Studies on the Respiration of Sugar Beets as Affected by Bruising, by Mechanical Harvesting, Severing Into Top and Bottom Halves, Chemical Treatment, Nutrition and Variety

MYRON STOUT[1] AND C. H. SMITH[2]

Introduction

Loss of sugar and quality from sugar beets during storage results from a combination of respiration and spoilage of the roots. Since two separate factors are involved it is necessary to study both in an attempt to improve storage conditions. If both factors can be studied at the same time on the same beets, kept under the same constant environmental conditions, the data secured should prove most valuable. The equipment and technique to be described was developed by C. A. Fort and the senior author to meet these requirements. The equipment and technique works very well in studies of various factors such as topping level, effect of partial drying before storage, various storage atmosphere compositions and chemical treatments of the roots. The method, however, has certain limitations for breeding and selection work. It is designed primarily for fairly large samples of beets (88 pounds or more) and it requires considerable time and space to get complete data on a large number of samples as needed in selection and breeding work. For this type of program it should be used for studies of progress made in breeding varieties and supplemented by some form of the Warburg technique for respiration and mycological method for resistance to organisms causing spoilage.

Equipment and Methods

The respiration chambers shown in Figure 1 are 55-gallon steel drums fitted with removable tops, gaskets and compression clamps. They are fitted with perforated metal false bottoms about 1 to 1/2 inches high and a series of about 20 finely perforated metal trays mounted on a small pipe extending from the bottom to near the top of the drum. Discarded centrifugal basket lining was used for making the trays. About six pounds of finely pulverized hydrated lime on the metal trays absorbs the carbon dioxide and some of the respiratory moisture from the beets which are piled around the column of trays. Two 3/16-inch copper tubes are sealed into the top of the drum. One is connected by rubber tubing to a 5-gallon bottle filled with oxygen and mounted on top of the drum. The other copper tube is used for with-

[1] Physiologist, Division of Sugar Plant Investigations of the Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Department of Agriculture.

[2] Agronomist, Division of Sugar Plant Investigations of the Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Department of Agriculture.

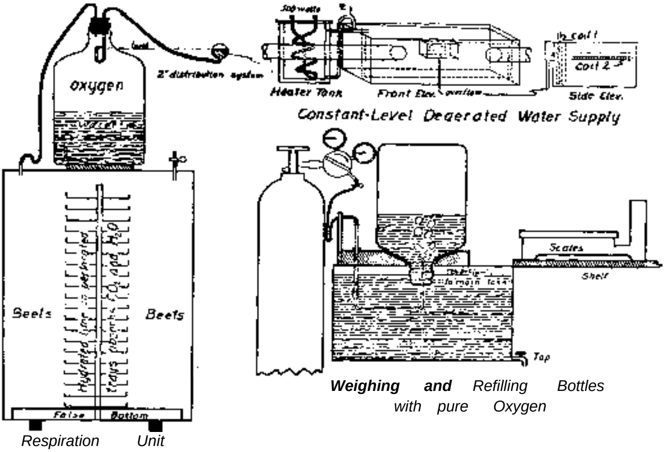

Figure 1. Equipment for respiration studies at constant-atmosphere composition.

drawing gas samples for analysis and for adjusting the oxygen concentration inside the drum. Each 5-gallon bottle is fitted with a two-hole rubber stopper. One glass tube for connecting to the drum should extend about two inches above the stopper (to prevent siphoning of water into the drum in the event that all of the oxygen in the bottle is used up). The other glass tube through the stopper is bent into a gooseneck about 1½ to 2 inches long, but narrow so that it can be inserted easily into the bottle. It should also extend through the stopper about 2 inches to enable easy adjustment with the constant-level, deaerated water supply without raising or lowering the drum.

