Variability of Open-pollinated, Inbred and Hybrid Sugar Beet Varieties in Greenhouse Experiments[1]

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One of the characteristic features of experiments with sugar beets is the large variation of the individual plants within a given beet variety. This variability is not serious for measurements based upon 20 or more plants, but where the space available for experimentation restricts the number of plants to less than 20, any reduction in variability becomes extremely important, not only to conserve space but to decrease the differences required for significance between treatment means. Of the two main avenues open to a reduction in experimental error, namely, improvement in technique and in the utilization of varieties of greater genetic uniformity, only the latter approach, *in* which inbred and hybrid varieties are contrasted with open-pollinated varieties, seemed desirable.

Such a uniformity trial may be conducted readily in an uncontrolled climate; however, to broaden the basis for judging the variability of each variety it is desirable to grow the varieties in a series of climates, preferably controlled climates, such as those now available in the Earhart Plant Research Laboratory at Pasadena, California (4) .[3] By growing each variety *in* a series of climates and by using a balanced statistical design for conducting the experiment approximately six times as much information was obtained with the same number of pots as proposed originally for comparing the uniformity and performance of each variety in a single climate. The results for six climates with eight varieties are reported in this paper.

Procedure

The eight sugar beet varieties used in this experiment are listed according to type and source of material in Table 1. Of these varieties two are open-pollinated commercial varieties, four are inbreds and two are hybrids. The six climates used in growing the plants are given in Table 2.

The sugar beet seeds of each variety were planted in expanded vermiculite at a depth of $^3/_4$ inch at the rate of 10 seed balls per pot on February 2, 1951. Twenty-four pots were used for each variety, or a total of 192 pots for the entire experiment. After the seeds were planted, the pots were watered daily with Hoagland's complete culture solution (solution 1) (2) in order to keep the plants well supplied with water and nutrients. The culture solution was always added in excess, and this excess was permitted to drain out through holes in the bottom of the pots.

During the initial growth period, February 2 to March 13, the pots were kept in the greenhouse in sunlight for natural day lengths. The air temperature during this period was 23° C. from 8:00 a. m. to 4:00 p. m., and 17° C. from 4:00 p. m. to 8:00 a. m. As the plants developed, they were thinned to a single plant per seed ball at the early two-leaf stage, to four

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[3] Numbers in parentheses refer to literature cited.

Table 1.—Sugar Beet Varieties.

Variety	Description	Source
U. S. 22/3 (Elite stock)	Open-pollinated	Utah-Idaho Sugar Company Salt Lake City, Utah
G. W. 304	Open-pollinated	Great Western Sugar Company Denver, Colorado
Female parent of H. 148 (Ac. 35 410605Es)	Inbred	H. L. Kohls, Michigan State College Lansing, Michigan (5)
Male parent of H. 148 (Ac. 32 57305)	Inbred	H. L. Kohls, Michigan State College Lansing, Michigan (5)
H. 148 (G. H. 1950)	Hybrid	H. L. Kohls, Michigan State College Lansing, Michigan (5)
CT9 (S. L. 69)	Inbred	F. V. Owen Division of Sugar Plant Investigations Bureau of Plant Industry United States Department of Agriculture Salt Lake City, Utah (6)
U. S. 35 MS x CT9 (S. L. 6105)	Hybrid	F. V. Owen Division of Sugar Plant Investigations Bureau of Plant Industry United States Department of Agriculture Salt Lake City, Utah (7)
402	Inbred	Henk Rietberg Instituut voor Rationele Suikerproductie Bergen op Zoom, Holland

plants per pot at the late two-leaf stage, and finally, on March 13, to two plants per pot at the eight-leaf stage. On March 13 the pots for each variety were assigned at random to one of the six climates, with four pots of a variety or a total of 32 pots for the eight varieties to a single climate. These pots were further assigned at random in units of eight pots (varieties) to two trucks of four pots to a truck, or a total of eight trucks for the 32 pots to a climate.

Table 2.—Controlled Climates.

