Changes in Raffinose Content and Other Characteristics of Sugar Beet Varieties During Six Different Harvest Dates

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Received for publication May 28, 1958

Breeding for improvement of sugar beets in the past has been largely confined to obtaining resistant varieties for several diseases and increasing yield and sucrose percent. However, from a processing viewpoint, the production of varieties of sugar beets having a minimum of melassigenic substances would be highly desirable and very profitable to the industry. One of the principally unwanted melassigenic substances in many areas is raffinose, which interferes with the recovery of sucrose from the sugar beet. Like sucrose, raffinose is precipitated by lime in the saccharate process and is retained in the syrups because of continued recycling of the juices in the sugar factory. Thus the elimination of this unwanted substance is in the hands of the beet breeder.

Zitkowski (8, 9, 10)[2] as early as 1910 recognized the troublesome characteristics of raffinose and published methods of isolating it from sugar beet products. However, breeding sugar beets for low raffinose content was not practical until the development of the paper chromatography method of determination as described by Brown (1) and Serro and Brown (5).

Zitkowski (10) also observed that the quantity of raffinose in beets increased when exposed to freezing weather and suggested the possibility of enzymatic action on other carbohydrates which would eventually form raffinose. Finkner and Bauserman (3) noticed that the raffinose content of the same varieties increased approximately 30 percent when harvested three weeks later. They also attributed this accumulation of raffinose to colder temperatures. Brown and Wood (2) reported that raffinose content of the same variety could vary from location to location, and that some increase in raffinose content was noticed during storage. Finkner et al (4) also demonstrated that the raffinose content of varieties increased with storage.

It has been clearly shown by several workers (2, 3, 6, 7) that varieties differed in their genetic make-up and strains can be selected which have a low raffinose content. Therefore it appears that several factors affect the raffinose content of beets. Among

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[2]Numbers in parentheses refer to literature cited.

them are: 1. Heredity, 2. Environment during growth, 3. Conditions of storage after harvest and 4. Interaction between these factors.

The investigation presented here was designed to determine what changes occurred in raffinose content and other characteristics of sugar beet varieties during a series of six consecutive harvests.

Materials and Methods

A split plot experimental design was used with varieties being the main plots and dates-of-harvest the sub-plots. The main plots were replicated six times in a Latin square arrangement. A single 35 foot row, 22 inches wide, was harvested for yield of each variety on each of the six dates. The beets from each plot were randomly divided into three equal samples and every beet within each sample was rasped. The resulting pulp for each sample was bulked together for chemical analyses.

Table 1.—F Values for Variety, Harvest Dates and the Interaction Between the Two.

Source of Variation	Tons Per Acre	Percent Sucrose	Pounds Sucrose Per Acre	% Raff.	% Gal.	No. Beets Per 35′
Variety	4.74[2]	23.39[2]	8.38[2]	24.89[2]	2.82[1]	4.97[2]
Harvest dates	8.22[2]	119.15[2]	12.50[2]	87.18[2]	9.51[2]	3.30[2]
Varieties x dates	NS	NS	NS	NS	NS	NS

The dates of harvest were approximately at 15 day intervals, starting on September 15. The other dates were as follows: October 1, October 15, November 1, November 15, and December 1.

Six varieties were chosen for this study. Four of the varieties had been previously selected for raffinose content. Varieties 55-401 and 55-402 were selected from the U.S.D.A. strain SP 53-104-0, for high sugar, and high sugar and low raffinose respectively. Another low raffinose selection with similar breeding background as the two above was 55-413. Variety 55-413 was selected from the U.S.D.A. strain SP 5352-0. Both of the parent varieties, i.e., SP 53-104-0 and SP 5352-0, were curly-top-leaf-spot resistant varities and appeared vary similar.

The remaining three varieties were very closely related and were used by Finkner and Bauserman in a previously reported study (3). 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 contents respectively.

The raffinose and galactinol contents were determined by the paper chromatography method and is reported as percent on dry substance. Sucrose determinations were made by the cold water extraction procedure and are reported as percent on beets.

