Genetic Improvement of Processing Quality in Sugar Beets[1]

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Received for publication February 27, 1959

In the past few years the improvement of processing quality in sugar beets has become of paramount importance to the beet sugar industry. The purpose of this article is to present information on the possibility of genetic improvement of processing quality in sugar beets.

Sugar Content

No critical data are available to adequately explain the inheritance of sucrose content. It has been generally assumed (for lack of evidence to the contrary) that sucrose percentage is conditioned by additive factors or genes, with no expression of dominance or heterosis for sucrose content. This assumption has been substantiated (over the years) by the results obtained from rigid selection for high sucrose content. These selections have resulted in so-called "sugar type" varieties that are high in percent sucrose but low in yield of roots and sugar per acre. The intermediate sucrose content of the first male-sterile hybrids, or top crosses, further supported the belief that sucrose content was conditioned by simple additive genes and that dominance or heterosis for sucrose content did not exist.

Current studies, however, conducted with inbred lines and their F_1 hybrids have provided evidence which strongly suggests the existence of dominance and even heterosis for sucrose content in sugar beets. These findings are of major importance to all breeding programs designed to utilize hybrids or synthetic varieties, and they forecast significant advances to be made in raising the sucrose percentage of commercial beets.

Table 1 lists the results of a preliminary test conducted in 1956 by Powers (unpublished data) with inbred lines and their F_1 hybrids. These data show that the sucrose content of the F_1 hybrids is not intermediate. With one exception the sucrose content of all F_1 hybrids exceeded the average of the respective parents and in most cases were not statistically different from the sucrose content of the higher parent. Specifically, hybrids

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[1] Cooperative investigations of the Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, the Colorado Agricultural Experiment Station, and the Beet Sugar Development Foundation. Approved by the Colorado Agricultural Experiment Station for publication as Scientific Series Article No. 574.

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1, 2, and 3 show complete phenotypic dominance while hybrids 5, 6, 7, 8, and 9 show partial dominance for higher sucrose content. Hybrid 4, on the other hand, indicates complete phenotypic dominance for low sucrose content.

Table 1.—Percentage Sucrose for F_1 Hybrids and Inbred Parents, 1956, U. S. Department of Agriculture.

Hybrid No.	Pedigree	P_1	P_2	F_1	$\frac{P_1 + P_2}{2}$
1	50-406 X 52-430	18.5	18.0	18.8	18.2
2	50-406 X 52-307	18.5	17.2	18.7	17.8
3	52-430 X 52-307	18.0	17.2	18.1	17.6
4	52-408 X 53-1278	18.3	17.4	17.4	17.8
5	50-406 X 52-414	18.5	14.2	17.9	16.4
6	52-430 X 52-414	18.0	14.2	17.8	16.1
7	52-414 X 52-305	14.2	18.5	17.4	16.4
8	52-414 X 52-307	14.2	17.2	16.4	15.7
9	51-319 X US 201	9.2	17.4	15.1	13.3

At the 0.05 level the value of t is 1.63 percent.

Evidence for the existence of heterosis with regard to sucrose content is shown in Table 2. These data, from current work by Powers et al. (6)[3] on population genetic studies with sugar beets at different levels of soil fertility, show that the F_1 hybrid has one percent more sugar on the fertilized plots than the highest parent (52-307). The odds against this difference being due to chance are well in excess of 99:1. This, therefore, demonstrates heterosis for increased sucrose content on the fertilized plots.

Table 2.—Population Means for Percentage Sucrose, Fertilized and Non-Fertilized Plots, 1956, U. S. Department of Agriculture.

Population	Fertilized	Non-Fertilized
	%	%
50-406 (P_1)	16.1	17.4
F_1 hybrid	17.6	17.6
52-307 (P_2)	16.6	16.5

Recent studies by Rush and Oldemeyer (7) on combining ability in sugar beets which involved 90 F_1 hybrids and their respective parents likewise showed clear-cut evidence of dominance and heterosis for sucrose content.

