Source of Recoverable Sugar Losses In Several Sugarbeet Varieties During Storage[1]

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Introduction

In many parts of the United States a major proportion of all beets are stored for considerable lengths of time prior to processing. During these storage periods the amount of bagged sugar which can be obtained from a ton of beets declines. This loss occurs as a result of two general changes. One is the direct loss of sucrose via respiration and sugar transformation. The other is the loss resulting from the accumulation of non-sucrose components in the factory thin juice resulting in an increased sucrose loss to molasses.

Barr *et al.* (1940) determined the loss of sugar by respiration at various temperatures over a 47-day storage period and found that the amount of carbon dioxide evolved accounted for approximately 60% of the total apparent sucrose losses. This early work of Barr (1940) indicated a very strong temperature effect where losses varied from 0.1 pound per ton per day at 3 C to 1.8 pound per ton per day at 35 C.

The decrease in recoverable sucrose during storage is not solely a result of sucrose lost as CO_2, but is also due to an increase of impurities in the factory thin juice (McGinnis, 1951; Carruthers *et al.*, 1962; Silin, 1964; Dexter *et al.*, 1965). Sucrose losses into molasses can be predicted by using the purity of the clear juice in conjunction with a formula derived by the Great Western Sugar Company. From this formula it can be shown that a one percent loss in clear juice purity (CJP) will cause approximately a 6 pound loss in recoverable sugar per ton (RSPT) of beets (Dexter *et al.* 1967).

In an examination of compositional changes in diffusion juice from stored beets, Walker *et al.* (1960) found a decrease in purity from 92.2 to 87.5% in 90 days at 10 C. The apparent impurities calculated from thin juice purity increased from

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8,500 to 14,700 mg per 100 grams of sucrose. The increase in total impurities (6042 mg per 100 gm sugar) was approximately equal to the increase in invert (6200 mg per 100 gms sucrose). Sucrose losses ranged from 0.1 to 0.2 lbs/ton/day.

This paper reports on the proportion of bagged sucrose losses occurring as the result of respiration and loss of CJP.

Materials and Methods

The beets in 1967 were grown in replicated plots near Sebewaing, Michigan. In the fall of 1966, 375 pounds of 0-0-60 was broadcast and plowed down. Just prior to planting, 900 pounds of 0-20-0 was applied broadcast and incorporated with a field cultivator. On May 3, 1967, the beets were planted in 28-inch rows with 200 pounds of 12-6-6 applied as starter fertilizer. After thinning to 120 beets per 100 feet of row, the beets designated as high nitrogen were side-dressed with 125 pounds of nitrogen per acre for a total of 150 pounds of applied nitrogen per acre. The beets with low nitrogen received only the 24 pounds per acre of nitrogen applied as a row fertilizer at the time of planting.

The five varieties and their quality ratings based on a combination of sucrose, clear juice purity (CJP), and yield are given below:

Variety Number	Variety	Type	Quality Rating
1	SP5481-0	Multigerm	Average
2	SP63194-0	Monogerm	Poor
3	02 Clone	Multigerm	Good
4	SP6322-0	Multigerm	Excellent
5	USH20	Current Commercial Hybrid Monogerm	Excellent

Harvests were made on October 6, October 26 and November 6, 1967. All five varieties were harvested on October 26, but only varieties 2, 3, and 5 were harvested on the other two dates. Beets from six field replications were pooled at harvest and lightly topped to remove the terminal bud. The samples were transported to the Michigan Sugarbeet Research Laboratory in Saginaw for analysis and storage. The beets were washed, sorted by specific gravity to improve uniformity (Dexter *et al.* 1969) and stored at 3 C in sealed 2 mil polyethylene bags for 130 days. Each sample consisted of 10 beets and all treatments were replicated four times.

Three varieties grown at East Lansing, Michigan in 1968, were harvested on November 6 and prepared for storage as in 1967. Storage was for 100 days at either 3 or 10 C. All treatments except temperature were replicated three times.

All samples were weighed into and out of storage. Chemical determinations based on fresh weight were corrected to the original sample weight at harvest. This correction was small since desiccation was less than 2% in all cases.

