Effect of Sugarbeet Root Size on Combining Ability of Sucrose Yield Components

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ABSTRACT

Definitive information is lacking about the effect of sugarbeet root size on combining ability (CA) for recoverable sucrose components. Four cycles of mass selection in a heterogeneous population for large and small roots with equal sucrose content, resulted in two lines with different root weights but the same sucrose contents. These lines and their source served as pollinators for a set of five diverse male sterile testers. The 15 resultant hybrids were subjected to CA analyses. Significant general and specific combining ability (GCA and SCA) variances occurred for root yield and sucrose content. Male GCA effects for sucrose indicated that the selection had effected additive gene changes without shifting the mean. There were no differences for sucrose due to SCA. For root yield there were SCA effects but no male GCA differences. Repartition of the variance into three male X female sources revealed root yield and sucrose differences due to small root effects but no differences due to large roots. Breeding conclusions were that large roots should be avoided in order to increase potential SCA for both root yield and sucrose content.

Additional Key Words: *Beta vulgaris*, variance components, root yield.

Most sugarbeets (*Beta vulgaris* L.) grown in the United States and Western Europe are hybrid cultivars. Hybrids are used because they are more productive and profitable for growers, processors, and seed producers. The productive advantage is due primarily to hybrid vigor for root yield which was reported a half century ago by Stewart, et al. (1940). They determined that the root yield advantage of their experimental hybrids was attributable to heterosis, and was not merely the expression of additive effects and simple dominant genes present in the parents involved. The experience of breeders capitalizing on hybrid vigor was explained by variance partitions (Hecker, 1967; MacLaughlan, 1972; Smith, et al., 1973) which showed that nonadditive genetic variance was the major component of root yield variance, but additive variance was predominant for sucrose content.

Breeders, using various but related methods, have identified and isolated breeding lines with high general and specific combining ability for sucrose yield. The component most influenced by combining ability (CA) is root yield. In the development of breeding lines, root size is a characteristic for which breeders always have been concerned, but they have had no direct research information about the effect of relative root size on combining ability for root yield. In the absence of information, breeders have let their experience and opinion be their guide.

It was the purpose of this research to provide definitive information to breeders about the relation of relative root size and CA for sucrose yield and its components root yield, sucrose content, and juice purity.

MATERIALS AND METHODS

The development of materials for experimental study of the CA-root size relationship involved selection for large and small root size in a genetically heterogeneous sugarbeet population while holding sucrose content constant. The resultant populations and their source were crossed onto a diverse set of five cytoplasmic male sterile (CMS) testers for CA comparisons. The 3 pollinators and 15 CA test hybrids were grown in field tests for 2 years at Fort Collins, Colorado.

The starting population for root size selection was GW674, a heterogeneous, multigerm, open-pollinated cultivar (obsolete) adapted to the irrigated high plains of the U.S. A population of about 3000 plants was grown in 10 square contiguous blocks, about 300 plants per block. Noncompetitive roots were eliminated immediately preharvest. A random sample of 20 roots was harvested from each block and leaves and petioles were removed. From each block of about 280 remaining plants, 30 large and 30 small (minimum 6 cm diameter) roots were selected, for a total of 300 large and 300 small roots. These roots were trimmed for potential use as seed production plants. These 300 roots were weighed and analyzed individually for sucrose content. Brei samples were taken by Keil rasp and the roots were stored at 5C for later selection and seed production. From the large and small roots about 50 were selected from each group. The criteria for selection were one standard deviation heavier and lighter than the population mean for root weight, and one-half standard deviation from the population mean for sucrose. These 50 large and 50 small roots were transplanted and interpollinated in separate outside isolations, and the seed was harvested as two separate lots. This seed was planted in selection strips, similar to the first cycle, for three more cycles of selection. In each cycle, the final 50 large and 50 small root selections had to have the same sucrose mean. In the fourth cycle crossing plots, five diverse CMS testers (three single-cross hybrids and two inbreds) were interplanted and the seed was harvested separately for CA tests. In the same year, a random sample of GW674 roots was used as the pollinator of the five CMS testers.

