of Sugarbeets¹

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Introduction

The optimum temperature for sugarbeet storage and the precision with which this temperature must be maintained are important factors to consider in designing permanent and semipermanent structures for long-term storage. Determining an optimum storage temperature for sugarbeet is difficult. Temperatures below 4°C substantially reduce respiration rates (2, 4)³ but increase raffinose accumulation (5, 8), so the optimum temperature represents a compromise.

Initial cooling and subsequent temperature control of beet storage piles is accomplished by the use of ventilation fans and available cool night air. Because the availability of cool air is not constant, the result is relatively slow cooling coupled with warming and cooling cycles. The effect of these fluctuations on beet storage life has not been studied. Dilley (4) reported large increases in respiration rates when roots were moved from lower to higher temperatures (in the range of 0 to 20°C) in short-term experiments. These data indicate that fluctuations in temperature may be important in determining the storage life of sugarbeets.

The objective of this study was to determine the effect of fluctuating storage temperatures (in the range of -1 to 10°C) on rate of respiration, loss of sucrose, and accumulation of reducing sugars during 140 days of storage.

Methods

The roots used in preliminary respiration studies had previously been stored for 100 days at 5°C (40°F). Ten samples of eight roots each were placed in a respirometer at an initial temperature of 5°C. The temperature of the roots was monitored continuously with thermocouples imbedded in the outer 1 cm and at the center of one root in each sample. The respiration rate was monitored every 3 hours.

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³Numbers in parentheses refer to literature cited.

The roots used in long-term studies were machine harvested, hand washed, and sorted into 13 storage treatments. Each treatment was replicated 10 times with eight roots per replicate. The storage-temperature treatments were as follows:

1. Constant -1, 1.5, 5, and 10°C.
2. Weekly fluctuations between -1 and 1.5°C, -1 and 5°C, -1 and 10°C; 1.5 and 10°C; 5 and 10°C; and 1.5 and 5°C.
3. Constant 5°C, except for 1 week per month at -1, 1.5, or 10°C.

Each sample was weighed before and after storage, and all analyses were corrected for weight loss. Sucrose was measured before and after storage by a method standard with many beet sugar companies and similar to the method outlined in A.O.A.C. (1) and corrected for the presence of raffinose and invert sugars (3). Raffinose and reducing sugars were determined by paper chromatography and dinitrosalicylic acid (6), respectively. Respiration rates were determined twice daily with an infrared gas analyzer and an automatic switching system. Air containing approximately 150 μ l/liter of carbon dioxide was passed (500 ml/min) through each container and the increase in CO₂ content measured. The respiration rates reported are those measured after 5 days at each temperature when the rates had stabilized. Although the samples were subjected to fluctuating temperatures as described above, respiration rates could not be measured on all samples every week because the number of samples exceeded the sampling capacity of the analyzer at 1.5 and 10°C.

For determination of temperatures causing cellular damage, 2x10-mm root disks were exposed to temperatures from -7 to 3°C for 2 hours. A 2.5 cm-thick aluminum plate was constructed with circulation tubes drilled in each end. Coolant at -10°C was circulated through one end and water at 5°C through the other; conductance by the aluminum plate established a linear temperature gradient over its length. Root disks were placed directly on the plate, and the actual temperatures of the disks were determined with thermocouples. After the cold treatment, the disks were placed in flasks containing 5 ml of water and kept at room temperature for 75 minutes. Cellular damage, manifested by a loss of cellular contents (primarily sucrose), was then estimated from the carbohydrate content of the solution, as measured by the anthrone method (7).

Results

Short-term Respiration Studies

In the first respiration experiment, root temperature was decreased from 5 to 1°C during a 24-hour period and then kept steady

for about 2 days. During this time, the respiration rate decreased by 50% (Figure 1). The root temperature was further decreased to -1°C during a 24-hour period and then held constant for 6 days. As the root temperature reached -1°C , the rate rose sharply; this proved to be a consistent pattern in subsequent studies. At -1°C , the roots had frost on the surface, but the root tissue itself was not frozen (visual evaluation based on absence of watery appearance). When roots were kept at -1°C , the respiration rate declined to a constant rate slightly higher than the rate at 1°C and then remained constant. As the root temperature was brought back up to 5°C , the respiration rate rose sixfold temporarily but then stabilized at a level almost double the original rate of 5°C .

