Molasses Produced, Percentage on Beets

Foreign seed		Great Western seed	
1933-4	4.39	193S-9-	3.S0
1934-5	4.48	1939-40	3,83
1035-6	4.21	1940-41	3.82
1936-7	4.15	1941-42	3.75
1937-S	4.10		
Average	4.27	Average	3.80

The figure obtained during the campaign just closed is the lowest on record for our company, and would have been still lower in a year with less leafspot.

We are, therefore, convinced that we have been justified in putting some emphasis on purity in our breeding program. As indicated above, the results obtained so far have been obtained mainly by attention to ash content and leafspot resistance, although the factor of harmful nitrogen has not been neglected.

Some Crossing Experiments with Sugar Beets

C. W. DOXTATOR AND A. W. SKUDERNA[1]

The increased yields in crop plants which can be attributed to hybrid vigor is a phenomenon which must be considered by every plant breeder. In the sugar-beet *(Beta vulgaris L.)* hybrids of certain inbred lines have been reported to give yields not only greater than their parents, but also greater than the check variety R. and G. Pioneer (4).[2] As in many other cross-pollinated crops, however, inbreds of sugar beets are commonly lower in yield than their parent varieties.

Unlike corn, where large-scale controlled pollination for hybrid-seed production is possible, the sugar beet at the present time can be totally crossed only on an experimental scale, and consequently a complete utilization of hybrid vigor effects in commercial production is impossible. If natural cross-pollination between 2 strains is resorted to for hybrid-seed production, this seed will be made up of 3 types: The true hybrid, parent A, and parent B. In order that such a synthetic variety may be highly desirable in yield, it is necessary that the parents themselves be high-yielding types, and that their hybrid be exceptionally high in yield.

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[2]Figures in parentheses refer to Literature Cited.

It is known that certain synthetic varieties which have originated from the natural crossing of several varieties or strains have had superior-yielding qualities. Synthetic Check, a cross-pollinated increase of 9 foreign varieties, has been used in many of the tests conducted by the United States Department of Agriculture for the past 10 years, and has been a consistently good yielder during this time (3). Recently, a synthetic variety developed and used by the American Crystal Sugar Company as American No. 1, has performed satisfactorily in leafspot areas, where beets are grown for this company (1).

At present, good commercial varieties are available which if used for the production of synthetic varieties would, in themselves, not be undesirable when found mixed with hybrids in the root crop. Therefore, it is important to know what average increase in yield might be expected from true hybrids between good commercial varieties. If increases in yields are obtained, it is equally important to determine which variety hybrid excels in yield, so that appropriate seed increases of synthetic varieties can be made immediately. Finally, information can be obtained which may be of value in the ultimate utilization of inbreds which originate from commercial varieties. Up to the present time, however, practically no experimental work has been conducted for the purpose of critically studying hybrid vigor effects in variety crosses of sugar beets.

This paper presents the results of tests obtained over the 2-year period 1940 and 1941, on a series of commercial varieties and the true, or nearly true, crosses between them.

Materials and Methods

In these studies, 14 varieties were used, representing a number of different seed sources. In the following table pertinent data are given with regard to these parent varieties:

Table 1.—Breeding number and source of varieties used in variety hybrid tests—1940 and 1941.

No.	Breeding No.*	Variety source
1	0-408	Terra
2	9-702-0	Dobroviee N
3	8-301-0	R & G Normal
4	7-401-0	American No. 4
5	Schreiber	Schreiber
6	9-801-0	Schreiber
7	8-406-0	American 1936
8	8-409-0	Flat Foliage
9	0-420	U. S. 200 x 215
10	0-419	American 1939
11	0-409a and 0-409b	Cesena
12	0-416	American 1938
13	8-401-0	U. S. 217
14	8-403-0	U. S. 217

•All varieties were mass selected except No. 8, which was inbred 2 generations.

All sib-seed increases and varietal crosses grown in field tests to be reported in this paper were made in the greenhouses at Rocky Ford, Colorado, during the 1940 and 1941 winter seasons. In both seasons, not less than 50 roots of all varieties to be crossed were brought out of winter storage by December 25 and potted with rich garden soil in 8-inch pots in the greenhouses. The first seedstalks were bagged early in February and hybridization work was well under way by February 25. Seed was ready for harvest by April 20 in each season.