In these studies the F_1 hybrids, as a class, were not intermediate with respect to sucrose content. Slightly more than

[3] Numbers in parentheses refer to literature cited.

one-third of the F_1 population showed either phenotypic dominance or heterosis for increased sucrose percentage. The average sucrose percentage of the F_1 hybrids was 14.47%, while that of the female parents was 14.08% and that of the pollen parents was 13.86%. Moreover, the mean sucrose content of the F_1 hybrids was significantly higher at odds of 99:1 than the mean sucrose percentage of either the female or pollen parents.

Table 3.—Percentage Sucrose for Selected F_1 Hybrids and Inbred Parents, Amalgamated Sugar Company.

Hybrid No.	Pedigree	P_1	P_2	F_1	$\frac{P_1 + P_2}{2}$
1	A2-9OHO X 5-188	13.92	13.84	14.80	13.88
2	175 H15 X 5-205	14.90	13.92	15.55	14.41
3	E21 X 5-239	14.12	13.32	14.82	13.72
4	E322 X 5-207	14.22	14.19	15.00	14.20
5	A2-9OHO X 5-231	13.92	13.90	14.75	13.91
6	E21 X 5-231	14.12	13.90	14.65	14.01
7	175 H15 X 5-188	14.90	13.84	15.26	14.37
8	A2-9OHO X 5-204	13.92	12.54	14.36	13.23
9	113H3 X 5-238	13.25	13.91	14.31	13.58
10	175 H15 X 5-237	14.90	13.88	15.09	14.39

LSD at 5% level = 0.62%, 1% level = 0.84%.

Table 4.—Percentage Sucrose for F_1 Hybrids and Their Inbred Parents, Holly Sugar Corporation.

Hybrid No.	Hybrid	P_1	P_2	F_1	$\frac{P_1 + P_2}{2}$
1	5152-01 X 6112-0	14.56	14.23	15.28	14.40
2	CT9MS X 6112-0	14.38	14.23	14.92	14.31
3	5152-01 X 6113-0	14.56	13.75	14.70	14.16
4	CT9MS X 6114-0	14.38	13.56	14.48	13.97

LSD at 5% level = 0.52%

Typical cases of heterosis and dominance for increased sucrose percentage are shown in Tables 3 and 4. In Table 3, hybrids 1 to 5, inclusive, illustrate heterosis; the sucrose content of the F_1 hybrids is significantly higher than the sucrose content of the highest parent. Hybrids 6 to 10, inclusive, demonstrate phenotypic dominance; the sucrose content of the F_1 hybrids is significantly greater than the average sucrose content of their respective parents. In Table 4, hybrids 1 and 2 show heterosis for percentage sucrose and hybrids 3 and 4 show complete dominance.

The findings regarding heterosis and dominance for sucrose content are of great importance to the beet sugar industry. They not only have a decided bearing on breeding programs, particularly those designed to utilize hybrids and synthetic varieties in the commercial production of sugar beets, but they also assure, within the near future, greater production of sugar per acre from beets significantly higher in sucrose content and improved processing quality.

Sodium

Data showing the possibilities for changing sodium content of the beet root by selection are presented in Table 5. An examination of the figures in the last column reveals that the high-sucrose, low-sodium selections resulted in a decrease in the sodium content of the beets. This was true for both the American Crystal and Great Western selections. Likewise in both cases the selections for high percentage sucrose resulted in an increase in this character, whether the accompanying selection was for high or low sodium. Selection for high sodium and high sucrose did not result in an increase in sodium above that of the check. However, data not listed in Table 5 showed that selection for high sodium produced strains having this characteristic. There was no increase in production of sugar per acre because the increase in percentage sucrose was offset by a corresponding decrease in tons of beets per acre.

Table 5.—Selection for Sodium Content of the Beet Root.

Sugar Company and Selection	Sugar per Acre	Beets per Acre	Sucrose	Na. Sodium
	Lbs.	Tons	%	%
American Crystal				
Check	8251	26.9	15.32	0.0572
Hi-su, Hi-na	7868	24.7	16.01	0.0554
Hi-su, Lo-na	8137	25.3	16.05	0.0314
LSD, 5%	638	2.1	0.46	0.0084
Great Western				
Check	6468	20.4	17.7	0.042
Hi-su, Hi-na	6537	20.1	18.1	0.043
Hi-su, Lo-na	6420	19.4	18.4	0.023
LSD, 5%	263	0.7	0.3	0.005

The conclusions drawn concerning sodium are as follows:

1. Selection pressure readily affects the sodium content of beets in either direction.
2. In most beet populations, sodium and sucrose content are negatively correlated to a rather high degree.