A surplus of water is deaerated by heating to about 140° to 160° F. and allowing it to flow in a thin film across a metal tray before entering the constant-level tank. Two copper coils in the constant-level tank serve the dual purpose of cooling the heated water and warming the feed water before it is finally heated in a small tank equipped with a 500-watt immersion coil heater. Cold water flows into a sight feed tube, then through the primary copper coil in the front compartment of the constant-level tank. This part is insulated from the main body of the tank by a double partition extending to near the bottom of the tank. The water then flows through the secondary coil which is supported in a horizontal position about 1/2 inch below the surface of the water *in* the larger compartment of the tank. It then flows to the bottom of the insulated immersion heater tank, is heated **to** 140° F. or more and flows across the metal tray and into the main body of the constant-level tank. Partially cooled water flows under the double-partition and into the front compartment where it is cooled to near room temperature for use in the distribution system or to the waste overflow. Sediment or floating solids are removed by the partition. The overflow is conducted to the tank for filling the bottles with water and then oxygen by water displacement.

With the convenient equipment for refilling the bottles with oxygen shown in figure 1, one man can weigh 16 bottles and refill them with oxygen in about 40 minutes.

Since temperature control is very important the drums are supported about two inches from the floor and air is circulated throughout the room by a fan. Air temperature in the room is kept constant by the addition of a small amount of heat from a 1,000-watt fan-equipped heater located near a good-grade thermostat equipped with a solenoid switch. The air from the heater is directed toward the thermostat so that the temperature of the room never exceeds the thermostat setting.

Periods of declining barometric pressure reduce the apparent respiration rate by causing expansion of the gas in the drum and bottle. This error can be corrected by calculating the expansion due to the change in pressure, but the practice at Salt Lake City has been to average daily values for periods long enough to compensate for changes in barometric pressure.

The use of 40 kg. of beets per drum was chosen because this is about the safe limit for some samples of beets to be supplied with oxygen from a 5-gallon bottle for 24 hours at 68°-70° F. and 655 mm. barometric pressure. By refilling the bottles twice daily or by lowering the temperature larger samples can be used.

Sampling the beets for respiration and chemical analysis is probably the most difficult problem. Each lot to be tested is washed, uniformly topped and the taproot trimmed off to avoid breakage in handling. Samples are then selected to give uniform number, weight and size distribution of beets. The beets are then sealed in the drums, connected to the oxygen and de-aerated water supply and the gooseneck adjusted about 1/4 inch above the water-supply level when the sampling outlet to the drum is open. A small amount of air is withdrawn to start the flow of water into the bottle and the sampling outlet closed. Any leakage to the system will cause the dropping of water into the bottle to stop. After a period of 12 to 20 hours of testing for leaks and allowing the sugar beet roots to reach thermal equilibrium with the room, the sampling outlet is again opened, the gooseneck lowered so that water barely drips into the bottle, the sampling outlet closed and the bottle refilled with oxygen. The water is weighed and the bottles refilled at the same time each day thereafter during the test.

Samples of the gas in the drum are withdrawn periodically for analysis and a correction for the volume of gas withdrawn is applied to the tare weight of the bottle. The oxygen concentration in the drums was usually held at 20 to 22 percent during the tests reported here. The CO- was less than 0.1 percent. A piece of 1/16-inch diameter rubber tubing is convenient for withdrawing samples for analysis so that the Orsatt apparatus need not be moved.

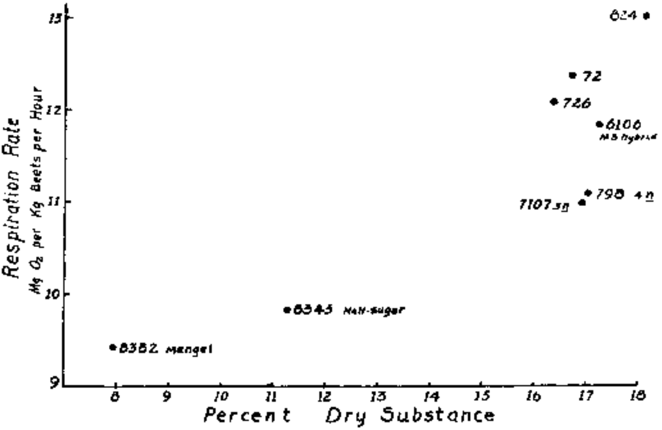

Figure 2. Relation of respiration rate of various varieties of beets to percent dry substance.