During the 1939 winter season, experiments were conducted on crossing methods, in order to determine what procedure could be used to produce a sizeable amount of pure hybrid seed. Hand emasculation and pollination methods were found to be much too slow for this purpose. The enclosing of 2 seedstalks originating from different mother roots in various sizes of kraft bags was also tried, but because in the greenhouses there are occasionally plants which differ greatly in time of flowering, this method was also found to be undesirable. A third procedure, that of bagging the main flowering stem of individual plants immediately prior to the opening of the flowers and the subsequent switching of each bag containing pollen between 2 plants was then tried. In the latter procedure, a kraft grocery bag (size 8) was used for each plant.

A check on the extent of hybridization obtained by the method of pollen transfers using kraft bags was made during the 1940 summer season, by pollinating plants having the "rr" factor for green hypocotyl with pollen from plants having the dominant red hypocotyl character. The parent plants used for crossing were also self-pollinated. In all, 15 check crosses were made in this experiment, but due to self-sterility of the parents, an accurate check on the R factor was obtained on only 5 crosses.

In table 2 are given the results obtained in testing this technique.

Table 2.—Results obtained in kraft-bag pollen transfers between flowering plants for production of hybrid seed, Rocky Ford, Colorado, 1940.

Cross No.	Varieties crossed	Hypocotyl character as determined frona in-bred seed	No. of pollen trans-fers	Total seed pro-duced	No. of seed-producing rr plants	Per-centage hybrid-ization
1	8-406-0 X 7-401-0	rr X RR	2	153	153	100.
2	8-406-0 X 7-401-0	rr X RR	1	260	258	99.2
3	0-419 X 0-409	rr X RE	1	48	46	95.8
4	8-403-0 X 8-403-0	rr X RR	1	270	141	52.2
5	8-403-0 X 7-401-0	rr X RR (a)	1	7	0	0
Average of rr X RR crosses						98.3

(a) Small amount of pollen available

In making these crosses, the first pollen transfer was made when one-third of the flowers on each plant were open. The second transfer (cross No. 1) was made when the flowers were approximately two-thirds open. In the case of cross No, 5, only a very small amount of pollen was available on the male parent for transfer to the female. The results obtained indicate that under the conditions existing in these greenhouses, one or two pollen transfers were required to effect complete, or nearly complete, crossing. Furthermore, it was apparent that plants producing large amounts of pollen were more suitable as male parents.

As a result of these tests, it was decided to carry on all crossing work by the use of this "bag switching" technique. Care was used to select productive*plants as parents. At least 2, and where conditions warranted, 3 reciprocal pollen transfers were made between 2 plants, both for crosses within varieties, for the production of variety seed, and between varieties, in the production of varietal crosses. Since the bagging of single-flowering stems of beet plants for the production of first-generation selfed seed in the greenhouses rarely produces more than 50 seeds, it was decided to discard seed progenies of less than this amount obtained from individual plants used in the crossing operations, thereby further reducing the possibility of contamination of the hybrid seed with self-pollinated seed.

In all crosses between varieties reported in this study, a minimum of 6 roots of each variety was crossed in pairs, reciprocally. In crosses within varieties, a minimum of 14 plants was used, and 7 pairs of crosses made reciprocally. The total seed produced for each sib or crossed progeny ranged from % ounce to 2 ounces in amount. In all, 33 variety hybrids and 14 parent stocks were made and tested in 1940, and 15 hybrids and 6 parent stocks in 1941.

The hybrids and parent varieties produced were arranged in 3 groups for field tests as follows:

Group No. 1 containing all 15 possible crosses of varieties, No. 1 to 6 inclusive, along with the 6 parents;

Group No. 2 containing 18 crosses originating from variety No. 4, and varieties 7 to 14 inclusive, along with 9 parents;

Group No. 3 which included the 6 parents Nos. 4, 7, 10, 11, 13 and 14, along with their 15 possible hybrid combinations.