Analyses of percent sucrose, CJP, RSPT, raffinose, reducing sugars and amino acids were made as described previously (Dexter *et al.,* 1967; Dexter *et al.,* 1970a). Apparent percent sucrose and CJP were corrected for the effects of raffinose and invert.

Respiration rates were determined by placing a 10-beet sample into a closed system and measuring the time required for the sample to produce 20 mg of carbon dioxide. The increase in carbon dioxide concentration (approx. 300 ppm) was monitored using a Beckman (model 215) Infrared Analyzer.

Results and Discussion

The recoverable sugar per ton (RSPT) yields at harvest and after 130 days of storage for five varieties grown on 24 and 150 lb N/A are given in Table 1. When beets were grown on low nitrogen, the RSPT yields at harvest were greater for all except variety 1. Varieties 2 and 5 appeared to be particularly sensitive to excessive nitrogen fertilization.

The effect of nitrogen fertilization on storage losses (RSPT) varied greatly between varieties, but all except variety 3 lost more RSPT when grown on 24 lb N/A than on 150 lb N/A. However, in three of the five varieties, net yields after storage were greater when grown on low nitrogen. Variety 2 definitely stored best at both nitrogen levels.

Table 1.—Recoverable sugar per ton yields at harvest and after 130 days of storage for five varieties grown on 24 and 150 pounds nitrogen per acre and stored at 3 C.

	At harvest Nitrogen, lb/A		Stored 130 days Nitrogen, lb/A		Loss in Storage Nitrogen, lb/A	
Variety	24	150	24	150	24	150
1	285	284	250	252	—35	—32
2	287	261	271	256	—16	— 5
3	292	271	268	245	—24	—26
4	278	259	253	243	—25	—16
5	303	268	278	255	—15	—13

LSD$_{.05}$ among losses 11.6 lbs/ton
LSD$_{.05}$ among yields 11.1 lbs/ton

Table 2 shows the proportion of RSPT losses resulting from the loss of gross sucrose and the accumulation of non-sugars, respectively. On the average, 65% of the loss in RSPT was due to the direct loss of sucrose; the remainder being the result of impurity accumulation in the clear juice. Note that the sucrose lost by transformation would contribute to both the direct sucrose loss and impurity accumulation.

Table 2.—Comparison of losses in gross sucrose and recoverable sugar in five varieties stored 130 days at 3 C (1967).

Variety	At harvest		Loss in Storage		Sucrose loss as percent of total RSPT loss
	Total sucrose	RSPT	Total sucrose	RSPT	
	lbs/ton	lbs	lbs/ton	lbs	percent
1	324	284	21	43	49
2	318	274	9	11	82
3	321	282	15	26	58
4	308	269	13	21	62
5	324	286	14	19	73
Mean			14.4	24	65
LSD.05			11	10	

The greater loss of recoverable sucrose in storage for the low nitrogen beets (18 vs 10 lb/T) was due to a greater loss of gross sucrose (Table 3). The accumulation of impurities accounted for the remainder of the RSPT loss and was essentially the same (7 and 9 lb/T) for the 24 lb and 150 lb/A treatments respectively. This increased direct loss may have been due to increased respiration rates. The low nitrogen beets were smaller in size and thus had a greater surface area per unit weight. Beet respiration has been found to be directly correlated with surface area (Stout, 1954).

Table 3.—Loss of total and recoverable sucrose per ton during 130 days of storage at 3 C for varieties 2, 3, and 5 grown with 24 and 150 lb N/A.

	Total sucrose		RSPT	
	Applied nitrogen, lb/T		Applied nitrogen, lb/T	
	24	150	24	150
	lbs/ton		lbs/ton	
A harvest	326	310	289	269
Stored 130 days	308	300	264	250
Loss in Storage	18	10	25	19
LSD.05 for loss	5		6	

Table 4 gives the loss of both gross sucrose and RSPT in storage at 3 and 10 C. The losses for variety 5 were exceptionally low at 3 C, but generally the direct loss of sucrose during storage was a greater percentage of the RSPT losses at 10 than at 3 C. This was presumably a result of increased respiration and a decreased accumulation of impurities, primarily raffinose. However, the loss of RSPT was not significantly increased at the higher storage temperature.

