Use of Red Garden Beet in Sugar-Beef Top Crosses[1]

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In sugar-beet improvement studies, strains representing one to many years of inbreeding are accumulated in considerable number. Continuance of inbreeding, together with evaluations to determine the lines of most value, soon involve very extensive breeding operations and field tests. Since inbred strains are chiefly to be used in production of hybrids or synthetic varieties, an early determination of combining ability and the finding of those which do not hybridize readily would afford a means whereby those inbreds likely to be of least value may be dropped. In corn breeding, the top-cross method is used for this purpose. Top crossing also seems applicable in sugar-beet breeding. Results of experiments in which the common red garden beet was used in top crosses with inbred sugar-beet strains are reported, not only to indicate possibilities in the method as applied to sugar beets but to show the value of the red garden beet as the tester.

Experimental Methods

A single large group planting has been used in which the red garden beet as the common pollen parent has been interp!anted with the inbred strains to be crossed. This has proved to be a practical method of obtaining top-crossed seed. In such a planting, chance pollination obviously will result in other offspring as well as the top-cross hybrids desired for actual testing. However, when the red garden beet is used as the common pollen parent, the dominant genes of this variety, particularly the R and Y color factors, permit all the top-cross hybrids to be readily identified. As will be discussed later, determinations of amount of hybridization taking place with given inbred strains are useful in appraisal of their potentialities. Experience over several years with red garden beet x sugar-beet hybrids has shown that root yields are high, often exceeding good commercial types, and sucrose percentages in the hybrids approximate the mean of the parents.

Sugar beet x red garden beet-top crosses were made at Fort Collins, Colo., in 1939 and 1940. Evaluation tests of the hybrids were conducted for each production in the next season. The units in these tests were the progenies produced by individual plants from the various sugar-beet inbreds which had been accumulated in several years

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of breeding.. A majority of the inbred plants used as seed parents produced over 40 grams of good seed. A randomized-block arrangement was used, consisting of 6 replications of single-row plots, 20 feet in length. In spite of the recognized limitations of this experimental design, the small total row length permitted use of seedlots as small as 30 to 40 grams. Planting was at the rate of approximately 15 to 18 pounds per acre. Seed was apportioned for plots in advance of planting. A Planet Jr. planter was used in which a tube 3 feet long, equipped with a 6-inch funnel at the top, replaced the ordinary seed hopper and agitator. One man pushed the planter and another man walked beside it dropping the seed from his hand into the funnel. Skill in dropping the seed is quickly developed and uniformity of seed distribution compares favorably with ordinary machine planting. In 1941, approximately 3,400 plots 20 feet in length were seeded in slightly less than 22 hours of working time.

The approximate percentage of topi-cross hybrids, identified by the previously mentioned color factors as markers, was obtained by counts, previous to thinning, of all or part of the seedlings in one replication. In most cases, a total count of about 200 seedlings appeared to be sufficient for a reasonably accurate determination of this percentage. At thinning time, the top-cross hybrids were left if they were present at about a 12-ineh spacing. Very low percentages of the desired hybrids sometimes made it necessary to retain non-hybrid seedlings. However, full stands of hybrids were obtained occasionally from seedling stands showing as little as 5 percent top-crossing, and satisfactory stands were usual when the amount of crossing was 20 percent or more. Stands of 18 to 21 plants per plot have been obtained with but few exceptions in the tests considered here.

At harvest time, only the top-cross hybrids were saved, the sugar-beet types when present being discarded after note was made of the approximate row-length occupied by the hybrids; the weight of roots from the partial row-length was calculated by the appropriate factor to a full-plot basis prior to analysis of the data. Such adjustments were more or less unsatisfactory when fewer than about 6 to 10 hybrids were harvested from a plot. Occasionally the percentage of top-crossing was so low that 5 or fewer hybrids were saved in a plot. Such plots were discarded at harvest and the top-cross which they represented dropped from current consideration. Precise measurement of small differences is obviously impossible with this plot technique ; nevertheless, it is believed that the larger differences furnish a safe criterion whereby that portion of the inbreds which are less likely to be of value in the breeding program may be discarded, without entailing great risk of loss of valuable material.

