An Improved Method for the Evaluation and Selection of Sugar Beets (Beta vulgaris L.)
I. The Selection of Individual Plants

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Introduction

This paper reports on the results of an investigation undertaken to evaluate the correlation of percent dry matter of the petiole (hereafter referred to only as percent dry matter) with root weight and sucrose percentage and to indicate the possible value of these correlations to affect improvements in the selection intensity for individual sugar beet plants.

Materials and Methods

Three heterozygous, open-pollinated populations and one F_1 hybrid were used in this investigation. The three populations were: (a) CS7, an open-pollinated, high-yielding population selected for Alberta conditions; (b) A90-54, an open-pollinated, high-sucrose-content population Udycz A, originally obtained from Poland; (c) 5957, an open-pollinated increase of plants selected from Udycz A for decument tops. The F_1 hybrid, A213, was obtained from Dr. J. S. McFarlane of the USDA as NBI $\times$ NB4. The experiments described below were conducted at the Research Farm, Canadian Sugar Factories, Taber, Alberta.

Experiment Number 1

The three populations and the F_1 hybrid were planted on May 14, 1960, in four separate rows spaced 22 inches apart. After emergence the plants were thinned to 12 inches apart within the row. Each row contained five plants. On August 3, 1960, five uniform petioles from the most recently matured leaves were taken from each of the five plants from each of the three populations and the F_1 hybrid. The percent dry matter was determined for each petiole independently by drying to constant weight in a vacuum oven at 75° C.

Experiment Number 2

The same three populations and F_1 hybrid were planted on May 14, 1960, in single-row plots 20 feet long and 22 inches apart. The plants were spaced 12 inches apart within the row. A randomized block design was used. The entire experiment was replicated five times. This gave a total of 100 plants per population.

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On September 1, 1960, one petiole from a recently-matured leaf was taken from each of the 100 plants from each of the three populations and the F_1 hybrid. The percent dry matter was determined for each of the petioles independently as described for Experiment 1. On October 12, 1960, the roots were harvested, washed and weighed. A uniform and representative sample of macerated root tissue was obtained from each root with a rotary rasp which removed a V-shaped portion from one side of the root extending from the crown of the root to the tip of the root. Sucrose determinations were made with a polarimeter on the extract of a pulp sample using the hot water digestion method (1)[2].

The means, variances and their standard errors were calculated for the percent dry matter and sucrose percentage data obtained from each of the 100 plants from each of the three populations and the F_1 hybrid. The formulae and methods for making the above calculations and for using the standard error of the F_1 hybrid for estimating the environmental variation and computing the calculated frequencies have been adequately demonstrated and explained by Goulden (2), Powers (5), and Leonard et al. (4). In fitting the frequency distribution to the normal curve the reasoning of Steel and Torrie (6) was accepted, in that class frequencies as low as four and five were allowed in computing the chi-square. The view of the latter authors (6) was that the frequencies in the tails of the distribution are of great importance because if genetic deviates are selected they would be selected from the tails of the distribution. Therefore, any major deviation in the tails of the distribution should be allowed to contribute to the chi-square value. The genetic variances of the open-pollinated populations were determined by subtracting the total variance of the F_1 hybrid from the total variance of each of the populations. The standard errors of the total and genetic variances were calculated by the formulae given by Kenney and Keeping (3) and Powers (5).

Results

Experiment Number 1

Table 1 lists the between- and within-plant variances, and variance ratios (F-values) for percent dry matter for the three populations and the F_1 hybrid.

The high F-values obtained indicate that the variation in percent dry matter between different plants within a population is significantly higher than the variation in percent dry matter be-

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[2] Number in parentheses refer to literature cited.

Table 1.—Between and within plant variances for percent dry matter of the petioles and the F-value for the three open-pollinated populations and the F₁ Hybrid[1].