To determine the relative proportions of the direct loss of sucrose which are due to respiration and sugar conversion re-

Table 4.—Proportion of RSPT losses due to loss of sucrose in three varieties stored 100 days at 3 and 10 C (1968).

			Stored 100 days at: 3 C			10 C		
	At harvest		Loss of:		Sucrose loss as percent of RSPT loss	Loss of:		Sucrose loss as percent of RSPT loss
Variety*	Gross sucrose	RSPT	Gross sucrose	RSPT		Gross sucrose	RSPT	
	lbs/ton	lbs	lbs/ton	lbs		lbs/ton	lbs	
5	308	273	3	8	37	22	27	81
6	272	225	11	28	40	14	24	58
7	328	294	6	21	28	24	28	85
Mean			6.6	18.9	35	20	26.3	75
LSD$_{.05}$ between var.			7.0	14.4		N.S	N.S.	

LSD$_{.05}$ among treatment means for total sucrose (3 vs 10 C) 8.2
LSD$_{.05}$ among treatment means for RSPT (3 vs 10 C) 9.4
*Variety 5—USH20
" 6—SP 6721-01 MS
" 7—SL 129 × UI 4661 × UI 4661 MS

spectively, the CO_2 evolution of variety 5 was monitored weekly during 112 days of storage at 5 C. During this storage period the CO_2 evolved substantially exceeded the sugar loss as determined by chemical analysis (Table 5). This phenomenon was substantiated in several other experiments where the loss of dry matter was always greater than the loss of sucrose (unpublished data), indicating that considerable non-sucrose compounds are acting as substrates for respiration. This is in contrast to the results of Barr *et al.*, (1940), and Barbour and Wang (1961) in which sucrose was essentially the substrate for CO_2 evolution. However, assuming from our results that raffinose and invert

Table 5.—Proportion of sucrose losses accounted for by respiration and interconversions in 112 day storage at 5 C.

	• gms/kg
CO_2 evolved	18.85
CO_2 evolved expressed as sucrose	12.21
Sucrose lost (by chemical analysis)	8.00
Raffinose lost	0.90
Invert gained	1.40
Total sugar loss	8 + 0.9 = 8.90
Total sugar gained	1.40
Net loss, by analysis	7.50
Approximate sucrose loss by respiration of CO_2	12.21

12.2 gm CO_2 evolved as Sucrose
—7.5 analyzed carbohydrate loss

4.7 gms/kg excess CO_2 evolved, from some source other than sucrose, raffinose or invert sugar.

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* Since 1 gm of CO_2 is derived from 0.648 gms of sucrose, 18.85 gms. CO_2 is equivalent to 12.21 gms. of sucrose respired.

came from sucrose, they would account for only 20% (1.4/8.0) of the loss in total sucrose with the remainder of the loss being due to respiration or conversion to compounds not found in the clarified juice.

Increased non-sucrose components found in the clear juice of the five varieties stored at 3 C for 130 days were primarily raffinose and invert (Table 6). Free amino acids decreased, but on the average the net change in raffinose, invert, and amino acids accounted for 80% (1877/2368) of the increased impurities. The moldy tips on many of the beet samples caused the accumulation of large amounts of reducing sugars. As a consequence of the mold, no valid conclusion could be drawn concerning the effect of variety on accumulation of reducing sugars.

Table 6.—Increase in total impurities accounted for by raffinose, reducing sugars, and amino acids in five varieties stored 130 days at 3 C.