3. Actually the sodium characteristic of the sugar beet is of questionable importance to the breeding program, unless a low-sodium variety is extremely important from the processing standpoint.

4. The value of low sodium content per se in beets for processing also is questionable, since the quantity of soda ash added for control of lime salts far exceeds the quantity found in the beet.

This was true for both sets of data, American Crystal and Great Western. For further data and discussion see (2), (3), (4), and (5).

Thin-Juice Purity

The summarized data for thin-juice purity are presented in Table 6. In all cases listed in Table 6, selection for greater purity has resulted in an increase in this character. This was true whether the work was done by the Holly Sugar Corporation or the Great Western Sugar Company. In the case of the Great Western selections this increase in purity was accompanied by an increase in percentage sucrose, and a corresponding decrease in yield of beets per acre. However, in the case of selection 732 made from GW 359, the decrease in yield of beets per acre did not offset all the increase in purity and percentage sucrose, and there was a net gain in tons of sugar per acre.

Table 6.—Selection for Thin-Juice Purity.

Sugar Company and Selection	Sugar Per Acre	Beets	Sucrose	Purity
	Lbs.	Tons	%	%
Holly				
Check	5495	18.4	15.0	92.87
Hi purity	5461	18.5	14.8	93.50
Lo purity	5686	19.5	14.6	92.00
LSD, 5%				0.68
Great Western				
Check, 359	5726	21.4	15.8	92.31
Hi purity, 732	5994	20.8	16.7	93.29
LSD, 5%	136	0.4	0.2	0.22
Check, 359	5898	21.5	16.1	92.64
Hi purity, 738	5884	20.5	16.6	93.40
LSD, 5%	216	0.7	0.2	0.37

Raffinose

The results of selection for percentage raffinose on dry substance in the press juice and accumulation of raffinose in storage are shown in Figure 1.

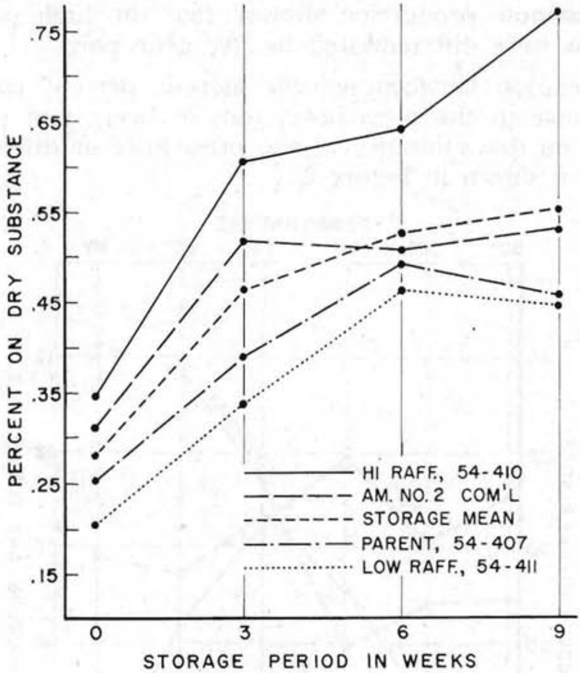

Figure 1.—Selection for percentage raffinose on dry substance in the press juice and accumulation of raffinose in storage, American Crystal Sugar Company.

Strain 54-407 was the result of a random selection of mother beets from the same parent strain (American No. 1) as selections 54-410 and 54-411. The latter two were selected for high and low raffinose content, respectively.

No significant differences for raffinose content were found between beets stored in a regular storage pile and those stored in the root cellar. However, all varieties showed a significant increase in raffinose content during storage, as shown in Figure 1. The percent increase for the low-raffinose selection compared with the high-raffinose selection was approximately equal after nine weeks of storage.