In a second experiment, the temperature was cycled between -2 and 1°C (Figure 2). This small fluctuation resulted in a threefold

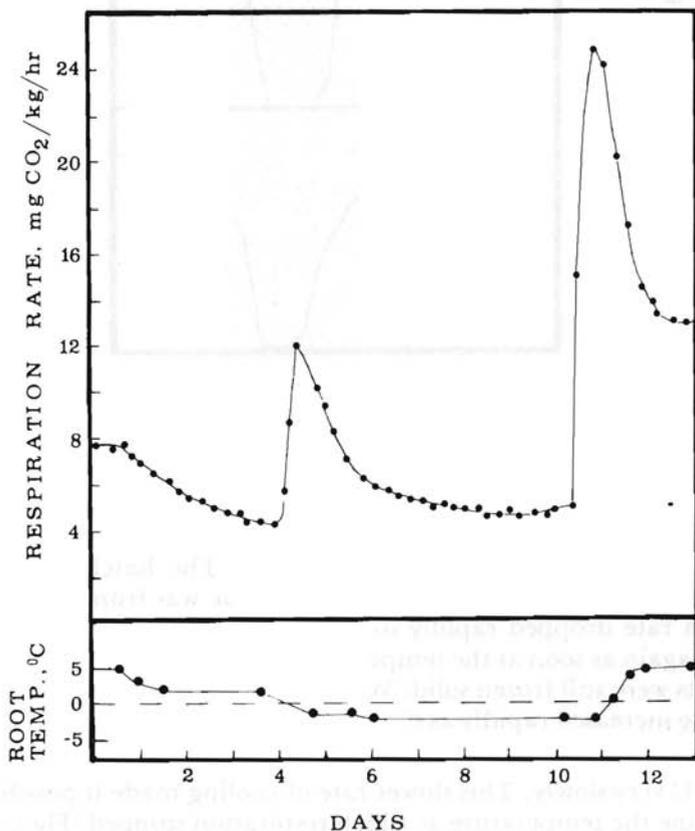


Figure 1.—Respiration rate of sugarbeet roots (previously stored at 5°C) subjected to steady temperatures near 0°C . Data recorded every 2 hours, but only 6-hour averages reported.

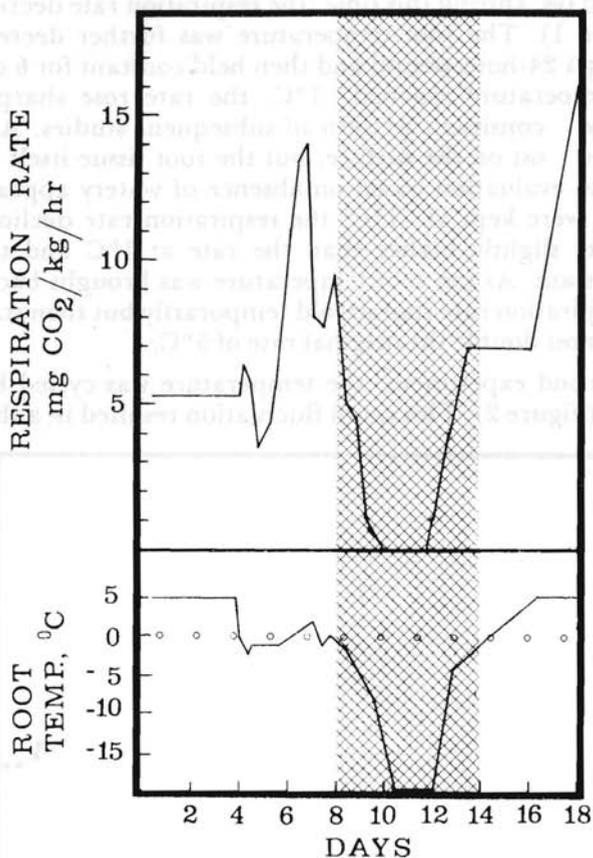


Figure 2.—Respiration rate of sugarbeet roots (previously stored at 5°C) subjected to fluctuating temperatures near 0°C.