Climate	Period from 8 a.m. to 4 p.m. (8 hrs.)	Period from 4 p.m. to 8 a.m. (16 hrs.)
1	20° C (Sunlight)	14° C (Natural day length)[1]
2	20° C (Sunlight)	14° C (Dark)
3	20° C (Sunlight)	20° C (Dark)
4	26° C (Sunlight)	20° C (Natural day length)[1]
5	26° C (Sunlight)	20° C (Dark)
6	26° C (Sunlight)	26° C (Dark)

[1] Natural day length at Pasadena, California, increased gradually from 10.6 hours for the time of planting, February 2, 1951, to 11.9 hours when the plants were placed into the above climates, March 13, 1951, to 14.3 hours when the plants were harvested, June 5, 1951. From February 2 to March 13, 1951, the plants were grown in a greenhouse kept at 23° C. from 8 a. m. to 4 p. m. and at 17° C. from 4 p. m. to 8 a. m.

Weekly counts of newly formed leaves and of old leaves were made during the 84-day growth period of the plants in their respective climates. The old leaves were removed, saved, dried and added to the dried material of the tops of the harvested plants. At the time of harvest on June 5, 1951, the beet plants were separated into roots and tops by cutting just below the base of the leaves which were still attached to the plant. The beet roots, including the crown, were weighed and analyzed for sucrose content by the hot extraction method (1) after freezing individual 26.0-gram samples of pulp prepared from the two beet roots of each pot. The tops were weighed and separated into distinct fractions of living leaf blades and a residue of

unclassified material. Each leaf fraction was weighed fresh and again after it had been dried in a forced-draft oven maintained at 80° C.

Xhe results of each measurement, summarized in Table 3, were analyzed statistically for each variety separately and for all varieties collectively by the method of analysis of variance (3). Xhe error variances (mean square error), mean values, coefficients of variation and the observed F-values were obtained for each measurement, as follows, using the beet root yields of the US 22/3 variety as an illustration:

Source of variation	Degrees of freedom	Sum of squares	Mean square (Variance)	Observed F-value
Total	23	764,998	.....	.....
Climates	5	497,156	99,431	6.68
Error	18	267,842	14,880	.

$$\text{Coefficient of variation (CV)} = \frac{(\text{error variance})^{1/2}}{\text{mean}} \times 100 = \frac{(14{,}880)^{1/2}}{305.6} \times 100 = 39.9$$

Mean = general mean of 24 values

For the beet root yields of all varieties the procedure used is:

Source of variation	Degrees of freedom	Sum of squares	Mean square (Variance)	Observed F-value
Total	191	8,541,129	.....	.....
Climates	5	3,990,563	798,113	96.23
Varieties	7	2,299,011	328,430	.....
Climate x variety	35	1,057,146	30,204	.....
Error	144	1,194,409	8.294	.....

$$CV = \frac{(\text{error variance})^{1/2}}{\text{mean}} \times 100 = \frac{(8.294)^{1/2}}{286.6} \times 100 = 31.8\%$$

Mean = general mean of 192 values

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Experimental Results

Xhe inherent variability of the plants of each beet variety is indicated by the coefficient of variation of the plants which were grown in the six climates (Xable 3). A careful inspection of these coefficients shows no great difference in variability consistently in favor of any of the varieties for beet root weights, percent sucrose, sucrose weights, fresh and dry weight of the tops, fresh weight of the living blades, the number of leaves at harvest, the total number of leaves produced and the final heights of the plants. Even genetically uniform material of fair viability, such as the Holland Inbred, has a coefficient of variation of root weights equal to 28.4 percent, in contrast to the values of 39.9 percent and 25.6 percent for the open-pollinated varieties U.S. 22/3 and G.W. 304, respectively. Xhis picture is not improved for the hybrid varieties, since H. 148 and U. S. 35 MS x CX9 have coefficients of variation of 24.3 percent and 29.6 percent, respectively.

Xhe coefficients of variation of sucrose percents are about the same for all varieties, except the Holland Inbred, which has a coefficient of variation of 6.9 percent compared to 10.2 and 12.4 percent for the open-pollinated varieties, G.W. 304 and U. S. 22/3, respectively. Xhis advantage in favor of the Holland Inbred may be valuable in studies where its slower growth rate, compared to the hybrid and open-pollinated varieties, is not important.

Table 3.—Summary of the Statistical Analyses of the Beet Root Weight, Sucrose Concentration, Sucrose Produced, Weight of Tops, Leaf Count and Height Measurements for Eight Sugar Beet Varieties in Six Climates.