Wood (8) reports that progeny tests of varieties B619 and B620 selected from GW 359 demonstrated the heritability of raffinose percentage. The low-raffinose selection B619 did not accumulate raffinose, in storage tests, at as great a rate as did either the parent or the high-raffinose selection B620. Some inbred lines in the cooperative indexing program have been found to have zero content of raffinose. Studies on the inheritance of raffinose production showed that the high parent and low parent were differentiated by five gene pairs.

The relation between percent sucrose, percent raffinose on dry substance in the press juice, tons of beets, and percentage galactinol on dry substance in the press juice at different dates of harvest is shown in Figure 2.

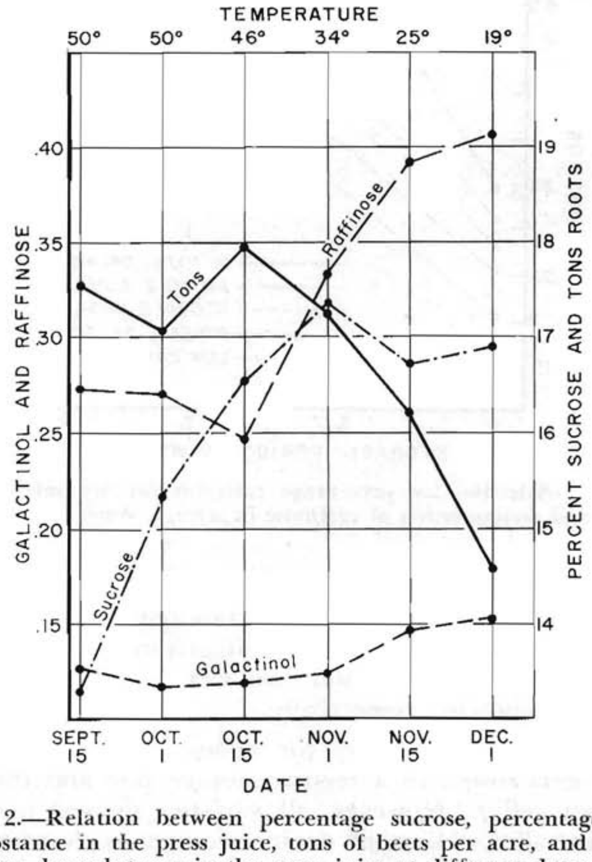

Figure 2.—Relation between percentage sucrose, percentage raffinose on dry substance in the press juice, tons of beets per acre, and percentage galactinol on dry substance in the press juice at different dates of harvest, American Crystal Sugar Company.

The decrease in tons of beets for the later harvest was due to freezing of the beets. It can be seen that both percentage sucrose and percentage raffinose increased between October 1 and November 1. Finkner from this finding postulates that since both sucrose and raffinose increased during the test period, each must be produced by its own physiologic system, and that raffinose is not necessarily a polymerized product of sucrose degradation.

Finkner's postulation on the independence of production of sucrose and raffinose in the beet may be examined further as follows:

First, both the data of Finkner presented in this manuscript (Figure 1) and evidence presented previously by Wood (8) and Brown and Wood (1) indicate that raffinose content continues to increase after the beets are harvested and stored. Such an increase in raffinose content must be at the expense of one or more of the other materials in the root and may result from (a) polymerization of smaller molecules or (b) degradation of larger molecules.

In either case there should be measurable intermediate products.

Second, raffinose and sucrose both rotate the plane of polarized light in the same direction; i.e., to the right. Raffinose, however, is 1.85 times as effective in this respect as is sucrose; therefore, even if sucrose is the basic substance destroyed to form raffinose, the loss would probably not be detected by means of the polariscope. Desiccation encountered during storage also tends to increase polarization. In our studies we have not shown differences in polarization during ordinary storage periods beyond what might be expected as result of errors in measurement and respired amounts. It is known, of course, that sucrose is used up by respiratory activity in stored beets.

Raffinose accumulation in 6 field-grown varieties at 6 dates of harvest is shown in Figure 3.

A study of Figure 3 reveals that from October 15 to November 15 all strains and varieties increased in percentage raffinose on dry substance in the press juice. From November 15 to December 1 there was no further increase in raffinose content for some strains, whereas for others increase in this chemical continued.