Results and Discussion

Highly significant differences as shown in Table 1 were obtained for varieties for all attributes studied except galactinol; however significance at the five percent level was obtained for that character. Highly significant differences also were found between harvest dates for each of the characteristics. However, no significant interaction between varieties and harvest dates was detected.

The dates of harvest means and LSD values are shown in Table 2 and the variety means and LSD values are shown in Table 3, for the six characteristics studied. Since the variety x dates interactions were not significant individual means are not shown.

Table 2.—Dates of Harvest Means and LSD Values for the Six Characteristics Studied.

Characteristics Studied	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	LSD .05
No. Beets per 35 Feet	45	42	42	43	42	41	2.40
Tons Roots per Acre	17.51	17.02	17.92	17.26	16.20	14.62	1.17
Percent Sucrose	13.26	15.32	16.50	17.34	16.73	16.87	0.38
Pounds Sugar per Acre	4656	5219	5927	5993	5433	4958	417
Percent Galactinol	0.131	0.117	0.119	0.124	0.148	0.151	.014
Percent Raffinose	0.27	0.27	0.24	0.33	0.39	0.41	.020

d.f. = 5 and 150

Table 3.—Variety Means and LSD Values for the Six Characteristics Studied.

Characteristics Studied	Varieties						LSD .05
	55-401	55-402	55-413	55-407	55-410	55-411	
No. Beets per 35 Feet	43	45	44	42	40	41	2.5
Tons Roots per Acre	15.22	17.16	15.83	17.97	16.99	17.36	1.40
Percent Sucrose	15.53	15.26	14.91	16.21	17.07	17.03	0.56
Pounds Sugar per Acre	4736	5237	4713	5801	5820	5890	557
Percent Galactinol	0.141	0.140	0.131	0.129	0.127	0.121	.013
Percent Raffinose	0.36	0.29	0.33	0.31	0.36	0.26	.023