A standard cheek variety was included in all tests for comparison purposes. Group 1 was made up of varieties suitable for Northern beet-producing areas, and was tested at East Grand Forks, Minnesota, in 1940. The leafspot-resistant varieties, groups 2 and 3, were tested at Rocky Ford, Colorado, in 1940 and 1941, respectively.

Due to the very small amount of seed available for test, it was found necessary to modify the usual technique of field testing to some degree. Group No. 1 was planted on May 20, 1940, in single-row

plots, 150 foot long without replication. Group 2 was planted on May 5, 1940, in 10 randomized blocks of 2-row plots 8 hills long. Spacing was 20 inches between rows and 15 inches between hills. Group No. 3 was planted May 10, 1941. in 10 randomized blocks of single-row plots 16 hills long. Hills were checked 20 inches x 20 inches in this test. Excellent stands were obtained in tests at Rocky Ford, but due to lack of moisture, very poor stands were obtained on the test located at East Grand Forks, Minnesota.

The harvest of varieties and hybrids in Group No. 2 was made by the competitive beet method as mother roots. These were washed, individually weighed, and analyzed as mother roots. Yields of each were then obtained by adding all individual weights of the beets from each plot. To reduce these weights to a commercial topped-beet basis, all plot weights were reduced by 12 percent. The weighted average sugar percentage was obtained from the weight and analysis' data. Group Xo. 3 was harvested without regard to competition. All beets from each plot were topped in normal manner, washed, weighed, individually split, and one-half of each root used to obtain a composite sample of pulp for sugar analysis. Sugar analysis was made by the Sachs-Le Docte cold-water digestion method. The analysis of variance (2) was used in tests No. 2 and No. 3 for the reduction of data-

Experimental Results

Since a very poor stand was obtained on the varieties and hybrids of group No. 1, only a weight index note was taken at harvest time. The results obtained indicated that most of the hybrids excelled the parents in productivity. One hybrid, 7-401-0 x 9-801-0, was exceptionally vigorous and far exceeded the appearance of all the parents and most of the hybrids. Eleven hybrids appeared intermediate in yield performance, and 3 appeared no better than their parent varieties.

In the test of group No. 2, only 18 of the possible 36 hybrids from the 9 varieties were made and tested. These data are given in table 3.

It is of interest to note that the top-ranking variety hybrid in this test, 8-406-0 x 7-401-0, had as parents 2 of the highest-yielding varieties. This hybrid was significantly higher than either parent in tons beets per acre, and in pounds sugar-per-acre yields. The lowest-yielding hybrid, 8-401-0 x 0-416, was produced from 2 of the lowest-yielding varieties in test. Despite the comparatively low yields of this hybrid and its parents, the hybrid was significantly higher than either parent in percentage of sucrose and in pounds sugar-per-acre yield. In comparing the yields of sugar per acre of all hybrids with their respective parents it was found that 6 of the 18 hybrids tested

outyielded both parent varieties by a significant margin, 10 significantly outyielded 1 parent variety, and 2 hybrids did not differ from their parents in yields.

Table 3.—Tons beets per acre, percentage sucrose, and pounds sugar per acre, of 9 varieties, 18 variety hybrids and check variety. Rocky Ford, Colorado, 1940.

Variety or hybrid	Tons beets Iter acre	Percentage sucrose	Pounds sugar per acre
8-406-0 x 7-101-0	25.51	12.57	0294 ~~
0-420 x 0-419	2o.r>ii	11 .K5	6220
0-419 x 7-401-O	2:?. 03	12.61	5929
8-406-0 x 0-420		12.07	5853
0-410 x 7-401-O	23. OO	12.56	5807
8-406-0 x 0-41.9	24.14	12.22	5737
8-409-0 x 0-419	22.42	12.75	5667
8-406-0 x 8-401-0	22.13	12.32	5446
0-419	20.33	12.79	522»
S-401-0 x 7-401-0	23.70	10.50	4983
8-406-0 xO 409a	19.33	12.74	4974
7-401-0	20.70	12.01	4945
0-420 x O-409a	22.38	10.94	4911
8-400-0	19.83	12.17	4796
0-409a	21.46	11.01	4741
8-409-0 XO-109H	20.85	12.43	4727**
N-403-0 x 7-401-0	20.50	11.55	4725
8-4O6-0 x N-409 0	18.48	12.19	4496**
0-419 x 0-409a	19.40	11.46	4495
Sellrciher S. K. (cheek)	19.83	11.54	4481
S 400-0 x 0-410	19.20	11.45	4383
S-400-0 x S 103-0	17.60	12.74	4349
S-401-0 x 0-116	17.22	12.63	4314
0-4120	18.37	10.84	3995
8-403-0	17.19	11.33	3850
S-401-0	15.97	11.17	3468
0-416	15.45	10.94	3367
S 109-0	14.82	11.49	3324*
Standard error	1.08	.34	' 274
DilT. req. for sig.. (19:1)	3.06	.96	774
F Value significant beyond:	1 percent	1 percent	1 percent