increase in respiration rate. After the temperature was cycled near freezing, it was rapidly lowered to -18°C . The hatched area in Figure 2 indicates the time that the root tissue was frozen. The respiration rate dropped rapidly to near 0 at -18°C , but respiration started again as soon as the temperature was increased, even though the roots were still frozen solid. When the roots thawed, the respiration rate increased rapidly as the roots quickly deteriorated.

In a third experiment, the temperature was decreased from 5 to -18°C very slowly. This slower rate of cooling made it possible to determine the temperature at which respiration stopped (Figure 3). The typical spike in respiration rate was encountered as the temperature passed -1°C . The respiration rate decreased gradually until the temperature reached about -8°C , at which point the rate

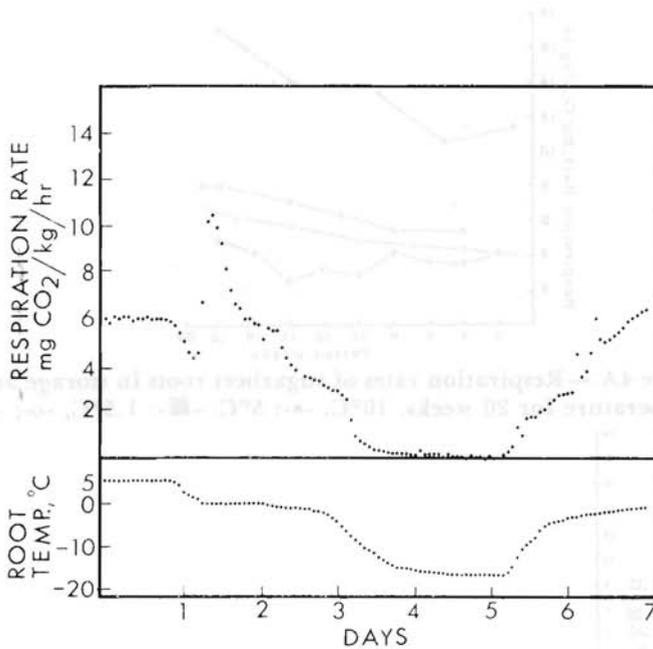


Figure 3.—Respiration rate of sugarbeet roots (previously stored at 5°C) between 5 and -15°C. Data recorded every 1.5 hours.

declined sharply to near zero. However, respiration was still detectable at -18°C. As in the second experiment, when the temperature of the root increased the respiration rate also increased, although the roots were still frozen.

Long-term Studies

The objective in the long-term studies was to determine the effect of weekly temperature fluctuations on sucrose losses. As the samples were moved from colder to warmer temperatures, the respiration rate increased rapidly to a peak and then decayed to an equilibrium level after about 4 to 5 days. The data shown in figures 4A and 4B are the equilibrium rates for the weeks and temperatures indicated.

Respiration rates of roots stored at a constant -1, 1.5, or 5°C remained relatively constant, indicating that the beets remained in excellent condition throughout the 20-week storage period (Figure 4A). With regard to respiration, little advantage is gained by storage of beets at temperatures below 5°C. In contrast, the respiration rate rose at 10°C, and the roots showed signs of mold after about 8 weeks of storage. If the data in Figure 4B are compared with those

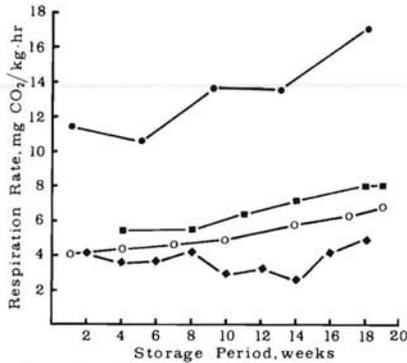


Figure 4A.—Respiration rates of sugarbeet roots in storage at constant temperature for 20 weeks. 10°C, -●-; 5°C, -■-; 1.5°C, -○-; -1°C, -▲-.

