A Method of Evaluating the Processing Characteristics of Sugarbeets, based on Juice Constituents: A Prescription of Beet Quality[1]

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In 1968 in Michigan about 75% of the beets were stored before processing. During storage, substantial changes occurred in the processing quality of the beets, as seen by the percentage of recoverable sucrose, the purity of the molasses, the rapidity of filtration, the need to add soda ash and the color of the juice. The simple determination of apparent sucrose and clear juice purity (CJP) at harvest gives little or no indication of the changes during storage.

The widespread interest and attention given to the general topic of "technological value" of the sugarbeet is well illustrated by the C.I.T.S. volume (5)[3] An objective and generally acceptable "formula" or "prescription" that will evaluate the "technological value" or the processability of the sugarbeet would accelerate the progress of those who now attempt to grow and breed better beets mainly in terms of yields, disease, etc. The world-wide interest in this is well illustrated by the C.I.T.S. volume (5). This paper proposes a chemical prescription for a beet that will process well, before and after storage. The effects of changes in sodium, potassium, amino nitrogen and invert sugar during storage on the need for soda are examined. Probable losses of bagged sugar in various lots of beets under different store conditions are computed. Corrections, additions, improvements, etc. in this method of evaluation are invited.

Review of Literature

From the figures (4), the values of $K + Na - 1.4\ NH_2N$ have been calculated as shown below. Since considerable NH_3 is lost in evaporation to give thick juice, the factor of $1.4\ NH_2N$ was used, rather than 1.0 as in thin juice.

To several of the "good juices", soda had been added in substantial amounts. It seems unlikely that it would have been added, and the juices brought to this essentially constant value,

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[3] Numbers in parentheses refer to literature cited.

European factories			British factories
1. 11.92	7. 12.80	13. 13.17	A. 20.71
2. 13.41	8. 13.80	14. 12.77	B. 12.22
3. 10.27	9. 12.88	15. 13.41	C. 17.40
4. 13.60	10. 13.24	16. 13.90	D. 22.88
5. 13.63	11. 14.34	17. 11.44	E. 21.19
6. 15.33	12. 13.44	18. 13.11	Mean 18.87—"poor juices"
Mean 13.23 "good juices"			

if it had not been needed. Juices in British factories seem to have been undesirably high in K and Na without addition of soda. The concept of a reasonable degree of uniformity in "good" factory juices, related to $K + Na - NH_2N$ seems justified.

Brüniche-Olsen (2) approached this evaluation of base-acid balance with his concept and titration value of "effective alkalinity" of factory thin juice. He subtracted "lime salts" from total alkalinity to give "effective alkalinity".

Rounds (13), using Brüniche-Olsen's concept and method, reported that an adjustment (by addition of soda ash) to 0.01% CaO "effective alkalinity" was adequate to obtain excellent factory performance, and was a compromise between excessive lime salts and a larger loss of sucrose due to further addition of soda. Andersen and Smed (1) developed a formula for equating the value of meq $K + Na - NH_2N$ to "effective alkalinity", (Eff. Alk $= 0.58\ (K + Na - NH_2) - 6.8$ (meq/100S) but indicated that the formula would not apply to beets containing much invert sugar. Each molecule of invert sugar (hexose) is converted into 1½ to 2 molecules of acid by fermentation or alkaline degradation (13,15).

The chart below combines the titration values of % CaO with Andersen-Smed's value expressed in meq alkalinity per 100 g sucrose. Since the values in column 1 (Brüniche-Olsen) do not involve sucrose concentration of the juice, true equating of the values is impossible unless a standard or average juice is assumed.

The figures in the last column were calculated by using the effective alkalinity values in column 2 with the Andersen-Smed formula shown above.

In the chart, a juice containing about 15% sucrose by weight, density of 1.07 and requiring 623 ml to contain 100g sucrose was used. Had a juice of 12% sucrose been assumed, with Round's alkalinity remaining at 0.01%, the corresponding value for $K + Na - NH_2N$ would have been 19.5 rather than 15.6. When the value of 15.6 is adjusted to the content of invert sugar in

Eff. Alk. % CaO	Meq alk/100S Eff. Alk.	$K + Na - NH_2N$ Meq/100S.
.000	0	11.7
.005	1.12	13.7
.010*	2.24*	15.6*
.020	4.48	20.0
.030	6.72	23.3

Andersen and Smed's beets, the standard value for minimum alkalinity becomes 11.2 meq/100g sucrose (0.01% CaO).