Population	Variance		F-value
	Between plants	Within plants	
CS7	4.476,353	0.063,666	70.31
A90-54	2.104,917	0.070,743	29.75
5957	7.468,575	0.092,412	80.82
A213, F₁ hybrid	0.685,975	0.065,619	10.45

[1] The degrees of freedom for these analyses are as follows: between plants = 4; within plants (error) = 20; and total = 24.

tween different uniformly mature petioles from the same plant. Furthermore, the between-plant variances for the three open-pollinated populations are significantly higher than for the F₁ hybrid whereas they are not significantly higher than the F₁ hybrid for the within-plant variances. This would be expected since the only sources of within-plant variation are errors of observation. Therefore, the difference in percent dry matter between genetically different plants should be distinguishable.

This finding prompted experiment number 2, the objective of which was to determine whether the percent dry matter data from the F₁ hybrid conformed to the normal distribution and whether indexing plants for percent dry matter would intensify the selection of plants for improved characters of economic value.

The means, variances and standard errors for percent dry matter and sucrose percentage are listed in Table 2. Table 2 also gives a comparison of the total variances of the F₁ hybrid with the total variances of each of the three open-pollinated populations.

The three open-pollinated populations had significantly greater total variances than did the F₁ hybrid, the level of sig-

Table 2.—The mean, variance, and standard error for percent dry matter of the petiole and sucrose percentage in the root for each of the three populations and F₁ Hybrid[1].

Population	Percent dry matter of petiole			Sucrose percentage in root		
	Mean	Variance	Standard error	Mean	Variance	Standard error
CS7	11.416	1.3868*	1.1776	17.54	1.7728*	1.3315
A90-54	13.086	2.0802**	1.4423	19.91	2.0002**	1.4143
5957	13.448	1.4799**	1.2165	19.75	2.0161**	1.4194
A213, F₁ hybrid	10.894	0.8864	0.9415	17.17	1.2135	1.1016

* Significantly different from the corresponding F₁ hybrid variance at P .05.
** Significantly different from the corresponding F₁ hybrid variance at P .01.
[1] Each population consisted of 100 individuals.

nificance being the same for both percent dry matter and sucrose percentage.

Table 3 lists the total variance and genetic variance together with their standard errors for both percent dry matter and sucrose percentage for each of the three open-pollinated populations and the F_1 hybrid.

Table 3.—The total variances and genetic variances for percent dry matter of the petiole and sucrose percentage in the root for the three populations and the F_1 hybrid[1].

Population	Variance			
	Percent dry matter		Sucrose percentage	
	Total	Genetic	Total	Genetic
CS7	1.3868 ± 0.1971	0.5004* ± 0.2339	1.7728 ± 0.2519	0.5593[ns] ± 0.3052
A90-54	2.0802 ± 0.2956	1.1938** ± 0.3213	2.0002 ± 0.2842	0.7867* ± 0.3324
5957	1.4799 ± 0.2103	0.5935* ± 0.2451	2.0161 ± 0.2865	0.8026* ± 0.3343
A213, F_1 hybrid	0.8864 ± 0.1260	—	1.2135 ± 0.1724	—

[1] The number of plants per population is 100.
[ns] Not significantly different from zero.
* Significantly greater than zero at P .05.
** Significantly greater than zero at P .01.

Table 4.—The obtained and calculated frequency distributions for percent dry matter of the petiole[1].

Upper limit of class	Population and distribution							
	CS7		A90-54		5957		A213	
	Obtained	Calculated	Obtained	Calculated	Obtained	Calculated	Obtained	Calculated
8.0	0	0.01	0	0	0	0	0	0.11
8.4	0	0.06	0	0	0	0	1	0.30
8.8	0	0.20	0	0	0	0	1	0.91
9.2	6	0.67	0	0	0	0	2	2.35
9.6	4	1.74	0	0.01	0	0	3	4.86
10.0	5	4.00	1	0.04	1	0.01	5	8.83
10.4	11	7.33	0	0.17	0	0.05	15	12.79
10.8	10	11.77	2	0.53	2	0.19	13	15.87
11.2	8	15.12	4	1.53	1	0.59	26	16.91
11.6	12	17.03	5	3.43	5	1.66	•17	14.41
12.0	11	15.31	14	6.80	5	3.68	8	10.76
12.4	14	12.07	9	10.76	9	7.17	4	6.42
12.8	4	7.61	12	14.94	14	11.16	4	3.36
13.2	6	4.14	11	16.97	8	15.23	0	1.41
13.6	0	1.92	9	16.10	11	16.62	1	0.51
14.0	2	0.71	9	12.52	15	15.88	0	0.20
14.4	4	0.23	4	8.52	6	12.14	0	0
14.8	3	0.06	7	4.64	8	8.13	0	0
15.2	0	0.02	1	2.22	1	4.35	0	0
15.6	0	0	7	0.84	2	2.04	0	0
16.0	0	0	3	0.28	7	0.76	0	0
16.4	0	0	1	0.08	0	0.26	0	0
16.8	0	0	0	0.01	3	0.06	0	0
17.2	0	0	1	0.01	2	0.02	0	0
17.6	0	0	0	0	0	0	0	0