From the data on tons beets per acre and percentage of sucrose shown in table 4, it will be noted that the 4 highest-yielding hybrids significantly outyielded both parent varieties in root weight. Three of these hybrids were significantly higher in sucrose percentage than 1 parent variety, and 1 hybrid, 0-409b x 7-401-0, was significantly higher than the 7-401-0 parent, and significantly lower than the 0-409b parent. A small increase in sucrose value for each of these 4 hybrids over the average of their respective parents was also observed.

In table 5, yields of sugar per acre of the 6 varieties and 15 hybrids are arranged so that the general combining ability of each parent can be observed through the average of all 5 of its single crosses.

A study of the individual sugar yields of the varieties and hybrids shows that 4 hybrids were significantly higher in yield of sugar per acre than either parent, 4 were significantly higher than 1 parent, and 7 did not differ significantly from either parent. In 3 of these

Table 4.—Yields of tons beets per acre, and percentage of sucrose of 6 varieties and all possible single crosses, with standard cheek (group No. 3), Rocky Ford, Colorado, 1941.

Variety No.	Tons beets per acre	Percentage sucrose	Comparative rank for percentage sucrose
0-409b x 8-401-0	22.38	15.95	(3)
0-409b x 7-401-0	21.04	14.63	(14)
0-419 x 7-401-0	20.00	14.55	(16)
0-409b x 8-403-0	18,43	15.69	(4)
8-401-0 x 7-4O1-0	17.08	14.60	(15)
7-401-0	16.46	13.69	(21)
8-403-0 x 7-401-0	16.91	14.38	(18)
8-406-0 x 8-401-0	15.68	14.23	(19)
8-406-0 x 7-401-0	15.68	14.72	(12)
0-419 x 8-403-0	15.51	15.39	(6)
8-406-0 x 0-419	15.44	15.97	(2)
0-419 x 8-401-0	15.26	14.84	(1D
0-41.9	15.07	14.39	(17)
8-406-O x 8-403-0	14.83	15.00	(8)
0-419 x O-409b	14.79	14.91	(9)
Schreiber S. S*. (chock)	14.68	13.64	(22)
8-406-0	14.23	14.85	(10)
8-403-0	13.56	14.69	(13)
8-401-0	13.27	14.18	(20)
8-406-0 x 0-409b	13.12	16.68	(1)
8-401-0 x 8-403-0	10.93	15.32	(7)
0-409b	10.01	15.46	(5)
Diff. req, for sig.	3,25	.63	
Sig. of F values	1 percent	1 percent	

Table 5.—Pounds sugar-per-acre yields of 6 varieties and all possible single crosses (Group No. 3), Rocky Ford, Colorado, 1941.

Parent variety number						Pounds sugar per acre of:		
S-406-0	0-419	0-409b	8-401-0	8-403-0	7-401-0	Parent Variety No.	Parent	Average of single crosses
	4892	4336	4567	4397	4620	8-406-0	4200	4562
	4381	4507	4707	5837	0-419	4305	4865	
		7152	5758	6148	0-409b	3114	5555	
			3332	4975	8-401-0	3758	4907	
				4819	8-403-0	3946	4603	
					7-401-0	4483	5280	

Diff. req. for sig. (19:1): for individual yields 895 pounds.
for single-cross averages 400 pounds.