As calculated from the standards in the literature cited, a value of 11.2 meq (or higher) per 100g sucrose for meq $K + Na - NH_2N$ − Invert sugar in the thin juice would indicate that the sample of beets analyzed would process without the need for soda ash. This value may be low, because of the high concentration of sucrose in the juice assumed. However, since the addition of soda ash is always something of a compromise, the value might be altered to the degree that lime salts can be tolerated.

Extensive changes in the concentration of raffinose and invert sugar during various storage conditions have indicated a need for correction of "apparent" sucrose and clear juice purity (CJP) (18,11,12) to arrive at more realistic values of extractable (white) sugar per ton (ESPT).

Results

Table 1 shows the analytical results and the method of computing the soda ash requirement. The values in column 8 were computed using the "Great Western" formula (17) and the sucrose and CJP values after correction for raffinose and invert sugar (11). (See Table 4 (12) for sucrose and CJP values.) Twenty-three, 39 and 14 are the meq for Na, K and NH_2N. Ninety mg of invert sugar was considered to be 1 meq since a molecular weight (180 g) results in 1½ to 2 equivalents of acid in fermentation and alkaline breakdown. The larger value was used because the presence of invert sugar often requires the use of sulfur dioxide (an acid) to reduce juice color. Column 5 indicates the alkaline reserve in meq per 100 g sucrose. (see formula in footnote). To raise this reserve to the minimum of 11.2 meq requires the amount shown in column 6. It is evident that when invert sugar became high, as in storage at 8 C., the alkaline reserve became low.

To convert the meq of soda ash required per 100 g sucrose into sucrose lost requires an estimate of the loss of sucrose per pound and per meq/100S of soda ash added. With the commonly used approximation of 1 gram-molecular weight (7) of sucrose lost per gram-atomic weight of sodium (53 g of soda ash contain

Table 1.—Adjustment of the alkaline reserve of beet juice and loss of extractable (white) sugar related to the addition of the necessary soda ash.

Treatment	Meq per 100 g sucrose							Lb per ton beets		
	Col. 0 Cl	1 K	2 Na	3 NH_2N	4 Inv. S.	5 Alk. Res.	6 Adj. to 11.2	7 (ESPT Lost) (soda)	8 ESPT*	9 ESPT**
At harvest										
14" rows	2.95	15.28	1.54	9.62	6.09	1.1	10.1	8.9	304	295
28" rows	5.54	20.75	2.27	10.24	5.69	7.1	4.1	3.7	298	294
After storage										
14" rows	3.95	17.30	1.47	7.47	14.59	−3.3	14.5	12.7	289	276
28" rows	5.44	19.91	2.03	7.56	18.76	−4.4	15.6	13.5	286	272
At harvest										
Topped	3.29	16.09	1.84	8.94	5.59	3.4	7.8	7.1	311	304
Untopped	5.19	19.94	1.98	10.92	6.18	5.6	5.6	4.8	291	286
After storage										
Topped	3.76	17.19	1.47	6.74	16.56	−4.7	15.9	15.2	293	279
Untopped	5.65	20.03	2.04	8.30	16.78	−3.0	14.2	12.1	282	270
At harvest	4.25	18.02	1.90	9.93	5.89	4.1	7.1	6.3	301	295
After 2°C storage	4.64	18.88	1.74	6.82	11.45	2.3	8.8	7.7	292	284
After 8°C storage	4.78	18.34	1.78	8.22	21.89	−10.0	21.2	18.5	284	265

Col. 0 Chloride content of thin juice. Not used in calculations. Notice relationship to Na, K and NH_2N. See text.
1 K used in formula Alk. Res. = K + Na — NH_2H — Invert Sugar. All in meq/100S in clear juice.
2 Na used in formula Alk. Res. = K + Na — NH_2H — Invert Sugar. All in meq/100S in clear juice.
3 NH_2N used in formula Alk. Res. = K + Na — NH_2H — Invert Sugar. All in meq/100S in clear juice.
4 Invert S used in formula Alk. Res. = K + Na — NH_2H — Invert Sugar. All in meq/100S in clear juice.
5 Alk. Reserve, by formula in 1 above.
6 11.2 — Col. 5 = Adj. to 11.2.
7 0.265 x Sucrose in ton of beets x Col. 6. Example 0.265 x 333 lbs. x 10.1 = 8.9.
8 Extractable (white) sugar/ton, corrected for raffin and invert (Table 4 (12).
9 Extractable (white) sugar/ton, corrected for raffin and invert (Table 4 (12).