Experimental Results

Eight varieties or treatments of sugar beets were studied in 1948. Respiration tests were run in duplicate, with two analytical samples of twenty beets each per drum. By analyzing separately the top and bottom halves of some of the samples of the sugar beet variety S. L: 710 from the Harraan farm, both before and after the respiration test, it was possible to obtain data on losses caused by severing the beets before storage as well as the differential losses from the top and bottom halves of beets which were stored intact and then the respective portions analyzed. The effect of three rates of application of "Barsprout," a commercial product used to prevent sprouting of potatoes, was studied. Barsprout contains 2.2% methyl ester of naphthaleneacetic acid in a fine, inert powder. It is dusted on the potatoes as they are stored.

Comparisons were made between beets which were harvested carefully by hand and others harvested by a machine equipped with a Reinks screen. Other comparisons were made between two different varieties grown on the same field and the same variety grown on two different fields.

Table 1.—Effect of variety, field, harvesting method and chemical treatment on respiration, chemical change and losses during respiration test at 68° to 70* F. for 45 days. (Respiration rates are average values of two tests for 10 days for each period.)

Variety, source and treatment	Respiration rate mg. O_2 per kg. of beets per hour 10-day period No.				Analytical losses (original minus final analysis)				Sugar losses per ton per day		
	1	2	3	4[1]	Dir. pol. (Sugar)	Dry sub.	Purity coef.	Invert (Incr.)	Resp. (2nd period)	Invert or spoilage	By anal. dir. pol.
	Mg.	Mg.	Mg.	Mg.	%	%	%	%	Lbs.	Lbs.	Lbs.
S. L. 710 (Harman farm)											
Carefully dug	13.0	10.8	10.4	10.0	0.98	0.73	2.05	0.20	0.46	0.09	0.44
Machine dug	13.1	10.2	9.7	9.6	1.26	0.86	2.95	0.21	0.44	0.09	0.56
Top and bottom halves severed	17.6	13.9	15.4	16.8	2.13	1.71	3.96	0.52	0.59	0.23	0.93
Top halves intact					1.36	1.04	2.71	0.21		0.09	0.60
Top halves severed					2.18	1.82	3.85	0.45		0.20	0.97
Bottom halves intact					0.94	0.58	2.32	0.20		0.09	0.42
Bottom halves severed					2.09	1.59	3.94	0.59		0.26	0.93
S. L. 710 (Hill farm)											
Carefully dug[2]	11.2	9.2	9.2	10.0	1.58	0.95	4.78	0.27	0.39	0.12	0.70
1.56 lbs. Barsprout[2]	16.8	12.6	13.7	16.4	2.02	1.32	5.70	0.36	0.54	0.16	0.90
3.12 lbs. Barsprout[2]	18.8	14.9	17.4	21.7	2.76	1.62	8.99	0.65	0.64	0.29	1.23
6.24 lbs. Barsprout[2]	16.9	16.7	17.0	18.4	2.08	1.29	6.16	0.41	0.71	0.18	0.92
S. L. 79 (Hill farm)											
Carefully dug	13.8	13.1	16.0	21.6	1.80	1.24	4.62	0.37	0.56	0.16	0.80
Average all treatments:	15.4	12.7	13.6	15.6							

[1] 15-day period

[2] Pounds Barsprout per ton of beets

Average respiration rates, grouped into three ten-day periods and one 15-day period, are shown in Table 1. The rather rapid decline in respiration rate after the first 10-day period is observed on nearly all samples harvested