4 superior-yielding hybrids, 0-409b was 1 parent, and in 2, 7-401-0 was I parent. Since these 2 varieties were the lowest and highest in yield respectively, it would appear that the yielding ability of the parent varieties in this test could not be used as an index of the yielding ability of their hybrids. It will be further noted that from the average yields of all single crosses obtained for each parent, 0-409b significantly exceeded all varieties for general combining ability, with the exception of 7-401-0.

It is of interest to compare the yield of 8-401-0 x 8-403-0 with the 2 parents. These two varieties were derived from the same original variety (table 1) through careful mass selection. From general variety tests in 1939 and 1940, these 2 varieties performed differently enough in tonnage yield and in percentage of sucrose to be considered as distinctly different varieties. The hybrid yield indicates, however, that these 2 varieties must have been similar in genetic factors

Table 6.—Tons beets per acre, percentage of sucrose, and pounds sugar-per-acre yields of 7 variety hybrids, compared with their parents. Average of 1940-41; Rocky Ford, Colorado.

Hybrid No.	Hybrid (axb)	Parent (a)	Hybrid (axb)	Parent (b)
		Tons beets per acre		
1	0-419 x 7-401-0	17.70	21.82	18.58
2	8-406-0 x 7-401-0	17.03	20.60	18.58
3	8-406-0 x 0-419	17.03	19.79	17.70
4	8-406-0 x 8-401-0	17.03	18.91	14.62
5	8-401-0 x 7-401-0	14.62	20.39	18.58
6	8-403-0 x 7-401-0	15.38	18.71	18.58
7	8-406-0 x 8-403-0	17.03	16.22	15.38
Schreiber	8. S. (check)	16.76		
	Dlff. req. for sig. (19:1)			2.23
		Percentage of sucrose		
1	0-419 x 7-401-0	13.59	13.58	12.85
2	8-406-0 x 7-401 -0	13.51	13.65	12.85
3	8-406-0 x 0-419	13.51	14.10	13.59
4	8-406-0 x 8-401-0	13.51	13.44	12.68
5	8 401 0 x 7-401-0	12.68	12.60	12.85
6	8-403-0 x 7 401-0	13.01	12.97	12.85
7	8-406-0 x 8=403-0	13.51	13.72	13.01
	Schreiber S.S. (check)	12.49		
	Diff. req. for sig. (19:1.)			.57
		Pounds sugar per acre		
1	0-419x7-401-0	4467	5883	4714
2	8-406-0 x 7-401-0	4498	5457	4714
3	8-406-0 x 0-419	4498	5315	4767
4	8-406-0x8-401-0	4498	5007	3613
5	8-401-0 x 7-401-0	3613	4979	4714
(I	8-403-0 x 7-401-0	3898	4772	4714
7	8-406-0 x 8-403-0	4498	4373	3898
	Sehreiber S.S[1]. (check)	4334		
	Diff. req. for ssig-. (10:1)			592

for yield. The general combining ability of these 2 varieties as shown by the average single-cross yields substantiates this conclusion.

In table 6 is given the 2-year average yields of 7 variety hybrids and their parents. The variety **0-409** (a and b selections) and its hybrids is not included because of the extreme difference in performance of the selections in these 2 years. This difference was so great that it was not reasonable to presume that it was due to seasonal variation. Since the original variety was found to be badly mixed in type, it is possible that the root selections of 1940 and 1941 used for crossing purposes were somewhat different in genetic character.

In this table the comparisons of the parents with their hybrids are of interest. Hybrid No. 1 exceeded both parents by a significant margin in tons beets and sugar-per-acre yield, and was measurably higher than 1 parent in percentage of sucrose. Hybrid No. 2 exceeded both parents in sugar-per-acre yield, and 1 parent in tons beets and percentage of sucrose. Hybrids 3, 4, 5, and 6 were significantly higher than 1 parent in tonnage and sugar-per-acre yields. The low-yielding hybrid, No. 7, was not significantly different from the sugar yield of the parent varieties.