[1] The estimated environmental standard error used in computing the calculated frequency distribution is 0.9415.

The genetic variances for both percent dry matter and sucrose percentage for the three open-pollinated populations are significantly greater than zero. The only exception is the genetic variance for sucrose percentage for CS7. This indicates that percent dry matter is under genetic control to a similar extent as sucrose percentage.

Tables 4 and 5 list the observed and the calculated frequency distributions for percent dry matter and sucrose percentage respectively for each of the three populations and the F_1 hybrid.

A class interval of approximately one half the standard error of the F_1 hybrid was used for both characters.

Table 6 lists the chi-square and P-values for each of the three open-pollinated populations and the F_1 hybrid for percent dry matter and sucrose percentage. It can be seen that the distributions of the F_1 hybrid data for both percent dry matter and sucrose percentage conformed to the normal curve with P-values between 0.10 to 0.05 and 0.95 to 0.50 respectively. However, in no instance

Table 5.—The obtained and calculated frequency distributions for sucrose percentage[1].

Upper limit of class	Population and distribution							
	CS7		A90-54		5957		A213	
	Obtained	Calcu-lated	Obtained	Calcu-lated	Obtained	Calcu-lated	Obtained	Calcu-lated
13.5	1	0.01	0	0	1	0	0	0.04
14.0	0	0.06	0	0	0	0	1	0.16
14.5	0	0.22	0	0	0	0	3	0.58
15.0	2	0.75	0	0	0	0	2	1.66
15.5	3	2.18	1	0.01	0	0.01	2	3.99
16.0	9	4.86	1	0.01	0	0.02	6	8.03
16.5	8	9.28	0	0.08	2	0.13	14	12.63
17.0	14	13.85	0	0.31	1	0.46	19	16.95
17.5	10	17.19	3	1.02	0	1.45	20	17.75
18.0	18	17.88	5	2.75	7	3.52	17	15.55
18.5	10	14.50	4	5.85	5	7.33	10	11.35
19.0	15	10.04	15	10.30	10	11.91	5	6.46
19.5	4	5.43	8	15.24	14	16.07	1	3.15
20.0	4	2.46	10	17.62	20	18.20	0	1.70
20.5	1	0.93	16	17.35	12	16.07	0	0
21.0	1	0.28	16	13.35	9	11.91	0	0
21.5	0	0.06	13	8.62	8	7.33	0	0
22.0	0	0.02	5	4.62	9	3.52	0	0
22.5	0	0	1	1.93	1	1.45	0	0
23.0	0	0	0	0.69	1	0.46	0	0
23.5	0	0	2	0.19	0	0.13	0	0
24.0	0	0	0	0.06	0	0.02	0	0
24.5	0	0	0	0	0	0.01	0	0

[1] The estimated environmental standard error used in computing the calculated frequency distribution is 1.1016.

Table 6.—Chi-square test for goodness of fit of the obtained and calculated frequency distributions for percent dry matter of the petioles and sucrose percentage in the root for the three populations and the F_1 hybrid.

Population	Percent dry matter		Percent sucrose	
	Chi-square	P lies between	Chi-square	P lies between
CS7	96.61	0.001	13.04	0.05 - 0.02
A90-54	55.11	0.001	12.90	0.05 - 0.02
5957	34.58	0.001	13.96	0.05 - 0.02
A213, F_1 hybrid	9.59	0.10 - 0.05	3.48	0.95 - 0.50

did the data from the three open-pollinated populations conform to the normal distribution within the limits of random error. Hence, if it is possible to identify and select genetically superior individuals for sucrose percentage, then it should be possible to identify individual plants which are genetically superior to the mean of the population for percent dry matter.