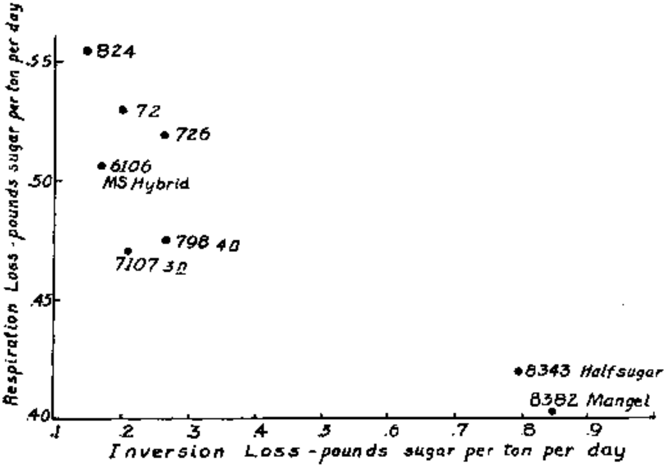

Figure 3. Relation of losses of sugar from several varieties of beets due to respiration and inversion or spoilage.

in the fall and is correlated with reversal of thermal induction when thermally induced sugar beets are stored at a warm temperature. Later increases in respiration rate are usually correlated with spoilage of the beets and may be due partially to respiration of fungi on the roots. The second 10-day period probably represents the normal, non-spoilage respiration rates of the beets under study.

The differences in chemical analysis of the beets before and after the 45-day period at 68° to 70° F. and losses of sugar in pounds per ton of beets per day as calculated from normal respiration, decreased direct polarization and increased invert sugars are also shown in Table 1. It is evident from the data that the normal bruising and abrasions the beets received in machine harvesting caused no increased loss due to respiration or inversion over beets which were harvested carefully by hand. The lower loss, based on direct polarization, of the carefully harvested beets might be questioned because it is lower than the normal respiration loss. This is theoretically improbable. Severing into top and bottom halves, however, greatly increased respiration

Table 2.—Respiration rates, chemical change and losses of different varieties of beets during respiration test at 68° to 70° F. for 48 days. (Respiration rates are average values of two tests for 10 days for each period.)

	Respiration rate mg. O_2 per kg. of beets per hour					Analytical losses (original minus final analysis)				Sugar losses per ton per day		
	10-day period No.											
Variety S. L. No.	1	2	3	4	5[1]	Dir. pol. (sugar)	Dry sub.	Purity coef.	Invert (incr.)	Resp. (2nd period)	Invert or spoilage	By anal. dir. pol.
	Mg.	Mg.	Mg.	Mg.	Mg.	%	%	%	%	Lbs.	Lbs.	Lbs.
798	12.9	11.1	11.0	11.1	10.1	2.34	2.06	3.78	0.64	0.48	0.27	0.98
824	14.8	13.0	13.3	13.0	11.5	2.06	1.84	2.80	0.35	0.56	0.14	0.86
7107	12.5	11.0	11.4	11.3	10.2	1.57	1.25	3.18	0.30	0.47	0.21	0.65
72	13.6	12.4	12.9	13.1	12.4	2.13	1.59	5.00	0.48	0.53	0.20	0.89
6106	13.7	11.9	11.5	11.6	10.3	1.01	1.07	0.49	0.40	0.51	0.17	0.42
729	14.0	12.2	11.9	12.3	11.0	2.31	2.00	4.13	0.62	0.52	0.26	0.96
8382	9.5	9.4	11.0	13.3	14.6	3.43	1.45	36.80	2.03	0.40	0.85	1.43
8348	10.2	9.8	11.5	13.9	13.0	3.63	1.66	24.13	1.91	0.42	0.80	1.51

[1] 7-day period

and inversion losses as well as loss in polarization. The top halves of beets stored intact showed no difference from the bottom halves in spoilage but sugar loss was greater from the top halves. This was no doubt due to a greater respiration rate of the top halves as shown in previous studies. Apparently translocation of sugar from bottom to top did not compensate for the greater respiratory loss of sugar from the top. Loss of sugar from the top halves of severed beets was slightly greater than that from the bottom halves but spoilage was greater in the bottom halves. This small difference again suggests greater respiration as being the cause.