Variety	Increase in total impurities	Change in:			Sum of changes in raffinose reducing sugars, amino acids
		Raffinose	Reducing sugars	Amino acids	
			Mg/Kg		
1	3583	645	3052	— 827	2870
2	1709	1028	1780	— 765	2043
3	3119	1023	2095	— 810	2308
4	2065	520	1950	— 595	1875
5	1362	— 18	1477	—1168	291
Mean	+2368	+ 640	+2071	— 833	+1877
LSD .05	N.S.	494	1270	416	1540

The average impurity content of the three varieties after storage at 3 and 10 C was similar at both temperatures (12,599 vs 11,916 mg/kg). The accumulation of impurities was actually higher at the lower storage temperature primarily as a result of the increase in raffinose. These varieties readily accumulated raffinose which accounted for 34% of the total impurities at 3 C. This tendency to accumulate raffinose at low temperature completely cancelled the benefits of lower respiration rates at low storage temperatures. Thus RSPT losses averaged only 7 lbs higher at 10 than at 3 C (Table 4).

At 3 C the net change in raffinose, reducing sugars, and amino acids accounted for over 100% of the increase in total impurities (Table 7). For this to be true, compounds not analyzed were either being metabolized, possibly as substrates for respiration (Table 5) and/or converted to substances which were precipitated by lime during clarification. In these varieties the accumulation of raffinose was the primary cause of the decline in clear juice purity at 3 C.

Although the total impurity content was similar at both temperatures, qualitatively the composition was very different. At

Table 7.—Change in total impurities of three varieties after 100 days of storage at 3 or 10 C accounted for by raffinose, reducing sugars and amino acids.

Treatment	Total impurities	Change in:			Net change in raffinose Reducing sugars amino acids	Percent of Total
		Raffinose	Reducing sugars	Amino acids		
3 C			Mg/Kg			
5	1662	1678	2	— 113	1567	94
6	3106	2803	180	300	3283	106
7	2824	3171	134	56	3361	119
Mean	2531	2551	105	81	2737	107
LSD .05	1212	344	57	325	724	
10 C						
5	1486	— 398	640	464	706	48
6	2463	490	614	1144	2248	91
7	1591	97	313	427	837	53
Mean	1847	63	522	678	1263	68
LSD .05	836	409	223	651	539	

the warmer temperature no raffinose accumulated and a smaller percentage of the increase in total impurities was accounted for by raffinose, reducing sugars and the amino acids. At 10 C reducing sugars, amino acids and other impurities not analyzed in this study predominated. These qualitative differences are particularly significant in terms of factory operating efficiency. During processing the reducing sugars are decomposed to acids. These acids, in addition to the amino acids, may require neutralization with sodium carbonate to prevent the development of acidic conditions during evaporation. However, for each pound of sodium carbonate added, five pounds of sucrose are lost to the molasses (Dexter *et al.,* 1970b). It is readily apparent that the reducing sugars are particularly significant in terms of storage losses. They not only represent the direct loss of sucrose, but also contribute greatly to the sucrose lost to molasses (Dexter *et al.,* 1970b). Raffinose, the major impurity accumulating during low temperature storage, is stable during processing and accumulates in the molasses. As a result, molasses yield is increased; but no particular processing difficulties are encountered. However, assuming a 62% molasses purity, each pound of raffinose in the molasses carries along 1.6 lb of sucrose.

Summary

Storage of several sugarbeet varieties without desiccation at 3 C and very little mold indicated substantial differences in their storage characteristics based on losses of RSPT. However, high yields of recoverable sugar per ton after storage were dominated, not by low storage losses but by high yields at harvest.

The losses in recoverable sugar were about equally divided between direct loss of sucrose by respiration and sugar conversion, and the accumulation of non-sucrose compounds in the clear juice.

Raffinose, reducing sugars, and the amino acids accounted for approximately 80% of the impurities which accumulated during storage.

Although the impurity content was approximately the same at both 3 and 10 C for the three varieties tested, qualitatively the content was very different. Reduction in clear juice purity (and consequently lower percent recovery) at higher temperatures resulted more from the respirational loss of sucrose than from increased impurities. At 3 C raffinose accounted for 34% of the total impurities after 100 days of storage. At 10 C reducing sugars, amino acids, and some unknown impurities predominated. The higher raffinose accumulation at lower temperatures was more or less balanced by the increased invert sugar and amino acid at higher storage temperatures. These qualitative differences were significant in terms of processing characteristics.

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