It would be of particular interest to index plants for percent dry matter if it could be demonstrated that percent dry matter is correlated with a character of economic value such as sucrose percentage. The correlation coefficients calculated from the data taken from the 400 plants are listed in Table 7. A highly significant positive correlation was obtained between percent dry matter versus sucrose percentage, whereas, highly significant negative correlations were obtained for percent dry matter versus root weight, and sucrose percentage versus root weight.

Table 7.—Simple correlation coefficients based on 300 pairs of observations within three populations for percent dry matter of the petioles, sucrose percentage and root weight.

Variate	Sucrose percentage	Root weight
Percent dry matter in petiole	+0.654**	—0.371**
Sucrose percentage	—	—0.429**

** Significant at P .01.

Table 8 lists the mean sucrose percentage and mean root weight of the three open-pollinated populations and of 10 plants highest in percent dry matter from the respective populations. As indicated in Table 8 the selection for high percent dry matter resulted in an increase in sucrose percentage in each of the three open-pollinated populations. This increase was highly significant for CS7 and 5957, but non-significant for A90-54. However, none of the three selections resulted in a statistically significant change in root weight.

Table 8.—The effects on sucrose percentage and root weight by selecting for high percent dry matter of the petiole within each of three populations[1].

	Population					
	CS7		A90-54		59557	
	Original	Selection	Original	Selection	Original	Selection
Percent sucrose						
Number of plants	100	10	100	10	100	10
Mean	17.54	18.80	19.91	20.68	19.75	20.88
Variance	1.7728	1.1733	2.0002	1.8956	2.0161	0.7311
Observed F value		3.43**		1.68ns		3.70ns
Tabular F value P .05		2.22		2.23		2.20
P .01		3.17		3.19		3.12
Root weight in ounces						
Number of plants	100	10	100	10	100	10
Mean	26.97	28.55	19.72	18.65	17.15	15.45
Variance	80.4031	103.8022	58.7844	23.5578	37.3662	4.9133
Observed F value		0.47ns		0.62ns		1.83ns
Tabular F value P .05		2.24		2.20		2.14
P .01		3.21		3.13		2.98

[1] Comparisons were made using statistical methods described by Goulden (2).

** Significantly different from parent population at P .01.

ns Not significantly different from parent population.

Discussion

It has been demonstrated that percent dry matter is under the control of a genetic system which appears to simultaneously influence sucrose percentage. Furthermore, it has been shown that the number of individual plants that occur in a class of the frequency distribution for percent dry matter may be predicted within the limits of random variation. Based on these two findings a procedure is now suggested that might be useful in intensifying a simultaneous sucrose percentage and root weight improvement, if indeed such improvements are possible. It is possible to index plants for percent dry matter of the petiole in advance of root harvest. Since the procedure for making percent dry matter determinations is simple a large number of plants may be indexed. The plants high in percent dry matter could be selected. Since there is a significant positive correlation between sucrose percentage and percent dry matter most of these plants would be high in sucrose percentage. Therefore, many large roots, probably low in sucrose percentage, need not be harvested. Of the harvested roots, from indexed plants with high percent dry matter, all small roots could be discarded as unsatisfactory in root weight. The large roots selected in this manner could be tested for sucrose content. On the basis of this sucrose determination a final selection of roots high in both weight and sucrose percentage could be made.

Summary

1. Data are presented which indicate that percent dry matter of the petiole is under the control of a genetic mechanism which also influences the sucrose content of the root.

2. Percent dry matter of the petiole is positively correlated with sucrose percentage in the root and negatively correlated with root weight.

3. Analysis of the frequency distribution and genetic variances reveals that it should be possible to select for both high and low percent dry matter of the petiole.

4. The possibility for using percent dry matter of the petiole to enhance the selection of individual plants for high sucrose percentage and high root weight simultaneously is considered.

Acknowledgement

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