Association of Chemical Characteristics in Sugar Beets

The correlation coefficient data pertaining to the association of chemical characteristics in sugar beets are provided by the Amalgamated Sugar Company.

The correlation coefficients showing the association between total nitrogen in the beets and in the thin juice, press juice and diffusion juice, and between these and monosodium glutamate extract are listed in Table 7.

In every case the association is high, indicating that a positive or negative change in one is accompanied by a proportionate and corresponding change in all the others. Total nitrogen in the beet is highly correlated with nitrogen in the different juices:

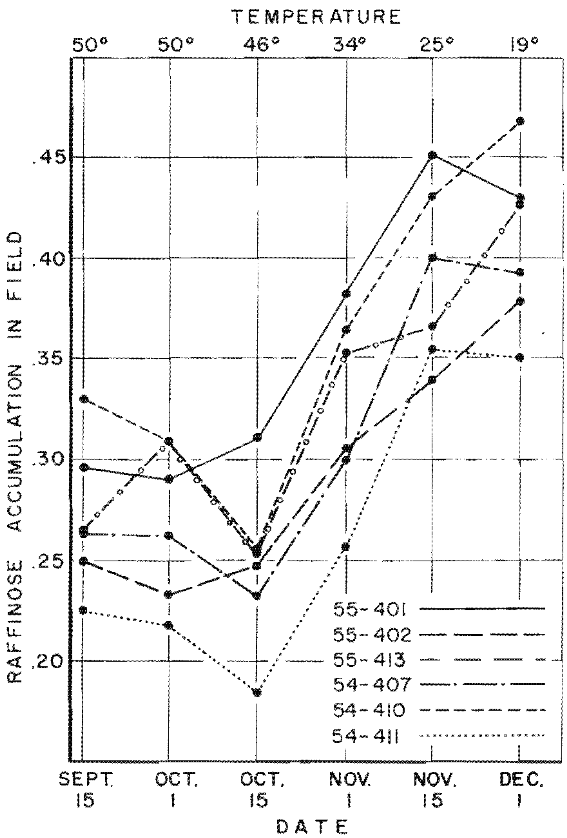

Figure 3.—Percentage raffinose on dry substance in the press juice accumulation in six field-grown varieties at six dates of harvest, American Crystal Sugar Company.

Table 7.—Simple Correlation Coefficients Based on 168 Pairs of Observations Within Seven Varieties and Three Nitrogen Levels for Total Nitrogen in Beets and Different Juices and Monosodium Glutamate, Amalgamated Sugar Company.

Variate	Amino N in: Thin Juice	Press Juice	Diff. Juice	Monosodium Glutamate
N in beets (lbs/ton)	0.93	0.92	0.94	0.89
Amino N, thin	....	0.96	....	0.91
Amino N, press	....	....	....	0.89
Amino N, diff.	....	0.96	....	0.91

thin, press, and diffusion. Also, N in the press juice is very highly correlated with N in the thin juice and N in the diffusion juice.

This raises the question whether one total N determination would suffice, which would almost have to be true with regard to association with other characters. This is borne out by the correlation coefficients with MSGE. There are no significant differences between the correlation coefficients between any of the nitrogen determinations and MSGE. The correlation coefficients between the four nitrogen determinations listed in Table 7 and percentage sucrose were —0.56, —0.56, —0.52, and —0.57, respectively. This finding was equally valid for seven other chemical characters with which these four nitrogen determinations were correlated. Hence in the discussion which follows, for the sake of simplification and clarity, only total N in the beet will be considered in relation to other characters.

The correlation coefficients between total nitrogen in the beet and 12 other characters are shown in Table 8.

Table 8.—Simple Correlation Coefficients Based on 168 Pairs of Observations Within Seven Varieties and Three Nitrogen Levels for Total Nitrogen and 12 Other Characters, Amalgamated Sugar Company.