Experimental Results

Factors Affecting Top-Crossing.—For individual progenies, the amount of crossing with the top-cross pollen parent has varied between wide limits (table 1). There seems to be a considerable tendency toward uniformity among closely related progenies.

Seasonal effects also seem to influence the results. Counts of top-crosses made in the 1940 tests were not complete but are sufficient to show- that the general level of the crossing in the seed-production year, 1939, was fairly high. In a few cases, very little crossing had occurred. In the 1941 plantings, counts of all the progenies were made and cover a much larger number of strains. The general level of crossing in the top-cross seedplot of 1940 *was* markedly lower than in the previous year. From table 1 it is seen that, in nearly 1/3 of the cases, hybridization was 20 percent or less. Almost without exception, all progenies obtained from sib roots from any one inbred line showed fairly concordant percentages of hybrids. However, this was not always true of roots from related lines arising from a common ancestor, one to several generations removed.

Table 1.—Classification of progenies with respect to percentage of identified hybrids from top-crosses between inbred sugar-beet strains and commercial red garden beets, Fort Collins, Colo., 1939 and 1940.

Year top-crosses were made	Progenies classified for amount of top-crossing	Progenies with indicated amounts of identified top-cross hybrids				
		0 to 20 percent	21 to 40 percent	41 to 60 percent	Over 60 percent	Range of crossing
	Number	Number	Number	Number	Number	Percent
1939	**50**	**4**	**7**	**21**	**24**	**3 to 93**
1940	487	159	185	116 27	0	to 81

Lack of available pollen of the red garden beet, when the inbreds bloom, may occasionally account for shortages of hybrids in a population. With an abundance of red garden beets in the seedplot, the effect of this is minimized. The principal factor affecting the amount of crossing appears to be the degree and the nature of self-fertility of the inbred, or, conversely, its tendency toward self-sterility. It may be assumed that self-sterile types after two or more generations of inbreeding automatically disappear. It appears probable that a moderate or fairly high degree of self-fertility in the inbred (as evidenced by continuity of the line) does not necessarily result in a low percentage of crossing, for some of these inbreds have yielded a very high percentage of hybrids when foreign pollen was present. However, other inbreds in these tests with high self-fertility gave only low percentages of top-cross hybrids.

Some evidence of the increase of self-fertility in inbred lines is afforded by the seed yields of a large number of roots on which kraft

paper-bag isolators were used in 1941. These seed yields, classed in several yield categories, are presented in table 2. The differences in seed yields are not great, but, as is to be expected, there is evidence of a tendency for the higher yields to be obtained from the roots having record of one or more generations of previous selfing.

Table 2.—Comparison of seed yields of strains with no previous selfing history with those of lines inbred one or more generations. Self-pollination enforced under kraft paper bags, Port Collins, Colo., 1941.

Inbreeding history of strains or lines under test	Plants classified for seed yield	Plants falling within indicated classes of seed yields				
		Less than 1 gram	1 to 2 grams	2 to 5 grams	6 to 10 grams	Over 10 grams
	Number	Percentage	Percentage	Percentage	Percentage	Percentage
Strains not previously selfed	269*	31.2	36.1	22.7	8.6	1.5
Lines previously selfed one or more generations	304*	21.4	33.6	19.7	14.5	10.9

*Approximately 4 percent in both types of plants with regard to selfing history yielded no mature seed. These cases were omitted from the above total number or classification, for seed yield since it was obvious, with few exceptions, that plants yielding no seed were abnormal or diseased.

Yields from Top-Crosses.—The results of the 1940 test of hybrids obtained by top-crossing are summarized in table 3. For the purpose of this discussion, the detailed results are not given, but the variances for gross-sugar yields are shown. The highly significant F value for the variance assignable to "hybrids," in comparison to the interaction, blocks x hybrids (error), indicates that there were certain high-yielding hybrids in the test. Examination of the detailed data indicated that in some cases these high-yielding hybrids were closely related and also that if two or more hybrids from the same inbred line were compared, their yields often tended to be somewhat similar. This would be expected if the particular inbred line in such top crosses was more or less closely approaching homozygosity for yield factors. It also indicates that for such top-cross tests seed from all sib roots of the inbred line might advantageously be pooled rather than to deal with many individual progenies, each arising from a single root of the given inbred line.