d.f. = 5 and 20

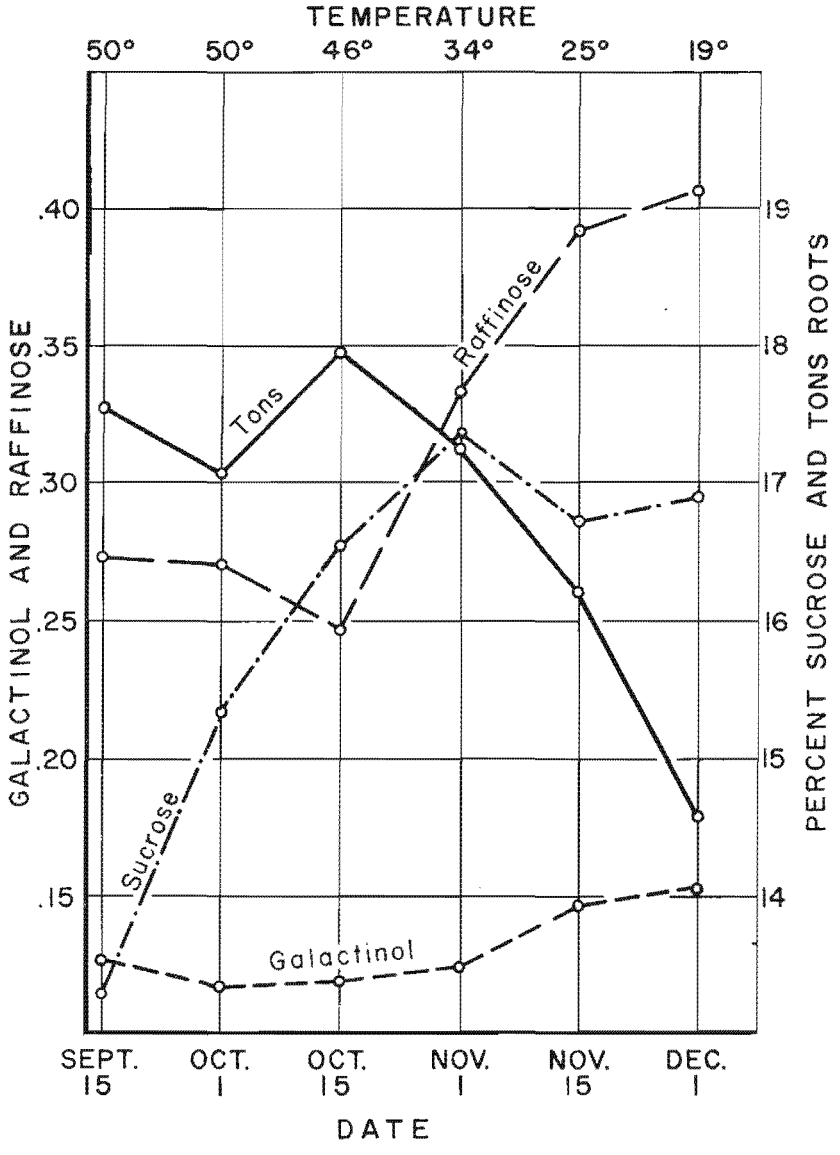

Figure 1.—The means of six varieties for tonnage, sucrose, galactinol and raffinose at the Six Harvest Dates and the Mean Minimum Temperatures from one date of harvest to the next.

Although significant differences were detected for number of beets per plot, stands appeared to be adequate. As shown in Table 2 the greatest range among varieties was a difference of five beets and between dates, four beets. In reality these differences were quite small and the yield potential of each strain should have been reached. To support this viewpoint it can be seen in Table 3 that the lowest tonnage variety was above average in number of beets per plot while the highest tonnage variety was below average in number of beets. Significance also was detected for dates of harvest, but again from a practical standpoint these differences were not great. The range in the average number of beets from the first date of harvest to the last consisted of only four beets.

Significant differences were detected for varieties and dates of harvest for tons per acre. Strain 55-402 which was selected for high sugar and low raffinose percent yielded significantly more tonnage than its sister selection 55-401, which was selected only for high sucrose content. Selection 55-412 which was selected for low raffinose and had a similar breeding background as those mentioned above was second lowest in yield of roots and significantly lower than 55-402. The three strains selected from American No. 1 did not differ significantly from each other and all yielded significantly more than 55-401

The tonnage of all varieties as shown in Figure 1 showed an increase at October 15 over the first date of harvest and then declined very rapidly. This decline probably was due to two main factors, freezing temperatures and drought. The night temperatures were very cold during the last part of October and all of November. These severe freezes killed most of the beet tops.

Table 4 gives the mean maximum and minimum temperatures and the amount of precipitation during the test period and the departure from a 63 year average.

Table 4.—Mean Maximum and Minimum Temperatures and Amount of Precipitation for September, October and November.

Month	Mean Maximum	Mean Minimum	Amount (Inches)	Departure from 63 Year Average
September	86.73	50.23	.00	—.83
October	75.74	40.03	.33	—.42
November	52.06	22.13	.25	—.21
			.58	minus 1.46

As shown in Table 4 the months during which this test was conducted were extremely dry. The most precipitation which occurred at one time was 0.33 inches in October. This test also was irrigated for the last time on September 15 right after the first harvest date. During the last harvest all leaves were brown and dry and the beet roots had shrunk enough that they were somewhat loose in the soil. This dehydration along with some loss due to respiration probably were the main factors in the loss of tonnage.

The three selections from American No. 1 were all significantly higher in sucrose than the curly-top-leaf-spot varieties. However strains 54-410 and 54-411 were both significantly higher than the randomly selected strain 54-407. The two curly-top-leaf-spot resistant selections 55-401 and 55-402 were approximately equal in sucrose content, but strain 55-413 was significantly lower than 55-401.