Variate	N in Beets (lbs/ton)	Variate	N in Beets (lbs/ton)
Sucrose, harvest	—0.56	Potassium, root	0.52
Sucrose, cossettes	—0.58	Sodium, root	0.70
Purity	—0.87	Ash, juice	0.64
Extraction	—0.73	Non sugars	0.88
Raffinose	—0.19	Yield	0.56
P_2O_5, beets	0.04	NO_3, petiole	0.64

The correlation coefficients between total nitrogen in the beets and percentage sucrose at time of harvest and percentage sucrose in the cossettes are high (—0.56 and —0.58) as compared with those found between characters in most biological material. The association is negative. Percentage purity and percentage extraction are even more highly correlated with total nitrogen in the beets. Again the association is negative. Since these four characters (percentage sucrose at harvest, percentage sucrose in the cossettes, percentage purity, and percentage extraction) are not independent of each other, that all should show similar relations with total nitrogen in the beets is to be expected.

The correlation coefficients between total N in the beets and raffinose and P_2O_5 are not of sufficient magnitude to indicate that any appreciable association exists.

Total nitrogen is positively correlated with potassium, sodium, ash, non-sugars, yield, and nitrate nitrogen in the petioles. The relation is positive. The degree of association for sodium and non-sugars is very high, while that for other characters is high.

The correlation coefficients for percentage sucrose and 10 other characters are listed in Table 9.

Table 9.—Simple Correlation Coefficients Based on 168 Pairs of Observations Within Seven Varieties and Three Nitrogen Levels for Percentage Sucrose at Harvest and 10 Other Characters, Amalgamated Sugar Company.

Variate	Sucrose at Harvest	Variate	Sucrose at Harvest
Yield of roots	—0.36	Ash, juice	—0.46
N in beets	—0.56	Non-sugars	—0.57
NO_3, petiole	—0.64	P_2O_5, (lbs/ton)	0.24
Sodium, root	—0.66	Purity	0.68
Potassium, root	—0.47	Extraction	0.75

The association between percentage sucrose and yield of roots, total N in the beets, nitrate nitrogen in the petioles, sodium, potassium, ash, and non-sugars is negative. The degree of association may be considered as average for yield and high for the other characters showing a negative relation with percentage sucrose. P_2O_5, purity, and extraction are positively associated with percentage sucrose, and the degree of association is rather high for purity and extraction.

The correlation coefficients for yield and nine other characters are listed in Table 10.

The only significant negative association is between yield and percentage sucrose, and the degree of intensity is not great. P_2O_5 and raffinose show very little if any relation with yield. Nitrogen. sodium, potassium, amino nitrogen, ash, and MSGE are positively associated with yield. With the exception of sodium, the degree of association is high.

Table 10.—Simple Correlation Coefficients Based on 168 Pairs of Observations Within Seven Varieties and Three Nitrogen Levels for Yield of Beets per Acre and Nine Other Characters, Amalgamated Sugar Company.

Variate	Yield	Variate	Yield
Sucrose, harvest	—0.36	Amino N, juice	0.54
P_2O_5 (lbs/ton)	—0.05	Ash, juice	0.50
N in beets	0.56	MSGE	0.53
Sodium, root	0.32	Raffinose	0.12
Potassium, root	0.48		

In evaluating the above correlation coefficients in relation to the bearing they may have on the possibility of altering chemical characters and recombining them by breeding procedures, the method of calculating the correlation coefficients must be kept in mind. They were calculated on the basis of 168 pairs of plot values within seven varieties and three nitrogen levels. Hence they are an average association of affects attributable to replications, varieties, and fertilizer treatments.

The means of percentage sucrose, parts per million NO_3-N in the petioles, and weight per root for the interaction of replications X populations X treatments are listed in Table 11. The following interpretation of these data is taken from Powers, Robertson, Whitney, and Schmehl (6).

For all five replication groups the percentage sucrose of the F_1 exceeds that of A54-1 on the fertilized plots, while the reverse is true (except for the 33-40 group) on the non-fertilized plots. For the first three groups 50-406BB, the F_1, and 52-307 show an increase in percentage sucrose on the fertilized plots as compared with the non-fertilized plots; whereas the reverse is true for populations A54-1, A54-1BB, and 50-406.