Seed for the four selection experiments and for the CA tests in 1988 and 1989 was planted between April 12 and 26 in rows 56 cm (22 in) apart. Plants within rows were thinned to 25 cm (10 in). Standard cultural and irrigation practices were used. Nitrogen was soil incorporated at a rate projected to produce 45 Mg ha^{-1} (25T/acre) of roots. All experiments were harvested between October 5 and 15. The CA tests (1988 and 1989) were in randomized complete block designs with six replications of single-row plots 6.1 m (20 ft) long. The plants in each plot were topped at harvest and analyzed for root weight, sucrose content, and thin juice purity. Amino N, sodium (Na), and potassium (K) were analyzed in pressed juice in 1988 and in sucrose filtrate in 1989.

RESULTS

Character means for the small and large root populations, as well as their original source, are shown in Table 1.

Table 1. Means (1988 and 1989) for 4th cycle small root selection, 4th cycle large root selection, and GW674 (source).

Population	Root yield (kg/plot)	Sucrose (%)	Purity (%)	Recov. sucrose (kg/plot)
Small root	15.7b†	15.2a	92.4a	2.03a
Large root	17.6a	14.8a	91.7a	2.15a
GW674	16.3ab	15.1a	92.4a	2.09a

† Means within columns followed by the same letter are not significantly different ($P = 0.05$)

Homogeneous variances for the two years allowed the data to be combined. Four cycles of mass selection for root size and constant sucrose succeeded in deriving significantly different small and large root populations with no significant change in sucrose content from each other or from their original source. There were no significant differences for juice purity or recoverable sucrose among the three populations, the latter being due to small offsetting differences in sucrose and root size. Hence, the selected populations met the minimum needs for the CA analyses to be executed.

The three nonsucrose characters, amino N, Na, and K, could not be combined over years because they were measured in pressed juice in 1988 and in sucrose filtrate in 1989 (Table 2). The large root population had significantly lower amino N than the small root population. Na content of the large root selection was higher than the source in 1988, and K was lower in 1989. These were the only significant differences for amino N, Na, and K among the three populations.

Table 2. Means of amino N, sodium (Na), and potassium (K) in 1988 pressed juice and 1989 sucrose filtrate.

	1988			1989		
Population	Amino N	Na	K	Amino N	Na	K
		(mg/100 ml)			(mg/100 ml)	
Small root	57a†	28ab	155a	7.0a	3.3a	21.5a
Large root	35b	36a	138a	5.2b	4.2a	18.0b
GW674	60a	22b	150a	6.5ab	4.1a	21.3a

† Means within columns followed by the same letter are not significantly different ($P = 0.05$)

The 15 hybrids in the 2 years had homogeneous variances and were analyzed as a subset. The means of the individual hybrids and hybrid groups are listed in Table 3. The only significant difference among the means of the three hybrid groups was for sucrose content, where hybrids with the small-root pollinator had higher average sucrose than the set pollinated by GW674, whereas the large-root pollinated set was significantly lower than the GW674 set. No significant differences occurred for root yield, purity, or recoverable sucrose among the three sets.

The design of the experiments allowed the partition of variances due to general (GCA) and specific combining ability (SCA). This analysis is presented in Table 4. Root yield and sucrose content were of most interest, because there were no differences among purity means and variances, and recoverable sucrose was a function of root yield, sucrose, and purity. The GCA effect of pollinators was not significant for root yield. The GCA effect of the set of females was highly significant.

Table 3. Means for yield and quality characters of 15 hybrids and three groups with common pollinators.