Measurement	Statistic	US 22/3	GW 304	♀ 146	♂ 146	H 146	CT9 Inbred	US 35 MS x CT9	Holland Inbred	All varieties
Root	Error var.	14,880	14,420	6,210	7,912	8,488	1,058	9,986	3,418	8,294
wt	Mean[1]	306	468	215	296	378	87	337	206	287
(gm)	CV[2]	39.9	25.6	36.6	30.0	24.3	37.0	29.6	28.4	31.8
	F-value[3]	6.68[5]	12.11[5]	9.17[5]	20.5[5]	33.6[5]	7.00[5]	18.3[5]	12.0[5]	96.2[5]
Sucrose	Error var.	1.12	0.85	0.60	0.84	0.66	1.09	0.76	0.48	0.80
(%)	Mean[1]	8.5	9.1	7.6	8.4	7.8	8.8	9.2	10.0	8.68
	CV[2]	12.4	10.2	10.2	10.9	10.4	11.8	9.5	6.9	10.3
	F-value[3]	3.80[4]	6.06[5]	7.90[5]	6.68[5]	8.97[5]	2.95[4]	6.70[5]	6.92[5]	56.3[5]
Sucrose	Error var.	202.8	149.4	48.3	105.4	105.9	10.3	110.2	50.1	97.81
(gm)	Mean[1]	27.3	44.2	17.4	26.2	32.4	8.0	32.7	21.5	26.20
	CV[2]	52.1	27.6	39.9	39.2	31.8	40.1	32.1	32.9	37.7
	F-value[3]	5.56[5]	15.99[5]	11.52[5]	16.99[5]	27.13[5]	8.06[5]	20.12[5]	12.18[5]	96.9[5]
Tops,	Error var.	30,542	53,992	55,980	50,156	39,182	5,966	22,305	25,038	32,645
fresh	Mean[1]	776	980	850	777	915	281	780	688	756
wt (gm)	CV[2]	22.5	23.7	27.8	22.4	21.7	27.5	19.0	22.1	23.9
	F-value[3]	5.11[5]	4.40[5]	3.64[4]	3.12[4]	8.39[5]	5.90[5]	11.89[5]	9.43[5]	38.3[5]
Tops,	Error var.	408	547	716	263	398	65	316	312	378
dry wt	Mean[1]	96	135	102	107	122	34	95	95	98.4
(gm)	CV[2]	21.0	17.3	26.5	15.1	16.4	25.7	18.7	18.6	19.8
	F-value[3]	3.79[4]	4.72[5]	2.98[4]	13.51[5]	10.10[5]	5.05[5]	10.84[5]	7.57[5]	43.5[5]
Blades,	Error var.	4,958	6,253	5,016	1,718	4,295	600	1,529	1,960	3,298
fresh	Mean[1]	237	348	295	279	313	88	217	194	246.4
wt (gm)	CV[2]	29.7	22.7	24.0	14.8	20.9	29.2	18.0	22.8	23.3
	F-value[3]	2.71	4.65[5]	2.72	9.23[5]	6.18[5]	2.88[4]	11.53[5]	5.84[5]	30.3[5]
Blades,	Error var.	84	158	129	57	67	53	58	77	85.5
number	Mean[1]	62	60	61	56	64	41	55	67	58.3
	CV[2]	14.8	23.5	18.6	10.9	12.8	17.8	11.2	13.1	15.8
	F-value[3]	4.88[5]	2.57	3.44[4]	8.94[5]	12.22[5]	6.89[5]	20.50[5]	12.60[5]	49.6[5]
Total	Error var.	81	337	158	75	102	142	76	92	132.7
number	Mean[1]	106	102	98	102	111	76	94	109	99.9
leaves	CV[2]	8.5	18.0	12.8	8.5	9.1	15.6	9.3	8.8	11.5
	F-value[3]	1.63	0.59	0.49	1.62	1.29	1.04	1.98	2.35[4]	4.5[5]
Height	Error var.	50	58	47	75	32	21	26	28	38.1
(cm)	Mean[1]	51	60	48	51	49	41	55	56	51.6
	CV[2]	10.8	10.4	14.2	16.6	11.5	11.1	10.7	9.5	12.0
	F-value[3]	1.09	1.08	0.69	1.00	1.89	2.91[4]	1.38	6.48[5]	7.8[5]

[1] Average of 24 pots.
[2] Coefficient of variability.
[3] The F-values represent the ratios of climate variance to error variance. The required values at the 5 percent and 1 percent levels are 2.77 and 4.25, respectively, for a given variety, and 2.28 and 3.15, respectively, for all varieties.
[4] Significant at 5 percent level.
[5] Significant at the 1 percent level.