The parts per million of NO_3-N in the petioles involving the above comparisons are of interest. On the non-fertilized plots A54-1 has an average of 588 parts per million of NO_3-N in the petioles for the first 3 groups and the average percent sucrose is 18.2. The same values of the F_1 for the first 3 groups on the fertilized plots are 630 and 18.3. Apparently the F_1 and A54-1 have the same optimum concentration of nitrogen in the petioles for maximum percentage sucrose in the roots. However, the F_1 reaches this optimum at the high fertility level, whereas, A54-1 reaches approximately this same concentration of NO_3-N at the lower fertility level. It seems that either A54-1 is more efficient in taking up nitrogen at the lower fertility and retains it in the petioles. or at the higher fertility the F_1 uses more nitrogen in metabolism, or does not retain it in the petioles. This difference in reaction of populations may have a decided bearing on breeding varieties and hybrids better adapted to sugar production at higher fertility levels.

Another comparison involving 50-406BB with A54-1BB and A54-1 for the first three groups and the fertilized and non-fertilized treatments is of interest. An average increase in NO_3-N in the petioles from 486 parts per million on the non-fertilized plots of 50-406BB to 1296 on the fertilized plots was not accompanied by a decrease in percentage sucrose, 17.8 to 17.9, whereas for A54-1BB and A54-1 the corresponding values are 634 to 1308

Table 11.—Means of Percentage Sucrose, Parts per Million NO_3-N in the Petioles, and Weight per Root for the Interaction of Replications X Populations X Treatments (from Powers, Robertson, Whitney, and Schmehl, 6).

Population and Character	Fertilized Replication Groups					Non-Fertilized Replication Groups				
	1-8	9-16	17-24	25-32	33-40	1-8	9-16	17-24	25-32	33-40
A54-1										
Sucrose, percent	17.1	17.6	17.7	16.8	14.6	18.0	18.4	18.3	18.2	16.6
NO_3-N, ppm	1724	1350	829	3484	13778	671	452	640	864	6055
Weight, lbs.	2.90	2.55	2.41	2.44	2.69	1.93	1.66	1.61	2.02	2.43
A54-1BB										
Sucrose, percent	16.9	18.2	17.9	16.2	14.5	17.8	18.7	18.3	17.5	17.0
NO_3-N, ppm	1505	1154	1264	5368	15132	499	702	702	826	5231
Weight, lbs.	2.85	2.57	2.51	2.66	2.61	1.82	1.51	1.47	1.62	2.13
50-406BB										
Sucrose, percent	17.6	18.1	18.1	17.0	15.5	17.4	18.0	17.9	17.7	16.8
NO_3-N, ppm	1482	1050	1357	2656	14791	500	406	554	569	5426
Weight, lbs.	2.09	2.24	2.07	1.82	1.96	1.44	1.43	1.20	1.35	1.58
50-406										
Sucrose, percent	16.8	16.8	16.6	15.6	14.7	17.9	17.8	17.7	17.3	16.4
NO_3-N, ppm	702	551	632	788	8812	530	436	359	538	2948
Weight, lbs.	1.11	1.09	0.98	0.96	0.98	0.79	0.61	0.68	0.79	0.87
F_1 hybrid										
Sucrose, percent	18.2	18.5	18.2	17.0	16.0	17.6	18.3	17.7	17.6	16.8
NO_3-N, ppm	852	390	648	2082	11328	234	374	524	398	4890
Weight, lbs.	2.29	2.49	2.19	2.03	2.16	1.60	1.39	1.20	1.67	1.82
52-307										
Sucrose, percent	16.6	17.4	17.6	16.4	14.9	15.7	17.3	16.6	17.4	15.6
NO_3-N, ppm	570	578	866	1817	14392	546	390	374	826	4126
Weight, lbs.	1.21	1.18	1.10	1.10	1.19	0.58	0.45	0.41	0.67	0.81