The sucrose percent of the varieties increased significantly as the harvest was delayed until the last two harvests at which time there was a slight decrease as shown in Figure 1. This loss of sugar probably was indirectly caused by cold temperatures, i.e., the foliage was killed because of freezing and then as the temperature increased during the day a certain amount of respiration occurred which lowered the sucrose content.

The amount of sucrose produced per acre followed fairly closely the trends shown by sucrose for varieties and dates of harvest, except for the last harvest date. Evidently the last harvest was markedly effected by the drop in tonnage.

Varieties were significantly different at the five percent level for galactinol as shown in Table 1. In general the strains selected from American No. 1 were lower in galactinol content than the curly-top-leaf-spot varieties. There also was a tendency, although not significant, for the low raffinose selections to be slightly lower in galactinol than their sister selections. Dates of harvest had a highly significant effect on the galactinol content of beets as shown in Figure 1. The galactinol content for harvest dates increased after the temperature dropped to or below 34 degrees Fahrenheit. It is not known what physiological processes were involved to produce this increase in galactinol content, but whatever process it may be, cold temperatures appear to have been one of the factors.

The raffinose content of beets also showed a very marked and striking increase as the temperature dropped as shown in Figure 1. However as early as 1911 Zitkowski (10) stated that one of the conditions which caused raffinose to form in large quantities

was undoubtedly the action of frost. Certainly the data verifies this observation.

All varieties reacted similarly to the various dates of harvest as no significant interactions, were found as shown in Table 1. However varieties were significantly different in raffinose content as shown in Table 3. Strain 55-401 was significantly higher in raffinose content than its sister strain 55-402. This was expected as 55-402 was selected for low raffinose. Strain 55-413 which was selected for low raffinose, also had less raffinose than 55-401 but contained a greater percent than 55-402. Selections 54-410 and 54-411 were of great interest because they had been selected for high and low raffinose content respectively from American No. 1. Selection 54-407 also was selected at random from the same parent variety but no selection pressures were applied for or against raffinose content. Therefore if the selection pressures applied were effective and equal in each direction, strain 54-407 should be exactly midway between the difference of the high and low strain. The mean of the high strain 54-410 was .36 percent, the mean of the low strain 54-411 was .26 percent or a difference of .10, therefore selection 54-407 should have been, and was .31 percent.

From the data presented here it is obvious that raffinose was more effected by harvest dates than were any of the other characters studied. These changes in raffinose also were shown to be associated with cold temperatures. The raffinose and the sucrose contents were found, as shown in Figure 1, to increase between the October 15 and November 1 dates of harvest. This may be an indication that each of these sugars has its own physiological systems and that sucrose was not being converted into raffinose. However, the increase of sucrose during these dates of harvest may have been affected by dehydration, as was tonnage. Therefore, additional data are needed to test this hypothesis.

Since the observations for dates of harvest were taken at equally spaced intervals the response of each character studied, can be easily characterized by the use of orthogonal polynomials. In only two of the characters studied, sucrose and raffinose were significances detected for any of the five possible polynomial regressions. The linear response of sucrose for dates of harvest was first tested and found to be significant but the deviations from linearity also were significant. The quadratic component was found to be significant and the deviations from the quadratic were non-significant. Therefore, this response curve as shown in Figure 1 can be satisfactorily approximated by a second degree polynomial, indicating that the rate of sucrose accumulation decreases as the dates of harvest were delayed.

The first degree polynomial was the only one which showed significance for raffinose indicating, within the range of this study, that the raffinose content increased in a linear response as harvest was delayed. This increase undoubtedly was due to the cold temperature which existed at the later harvests.

Summary

Raffinose content was found to increase significantly and in a linear trend as harvest was delayed when the mean minimum temperature was near 34 degrees Fahrenheit or below. Strains which were selected for high and low raffinose content bred true.

Tonnage dropped sharply with colder temperatures and later harvests. This reduction was believed to be due to respiration and drought.

Sucrose increased very rapidly until freezing temperatures occurred and then declined slowly. The quadratic component of this curve was found to be significant.

The galactinol content increased with later dates of harvest, but not to the same extent as raffinose.

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