23 g of Na), the loss of surcrose would be $342 \div 53 = 6.5$ pounds of sucrose lost into molasses per pound of soda ash added. However, from examination of the literature and discussion with factory chemists, a 5-pound loss per pound of soda ash added seems nearer a consensus.

The sucrose lost, when soda ash is added at the rate of 1 meq (53 mg) per 100 g sucrose, may be calculated as follows:

$$\frac{53 \text{ mg soda ash}}{100{,}000 \text{ mg sucrose}} = \frac{0.053 \text{ lbs soda ash}}{100 \text{ lbs sucrose.}}$$

Since one pound of soda ash results in the loss of 5 pounds of sucrose, $0.053 \times 5 = 0.265$ lbs sucrose loss/100 lbs sucrose or 0.265% of the sucrose in the juice is lost per meq of soda ash required. Column 7 shows the sucrose per ton of beets lost into molasses as a result of adding soda ash in the amounts shown in column 6—the amount needed to obtain optimum alkalinity. Column 8 shows the ESPT, corrected for raffinose and invert sugar effect. Column 9 shows the ESPT after subtracting the values in column 7 from those in column 8, and represents the ESPT corrected for further addition of soda. No correction is shown for the loss of weight in topping (12).

Discussion

The cations K and Na were regularly higher in beets from 28 than from 14-inch rows, as were untopped versus topped. Correspondingly, chlorides and nitrogen in amino acids were higher, indicating the approximate balancing of cations and anions in the mineral uptake from the soil. Of the 11.2 meq/100S of alkali indicated as necessary for an alkaline reserve, about 3.5 and 5.5 meq were neutralized by the chloride in beets from 14- and 28-inch rows, respectively.

There is a considerable amount of nitrate and a trace of sulphate and phosphate anions in clarified beet juice, as well as various organic acids with soluble calcium salts to neutralize the base further. A substantial loss of ammonia during evaporation further decreases alkalinity from the approximately 9.2 pH of the finished thin juice. The alkaline reserve of 11.2 is intended to keep the juice from becoming acid as a result of these various sources of acid unaccounted for in the formula $K + Na - NH_2N - \text{invert sugar}$, mg/100S. From the results of this experiment, it appears that invert sugar is a major problem in stored beets. It leads to sugar loss 1) due to its origin from sucrose; 2) due to its addition to the "impurities" in the juice (and lowered CJP and % crystalization); and 3) due to common necessity of adding soda ash to neutralize the acids from its decomposition in the juice. In spite of storage virtually without molding, rotting or wilting, invert sugar increased substantially at 2°C and even more at 8°C. A solution through plant breeding as well as storage practice is indicated (as with potatoes).

Summary and Conclusions

Beets of one variety were grown in 14- and 28-inch rows. They were harvested with complete and minimum topping and stored at 2 and 8°C until February 15. Analyses were made before and after storage.

1. Increase in invert sugar due to lack of topping was insignificant in comparison with the increase during storage, particularly at 8°C. At harvest, invert sugar was about 50 mg/100S higher in untopped than in topped beets; after storage at 8°C, invert sugar was about 1300mg/100S higher than at harvest.

2. Analyses for K, Na and NH_2N meq/100S in clear juice were made, and alkalinity, as $K + Na - NH_2N$ was computed. Relatively little change in this value occurred in storage.

3. When the acidity resulting from the decomposition of invert sugar was subtracted from $K + Na - NH_2N$ widely different values resulted in beets stored at 2 and 8°C. Beets stored at 8°C were far more acid than those stored at 2°C.

4. A formula was derived indicating how much soda ash must be added per ton of beets to bring the juice to an acceptable condition for evaporation. Knowing the loss into molasses from adding a pound of soda ash, the loss of ESPT was computed. Losses of ESPT resulting from the addition of soda ash averaged 19 versus 8 pounds after storage at 8 and 2°C, respectively.

5. In addition to the necessary agronomic characteristics, we conclude that a beet should be low in organic constituents that produce acids with soluble calcium salts, both at harvest and after storage. Soluble amino acids, a main source of acidity, did not increase in sound beets in storage, and decreased appreciably at lower temperatures. It is of particular importance that a beet should not increase in invert sugar (an acid former) during storage.

6. The acidic components above are not removed in conventional processing and should be as low in concentration as possible to avoid exhausting the alkaline reserve. Potassium and sodium should be no higher than is necessary to neutralize the acids and can be added if necessary at the factory.

7. In considering a variety for release, its processing quality should be examined after appropriate storage, and the influence of common cultural practices should be examined.

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