accompanied by sucrose values of 18.3 to 17.7 and 588 to 1301 accompanied by sucrose values of 18.2 to 17.5. These results indicate that certain populations may be able to tolerate more NO_3-N in the petioles than others without an accompanying reduction in percentage sucrose. Finally, the second order interaction of replications X population X treatments is of interest in connection with information it furnishes concerning the possible nature of heterosis in this hybrid. Both the F_1 and the inbred parent 52-307 on the fertilized plots produced higher percentage sucrose for the first three replication groups than they did for these same replication groups on the non-fertilized plots. The reverse is true for 50-406, the other inbred parent, as regards these same replication groups. The percentage sucrose for both the F_1 and 52-307 is less on the fertilized plots than on the non-fertilized plots for the last two replication groups. Thus the behavior pattern for the F_1 and 52-307 is the same, as regards the ability to produce higher percentage sucrose at the higher level of soil fertility. Hence, this ability to produce high percentage sucrose at the higher fertility level is partially or completely dominant. On the other hand the 50-406 inbred potentially is the higher percentage sucrose parent. This is shown by a comparison of 50-406 and 52-307 on the non-fertilized plots. The ability of 50-406 to produce a high percentage sucrose is at least partially if not completely dominant in the F_1 hybrid. The ability of the F_1 to react as the inbred parent 50-406 in respect to high potential percentage sucrose production and as the 52-307 parent at the higher fertility level results in the heterosis of the F_1 grown on the high-fertility plots; that is, the F_1 exceeds either parent in percentage sucrose on the fertilized plots.

Further study of the percentage sucrose values of Table 11 reveals that the behavior pattern of 50-406BB as compared with 50-406 on the fertilized and non-fertilized plots is very similar to the behavior pattern of the F_1 as compared with 50-406. The populations 50-406 and 50-406BB differ from each other in that the seed producing the plants of 50-406BB came from mother beet plants of 50-406 which at the time of flowering were exposed to pollen from 22 other varieties, strains, and inbreds. This evidence is important because it lends support to the finding that heterosis for percentage sucrose exists, and indicates that it is not of too rare occurrence in sugar beets.

Another comparison of interest involves the relation between these three characters in replication group 1-8 and replication group 33-40. As can be determined from a study of Table 11 there is a decrease in both percentage sucrose and weight per root of group 33-40 compared with group 1-8 on the fertilized plots. Also there is a decided increase in parts per million of nitrate nitrogen in the petioles of group 33-40 as compared with group 1-8. Under conditions of this experiment the application of excesses of nitrogen results in a decided reduction in percentage sucrose and a slight reduction in weight per root.

Summary and Conclusions

1. Heterosis for percentage sucrose in F_1 hybrids produced from certain inbreds was found independently by three investigators, each working under the diverse climatic conditions found in three different States—Colorado, Idaho, and Wyoming. Also, dominance or partial dominance of higher percentage sucrose was found to be of rather frequent occurrence. These findings regarding heterosis and dominance for sucrose content are of considerable importance to the beet sugar industry. They provide the information needed for producing hybrids and synthetic varieties of higher sucrose content. Hence, these findings assure for the industry within the near future greater production of sugar per acre from beets significantly higher in sucrose content and improved processing quality.

2. The data on the inheritance of sodium, potassium, and raffinose demonstrate that these chemical constituents are subject to change by breeding procedures. That is, they can be either increased or decreased in inbreds, hybrids, and varieties according to the dictates of thee beet sugar industry.

3. Studies on the relations between yield of roots per acre, percentage sucrose, and chemical constituents show that these characters, both chemical or agronomic, can be recombined into desirable combinations. Recombination within the nitrogen group of characters may be the exception, as the positive relation between the different nitrogenous compounds was rather marked.

The fact that covariance accounted for only a relatively small amount of the total variance of characters other than the nitrogenous compounds and the fact that these characters were not closely correlated with the nitrogenous compounds indicate that desirable recombination of chemical constituents can be attained.

4. The population genetic studies at different levels of soil fertility show that populations differ in their ability to produce higher percentage sucrose at the higher nitrogen fertility level. Hence it seems that the plant breeder can aid in the solution of

the problems encountered because of the application of greater amounts of nitrogenous fertilizers. It should be possible for the plant breeder to produce varieties and hybrids of sugar beets that will yield higher percentage sucrose at the higher levels of nitrogen concentration in the soil than do the varieties now being grown. However, it should be pointed out that such improved varieties and hybrids probably will not be able to completely overcome the harmful effects of the indiscriminate use of nitrogenous fertilizers. These improved hybrids and varieties must be accompanied by reasonable fertilizer practices if their high quality potentials are to be realized.

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