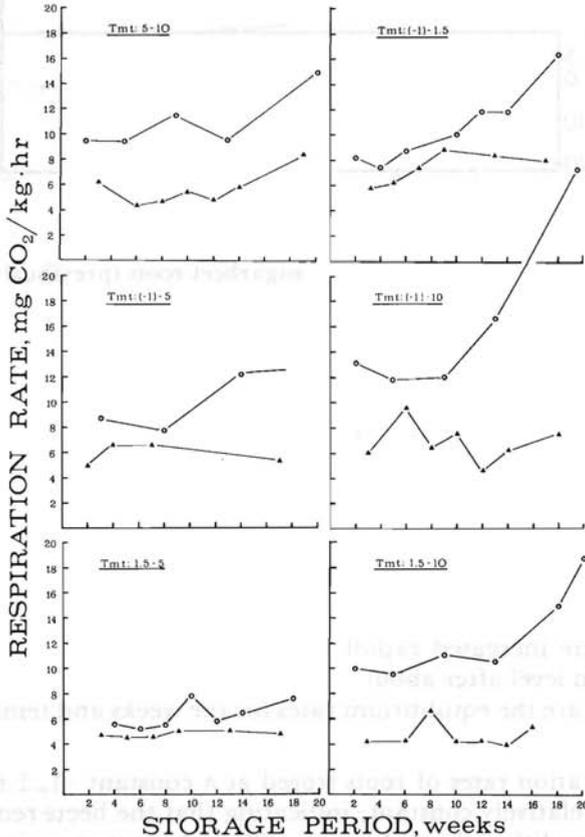


Figure 4B.—Examples of the respiratory rates of sugarbeet roots exposed to weekly temperature fluctuations of varying magnitude. -○- Respiration rate during period when samples were at warm temperatures, =▲=, respiration rate when samples were at colder temperature.

in Figure 4A it is apparent that any fluctuation in temperature reduced storage life; the respiration-rate curves are more upward-sloping than those for constant temperatures. However, the 1.5-5°C treatment (Figure 4B) appears to be the least detrimental during 20 weeks of storage.

Loss of sucrose did not differ significantly in roots stored at a constant -1, 1.5, or 5°C (Table 1). The roots remained in excellent condition and losses were minimal. The respiration rates of roots stored at these temperatures differed very little (Figure 4A).

Table 1.—Loss of sucrose and accumulation of reducing sugars in sugarbeet roots stored at constant or fluctuating temperatures for 20 weeks.

Root Temperature		Mean Temperature °C	Loss of Sucrose kg/ton	Accumulation of Reducing Sugars mg/kg
Treatment °C	Fluctuation °C			
-1	0	-1	43	369
1.5	0	1.5	44	1076
5	0	5	47	1529
10	0	10	58	3976
1.5 and 5	3.5	3.3	44	1614
-1 and 5	6.0	2.0	57	1992
1.5 and 10	8.5	5.8	57	3261
5 and 10	5.0	7.5	67	4518
-1 and 1.5	2.5	0.3	70	5645
-1 and 10	11	4.5	91	9689
5 and -1*	6.0	3.5	54	3718
5 and 1.5*	3.5	4.1	48	1553
5 and 10*	5	6.3	58	1990
LSD (.05)			7.3	1254

*Constant 5°C except for 1 week per month at indicated other temperature.

There was a small but consistent increase in accumulation of reducing sugars with an increase in temperature in constant-temperature conditions but not enough to justify storage of beets below 5°C. Increasing the temperature to 10°C significantly increased loss of sucrose and accumulation of reducing sugars. From visual observation, it was apparent that roots stored at 10°C had more mold growth, particularly in the injured areas, than roots stored at 5°C or below.