Variety S. L. 710 from the Hill farm sustained a lower respiration loss but greater spoilage than S. L. 710 from the Harman farm. The loss in purity of S. L. 710 from the Hill farm was also more than twice that of the same variety grown on the Harman farm. Losses were greater in variety S. L. 79 from both respiration and spoilage than S. L. 710.

Dusting beets with Barsprout at either one-half, normal or twice the amounts recommended for potatoes greatly increased the respiration, spoilage and loss of sugar from the beets. Barsprout cannot be recommended for the storage of sugar beets. Research at the Boyce Thompson institute for Plant Research has shown that methyl ester of naphthaleneacetic acid is effective in preventing the accumulation of objectionable sugars in potatoes stored at cool temperature. It seems probable that increased respiration of the potatoes utilizes the sugars as fast as they are formed and thus prevents accumulation. However, the writers know of no reports on the effect of this chemical on the respiration of potatoes.

Effect of Added Commercial Fertilizer on the Respiration and Spoilage of a Single Variety of Sugar Beet

Applications of commercial fertilizers were made to 4-row strips of beets on the Carlisle farm, near Salt Lake City, May 25, 1949. The field had been planted April 14 with variety U. S. 22/3. The plot was selected because it was a light sandy loam soil, had been in beets the previous year, had not been fertilized following the beet crop and had shown no evidence of nematode infestation. Eight treatments were included in the test. The fertilizer was added to both sides of each of the two center rows and these were used for the yield, chemical analysis and respiration studies. There was little evidence of response to the added fertilizers during the summer or at harvest September 23, 1949.

The yields and chemical analyses indicated no evidence of nutritional deficiency but did indicate some small reductions in sugar and purity of the beets which received large applications of nitrogen fertilizer. The addition of a mixture of minor elements apparently increased the yield of beets and reduced sugar and purity slightly. The respiration data indicated only small differences between treatments. The addition of minor elements to plots which received large amounts of phosphorus and nitrogen apparently increased respiration slightly. Losses expressed in terms of pounds of sugar per ton per day as calculated from respiration rates, inversion and direct polarization, also indicated slightly greater losses were sustained by the beets fertilized with minor elements. Lower loss from inversion or spoilage of the beets which received no added fertilizer and greater losses from those which received minor elements were indicated by the data.

It seems reasonable to expect that, in the absence of nutritional deficiencies, normal rates of application of commercial fertilizezrs will affect storage only slightly if at all.

Large beets respire more slowly than an equal weight of smaller beets. In selecting comparable sized beets for respiration studies one probably unconsciously eliminates nutritional differences by selecting more closely spaced beets from highly fertilized plots and widely spaced beets from low-fertility plots. Space allotments, therefore, may greatly alter nutritional differences which are expressed in pounds of nutrients per acre. Nutritional deficiencies or greatly unbalanced nutrition might be expected to affect storage. It is almost certain that high yields, if due to larger beets, would result in lower respiration losses.

Respiration and Spoilage of Widely Different Varieties of Beets

Beets of widely different genetic constitution and growth habits were grown on the Harman farm near Riverton, Utah, in 1949. Some of the more pertinent information regarding the genetic character of these varieties is as follows:

S. L. 798—4n U. S. 22/2
S. L. 824—High-sugar selection U. S. 22/3
S. L. 7107—3*n* male-sterile hybrid
S. L. 72—Curly-top selection U. S. 22/3
S. L. 6106—U. S. 41 male sterile x CT9 inbred
S. L. 726—Low-sugar selection U. S. 22/3
S. L. 8382—Barres mangel
S. L. 8343—Half-sugar from Holland

The Barres mangel is a globe-shaped, orange-colored beet which grows high above the soil level. The half-sugar beet from Holland produces a high tonnage of green-colored, elongated roots which also grow high above the level of the soil. Because of their elongated shape the half-sugar beet has a much larger surface per unit of volume than the Barres mangel.