Table 3.—Analysis of variance for gross pounds sugar per plot in top-crpss test, Port Collins, Colo., 1940.

Variance due to	D/P	M. square	P value
Blocks	5	21.5259	
Hybrids	107	0.520Q	2.15 (exceeds the
Blocks x hybrids	535	0.2416	1-percent point)

Table 4.—Analysis of variance for root weight per plot in top-cross test, Fort Collins, Colo., **1941.**

Assignable variance	D/F	Mean squares	F values
Hybrids in the test			
Blocks	5	158.55	
Inbreds	47	61.57	4.31** **3.77**t**
Blocks x inbreds	235	14.28	
Inbreds: Total	(287)		
Within inbreds	96	16.31	2.46**
Interaction	480	6.64	
Hybrids: Total	(863)		
Commercial or check varieties in the test			
Blocks		10.38	
Varieties	1	78.91	5.67
Interaction: Block x varieties	5	13.91	
Varieties: Total	(11)		
Samples of varieties	24	8.65	
Checks: Total	(35)		
Whole test: Total	898		

**F value exceeds the 1-percent point,

$$t = \frac{\text{Variance for inbreds}}{\text{Variance within inbreds}} = 3.77$$

Table 5.—Analysis of variance for gross sugar per plot in top-cross test, Fort Collins, Colo., 1941.

Assignable variance	D/F	Mean squares	F values
Hybrids in the test			
Blocks	5	3.129235	
Inbreds	47	0.655675	2.59** 3.74**f
Interaction: Blocks x inbreds	235	0.252729	
Inbreds: Total	(287)		
Within inbreds	96	0.175192	3.23**
Interaction:	480	0.054244	
Hybrids: Total	(863)		
Commercial or check varieties in the test			
Blocks	5	0.063301	
Varieties	1	13.045340	**58.79****
Block x varieties	5	0.221871	
Varieties: Total	(11)		
Samples of varieties	24	0.032344	
Checks: Total	(35)		
Whole test: Total	S98		

**F value exceeds the 1-percent point.

$$f = \frac{\text{Variance for inbreds}}{\text{Variance within inbreds}} = 3.74$$

In 1940, a larger number of roots to serve as seed bearers had been planted in the top-crossing seedplot and, in a number of cases, seed was obtained from 3 or 4 sib plants of the same inbred progeny. The seedlots were planted in 1941 in such a manner that comparison of the variance within the several inbred groups, i. e. between progenies of sib roots from the same inbred lines, as well as the variance between the inbred lines themselves, and the variance between hybrids (ignoring relationship) could be calculated. Analyses of variance for root weight and gross sugar are presented in tables 4 and 5 for the 1941 test that included 3 top-cross sib progenies from 48 inbred lines. Data from the much smaller number of inbreds with 4 top-cross progenies per line were essentially in agreement with the results given.

A good commercial sugar beet and a globe-type red garden beet were included in these tests as check. The data from the hybrids and the checks were separated for statistical analysis, one degree of freedom being dropped for the variance between tests. The red garden beet was equal to the commercial sugar beet in yield of roots but was significantly low in yield of sugar because of the much lower sucrose percentage when compared with sugar beets.

The highly significant F values between inbreds and within inbreds, in the analysis of the top-cross hybrids, indicate that there were significant differences in yields regardless of the basis of comparison. The analysis of the data also indicates that a proportionally greater part of the total variance was between inbreds rather than within inbreds. This last finding seems important, since it indicates that seed from a number of sib roots of the same inbred line may be combined for use in a test of the top-cross hybrids. However, it should be recognized that such combination of seedlots will obviously be most efficient with relatively homozygous inbreds. If top-cross testing is used to evaluate strains expected to be heterozygous, single-plant progenies as units for testing probably wdll yield more information than bulked seedlots. With such material, to save time, inbreeding for the given progeny concurrently may be carried on.

Summary

From the tests reported, it appears that the top-cross may be useful in the elimination of sugar-beet inbreds which are less likely to be of value in the breeding program. The red garden beet appears to be a satisfactory pollen parent for such top-crossing. Final judgment of the value of the proposed top-cross method must rest on results obtained by the combination of inbreds which the top-cross method indicates as superior.