All weekly temperature fluctuations significantly increased sucrose loss over storage at a constant temperature, except the fluctuations between 1.5 and 5°C. The temperature extreme was more important than the magnitude of fluctuation or the mean-treatment temperature; for example, samples exposed to extremes of -1 to 10°C had higher losses than samples exposed to extremes of 1.5 or 5°C.

Sucrose loss in roots stored at a constant 5°C, except for 1 week per month at 1.5°C, was not significantly different from that during storage at a constant 5°C. However, exposure for 1 week per month to -1 or 10°C significantly increased sucrose loss over that during storage at a constant 5°C.

Accumulation of reducing sugars and loss of sucrose were highly correlated ($R = 0.96^{**}$) in roots subjected to fluctuating temperatures. Therefore, the loss of sucrose was not only a function of respiration rate but also conversion to reducing sugars.

Freezing-point Determinations

The amount of carbohydrate released by root disks increased as temperature was decreased below 0°C (Figure 5). At 0°C, the first cells began to show damage. At -2°C, cell damage became extensive, and at -3°C, half of the cells were damaged, or frozen. All cells were damaged, or frozen, at -5°C.

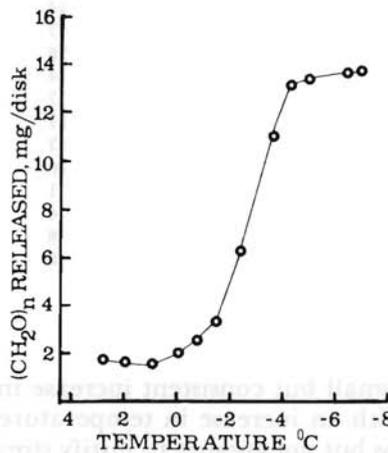


Figure 5.—Loss of carbohydrates by sugarbeet root disks exposed to temperatures from 3 to -7°C.

Discussion

The results indicate that storage life is reduced and sucrose loss and reducing sugars are increased when sugarbeet roots are exposed to fluctuating temperatures or temperatures of -1°C or below.

The optimum temperature range for storage appears to be between 1.5 and 5°C. Fluctuations within this range can be tolerated without increasing sucrose loss over that incurred by storage at a constant 1.5 or 5°C. Roots stored at these temperatures can

also tolerate brief exposure to warmer temperatures with only moderate damage. Irreversible damage, as demonstrated by loss of cellular contents and increased respiration rates, results from exposure to temperatures below -2°C .

From a practical standpoint, these results indicate that outside air, or plenum air, below -2°C should not be introduced into a beet storage pile destined for long-term storage unless the beets are to be frozen. The only time that lower temperatures would be warranted is when pile temperatures were excessively high (above 10°C), and the potential losses from the high temperature would outweigh the reduction of storage life induced by the excessive cooling. Undoubtedly, the advantages of cooling beets immediately after harvest with air at -2°C under these conditions would outweigh the disadvantage of reduced storage life. When the pile is relatively warm (10 to 15°C), only those beets within a few feet of the ventilation tubes are exposed to the air at -2°C . Therefore, -2°C can be safely introduced into a storage pile early in the storage period if due caution is observed.

The carbohydrate-release data indicate a loss of metabolic control and an increase in membrane permeability at 0 to -1°C . It is not readily apparent whether these changes result from actual freezing or merely chilling injury. For some epidermal cells with a low osmotic potential, -1°C may be very near the freezing point. Also, freezing of water in the free space at -1°C may cause desiccation of cells and, thus, indirect injury.

Chilling injury normally occurs in nonhardy plants exposed to cool temperatures (5 to 10°C). Because the sugarbeet is semihardy, chilling injury may not occur until temperatures approach 0°C . In this study, the sugarbeets were injured near 0 to -1°C , but chilling and freezing injuries could not be differentiated.

It is interesting that respiration did not stop until the root temperature reached -18°C , at which point the roots were frozen solid. Therefore, when a pile of beets is to be deep-frozen, the temperature should be reduced below -5°C as quickly as possible. Insufficient freezing air could result in cooling only to -1 to -3°C , causing an increase in respiration rates and, subsequently, increasing the amount of freezing air and time required for completion of deep-freezing.

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