The beets were sampled and sealed in the respiration chambers November 1, 1949. The respiration and spoilage test was discontinued December 19 after a storage period of 48 days at 68° to 70° F. Respiration based on average rates for 10-day periods is shown in Table 2. Varieties S. L. 824, S. L. 72 and S. L. 726 respired more rapidly than the other varieties of sugar beets. The Barres mangel and half-sugar respired much more slowly during the early part of the test but increased considerably during later periods, indicating greater spoilage of these two varieties. Although the mangel and half-sugar showed little evidence of spoilage when the test was discontinued they showed large losses in purity and increases in invert sugar when analyzed. The analysis of the various samples before and after storage show that the mangels lost more than one-half their original purity value during storage.

The freshly harvested Barres mangels contained nearly eight times as much invert sugar as did the sugar beets. The freshly harvested half-sugar beets were more nearly comparable to sugar beets in invert sugar percentage but after storage they were more nearly comparable to the mangels.

Losses in pounds of sugar per ton of beets per clay of storage are also shown in Table 2. Interrelationships of some of the data in Table 2 are shown graphically more clearly in Figures 2 and 3.

Figure 2 shows a fairly good positive correlation between percentage dry substance and respiration rate with the exception of varieties S. L. 7107, S. L. 798 and S. L. 6106. The two polyploid varieties have considerably lower respiration rates in relation to dry substance than the normal diploids. The male-sterile hybrid S. L. 6106 is intermediate in respiration rate in relation to dry substance.

The relationship between inversion or spoilage and respiration losses shown in Figure *3* indicates a fairly close negative correlation between these two factors responsible for the overall storage losses. Here again, the polyploids show superiority with the male-sterile hybrid in an intermediate position. The data also show a fairly close negative correlation between percentage sugar and spoilage or inversion loss. These interrelationships of the data presented on the varieties studied indicate good possibilities of breeding for improved storage, especially in relation to polyploid varieties of beets.

Summary

A method for measuring the respiration rate and spoilage of fairly large samples of sugar beets (88 pounds) in an atmosphere of constant composition and temperature is described.

The bruising which the sugar beet roots received in harvesting by means of a mechanical harvester equipped with Reinks screens did not cause appreciable increase in respiration rate or spoilage.

Beets severed into top and bottom halves before storage respired more and spoiled more rapidly than beets stored intact. Greater losses from respiration were evident in the top halves but greater losses from spoilage occurred in the bottom halves. Beets stored intact showed greater sugar loss from the top half than from the bottom half, indicating that translocation of sugar does not compensate for the greater drain of sugar from the top halves.

Barsprout, containing methyl ester of naphthaleneacetic acid, greatly increased the respiration rate and growth of rootlets on sugar beets. It cannot be recommended for the storage of sugar beets.

The data to date show no advantage of highly fertilized over normally fertilized beets. In one test, where there were evidently no deficiencies in the check beets, the addition of nitrogen and phosphorus and a mixture of minor elements produced no improvement *in* storage ability. The effect of added fertility on samples of uniform sized beets is discussed.

Of eight varieties studied, including a mangel and a half-sugar beet, in relation to respiration, there seems to be a rough positive correlation between sugar percentage and respiration rate. However, one male-sterile hybrid (S. L. 6106), a triploid (S. L. 7106) and a tetraploid (S. L. 798) were lower in respiration rate in relation to sugar percentage than the other three varieties of sugar beets (S. L. 726, S. L. 72 and S. L. 824). This may offer promise of breeding for lower respiring commercial varieties.