Discussion of Results

In this study of variety hybrids, attempts were made to obtain true F_1 crosses for test purposes. From the results obtained (table 2) it is thought that the method of pollination used produced complete, or nearly complete, cross-pollination. The varieties used in these crossing experiments were mass selected (with one exception. 8-409-0, table 1,) and consequently contained a maximum amount of self-sterility. It is probable that more exact hybridization technique might be required for inbred lines which produce abundant self-pollinated seed, in order to insure the maximum amount of crossing.

As mentioned previously, extremely small amounts of seed were obtained from the cross-pollination **work.** This was due to several factors. A large number of roots of each variety were planted in the greenhouses each winter, in order to sample efficiently each variety. To accommodate these roots in the greenhouses, it was necessary to plant them in 8-inch pots and space the pots closely in rows. Kraft bags, size 8, were used because of ease in handling, but in order to eliminate damage to the flowering stems, only a small part of the main stem could be bagged. Despite the small amounts of seed produced, however, it was possible by the use of very small plots in the field testing, and also because of the large differences in the yield of the progenies tested, to obtain statistically significant differences.

The results obtained show that certain of the hybrids tested gave yields significantly higher than one, or both, parents. This was ob-

served by the notes taken on the 6 varieties and 15 single crosses grown at East Grand Forks, Minnesota, in 1940, and was statistically demonstrated in each of the two tests grown at Rocky Ford, Colorado, in 1940 and 1941. The increased yield of the hybrids over their parents in these experiments can, without doubt, be attributed to hybrid vigor. This increased sugar-per-acre yield was obtained mainly through increase in size of root, as evidenced by increased tonnage. In no case was a hybrid found which was measurably lower in yield of roots than either parent. A corresponding reduction in percentage of sucrose was not obtained, however. In fact, there is a possibility that in some of the hybrids, percentage of sucrose may actually have been increased.

Since increased yields may be obtained from crossing of standard varieties, as has been observed in these tests, it is of interest to determine what yields could be expected from natural crosses made by mixing seed lots in commercial seed production. Using the formula

$a = b\frac{1}{n}(b-c)$, where "a" is the synthetic variety, "b" the average of all single-cross yields, "c" the parent yield, and "n" the number of varieties (5), it is possible to predict on the basis of random, equal, and complete cross-pollination, the probable yields of a synthetic variety made from any number of varieties. Using the yields obtained from the 2-year average data (table 6), it will be found that the superior varieties 0-419 and 7-401-0, if used for a synthetic variety, would have produced 5,237 pounds of sugar per acre under these same conditions of test. Comparing this predicted yield with the average of the parent varieties, a difference of 646 pounds in favor of the synthetic variety is observed.

As has been mentioned previously, a synthetic variety, in order to be high in yield, must be made of high-yielding parents having desirable combining ability. Furthermore, crossability must be maintained to a high degree. Normally, the common varieties of sugar beets are highly cross-fertile, and to a very high degree, self-sterile. In this character they differ from established inbred lines, which although are commonly cross-fertile, are also self-fertile. The general tendency for yielding ability to decrease with successive generations of inbreeding has been observed by these authors as well as others (4). Therefore, in producing synthetic varieties, well-bred varieties can be considered satisfactory parent material, since they are in themselves good producers, and, in seed increase fields, should produce a maximum of "true" hybrids.

Summary

1. A method of cross-pollination commonly known as "bag switching/' has been used in the greenhouse to produce Fi single crosses of varieties and sib increases of parents, for field-test purposes. Complete, or nearly complete, crossing was obtained by this hybridization method.

2. Highly significant differences in yield of sugar per acre were observed in both the 1940 and 1941 tests (a) between varieties, (b) between variety hybrids, and (c) between varieties and variety hybrids.

3. Average yield data obtained from 7 hybrids and their parent varieties tested in both 1940 and 1941, showed that 2 hybrids were significantly higher than both parents, and 4 were significantly higher than 1 parent in pounds sugar per acre. One hybrid did not differ significantly from either parent.

4. The observed increase in yield of sugar per acre of the variety hybrids over the parents was obtained mostly through increase in size of root, as evidenced by increased tonnage. Increases in percentage of sucrose, although relatively large, were not statistically significant.

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