The coefficients of variation of the sucrose weights per pot, as might be expected, are higher than either the coefficients of variation of beet root weights or of sucrose percents. The coefficients of all varieties are about the same, except for U. S. 22/3, which is considerably higher than the others. The reason for this is probably due to the fact that the coefficients of variation of beet root weights and of sucrose percents of U. S. 22/3 are the highest of all varieties. Certainly a value of 52.1 percent for U. S. 22/3, in contrast to the lowest value of 27.6 percent for the GW 304, does not point conclusively to a higher variability of commercial varieties in comparison to the inbred and hybrid varieties used in this study.

The coefficients of variation of the fresh weights and dry weights of the tops again do not differ greatly from each other. As a rule, the coefficients of variation of the dry weights of the tops are less than those of the fresh weights; however, the difference, while consistent, is not large. The coefficients of variation of the fresh weights of the living blades differ considerably from each other, but this variation is not related to the genotype of the beets. The variability of the number of living blades is the highest in the GW 304 variety and the lowest in the male 148 inbred and the U. S. 35 MS x CT9 hybrid, while the remaining varieties have intermediate variabilities. The total number of leaves produced by the plants during their entire growth period and the heights of the plants at harvest have the lowest variabilities of any of the measurements made, except for sucrose concentrations, but again there is no consistent advantage of one variety over the others.

Discussion

A careful review of the coefficients of variation shows no distinct advantage of the inbred or hybrid varieties over the open-pollinated varieties in these experiments. Theoretically, the inbreds and hybrids should have shown a decrease in variability, and their failure to do so indicates that the improvement in genetic composition of the varieties has been slight or that the variations associated with the technique used in growing the plants has masked the reduction in variability induced by plant breeding. Since the coefficients of variation do not decisively favor one variety over another, the best variety to use in physiological studies must be selected on other bases. At present the variety which has the greatest growth potential in the widest range of conditions, as, for example, GW 304, should be selected, rather than a variety that grows poorly.

While the coefficient of variation and rate of growth are important criteria for the selection of a variety of beets to be used for plant physiological studies, the selection of a measurement suitable for detecting growth changes should consider also the F-values of the treatment to error-variance ratio (Table 3) . Thus, the coefficients of variation of the beet root weight and sucrose weight of the varieties individually and collectively are the highest in all measurements taken; however, the calculated F-values are also the highest throughout, indicating that the effects of climate on beet root and sucrose weights are even larger than the error variabilities which occurred in these measurements. In contrast, the sucrose percents have the lowest coefficients of variation of any measurements, and yet the F-values are, on the average, less than one-half of the F-values of the beet root and sucrose weights. This suggests that the sucrose concentration of the beet roots is less affected by differences in climate than beet root weights and sucrose

yields. The fresh and dry weights of the tops, the fresh weight of the blades, and the number of living blades at the time of harvest have intermediate F-values, while the total number of leaves produced by the plants during the growing season and the height of the plants at the time of harvest have the lowest F-values, which in most instances are not significant at the 5 percent level. This again indicates that the coefficient of variation should not be used exclusively as a criterion for selecting the measurement to be made to detect changes in plant growth.

Summary

The variability of eight sugar beet varieties, consisting of two open-pollinated commercial varieties, four inbreds and two hybrids, was studied in six climates. A review of the coefficients of variation obtained showed no consistent decrease in variability in favor of the inbreds and hybrids over the open-pollinated varieties, indicating that the improvement in the genetic uniformity of the inbreds and hybrids has been slight or that the technique used in growing the plants has masked the reduction in variability induced by plant breeding. Accordingly, the logical variety to use in plant physiological studies is the one which grows rapidly in a wide range of conditions rather than a variety that grows poorly.

In the selection of a measurement to make on plants to observe growth changes the ratio of the treatment variance to its error variance (F-value) must be considered as well as the coefficient of variation. Thus, at times, the effect of climate on the growth of sugar beet plants may be observed better by recording factors with a very high coefficient of variation, such as beet root weight or sucrose produced, rather than by measuring some factor with a low coefficient of variation, such as counting the total number of leaves developed by the plants or by measuring their heights at the time of harvest.

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