Hybrid or group		Root yield (kg/plot)	Sucrose (%)	Purity (%)	Recov. sucrose (kg/plot)
52-305CMS X	large root	15.8BC†	14.4EF	92.5A	1.93CDE
SP73747-01 CMS X	" "	16.2AB	14.2F	92.6A	2.00BCD
(FC506CMS X L36) X	" "	17.9AB	14.6DEF	92.8A	2.22ABC
(FC604CMS X Polish OT)X	" "	17.0AB	14.6DEF	92.6A	2.10ABCD
(SLC129CMS X SLC133)X	" "	18.0AB	14.8CDEF	92.6A	2.26AB
Means of hybrids with	" "	17.0a	14.5c	92.6a	2.10a
52-305CMS X	small root	13.7CD	16.0A	91.5A	1.83DE
SP73747-01 CMS X	" "	16.9AB	15.3BCD	91.2A	2.13ABCD
(FC506CMS X L36) X	" "	17.6AB	15.1BCD	91.8A	2.16ABC
(FC604CMS X Polish OT) X	" "	18.4A	15.4ABC	92.0A	2.36A
(SLC129CMS X SLC133) X	" "	15.8BC	15.7AB	92.4A	2.12ABCD
Means of hybrids with	" "	16.5a	15.5a	91.8a	2.12a
52-305CMS X	GW674	13.3D	15.5ABC	90.5A	1.67E
SP73747-01 CMS X	"	18.4A	14.8CDEF	92.0A	2.27AB
(FC506CMS X L36) X	"	17.0AB	15.0CDE	92.7A	2.18ABC
(FC604CMS X Polish OT) X	"	16.4AB	15.2BCD	93.0A	2.12ABCD
(SLC129CMS X SLC133) X	"	16.3AB	15.2BCD	92.8A	2.09ABCD
Means of hybrids with	"	16.3a	15.1b	92.2a	2.07a

† Means within columns followed by the same upper case letter are not significantly different ($P = 0.05$); likewise for lower case letters.

However, the female effect is not of great concern in this study because the females were considered to be a random set and were only used as testers for the purposes of this study.

The 14 degrees of freedom for hybrids was partitioned into effects of individual pollinators, Table 5. The GCA effect is the same portion of the variance as shown in Table 4. There was no significant effect of large-root hybrids for any of the four characters, whereas the small root hybrids contributed significant variance for root yield, sucrose content, and recoverable sucrose. Hybrids with GW674 contributed significant variance for root yield and recoverable sucrose.

Table 4. Analyses of variance for general and specific combining ability (GCA and SCA) for yield and quality characters.

Source of variation	df	Root yield (kg/plot)	Sucrose (%)	Purity (%)	Recov. sucrose (kg/plot)
GCA pollinators	2	NS	**	NS	NS
GCA females	4	**	*	NS	**
SCA female X male	8	*	NS	NS	NS

*, ** = significant at $P = 0.05$ and 0.01, respectively; NS = not significant.

Table 5. Partition of variation due to combining-ability effects into male X female effects within individual males.

Source of variation	df	Root yield (kg/plot)	Sucrose (%)	Purity (%)	Recov. sucrose (kg/plot)
GCA pollinators	2	NS	**	NS	NS
Small root X females	4	*	*	NS	*
Large root X females	4	NS	NS	NS	NS
GW674 X females	4	**	NS	NS	**

*, ** = significant at $P = 0.05$ and 0.01, respectively; NS = not significant.

DISCUSSION

This limited but unique experiment has produced information directly useful to sugarbeet breeders. First, it is of practical interest that four cycles of mass selection for root size and constant sucrose did effect genetic changes for root yield, as demonstrated in the two years of testing. The changes in frequencies of genes affecting root size might be different than if constant sucrose content had not been selected simultaneously. Realized heritability calculations were impractical in this study because of the potential of confounded selection effects.

Root yield was the only sucrose yield component significantly affected by the selection. Sucrose content and juice purity were unaffected, but the purity components amino N, Na, and K were affected modestly. These chemical character changes were not great and could not be combined over years, hence, no emphasis is given to amino N, Na, and K changes. Recoverable sucrose, calculated from root weight, sucrose content, and juice purity, is functionally related to them.

The set of five CMS lines used as combining ability testers was limited, but each was unrelated and the set was diverse. The set could be considered to be random. Differences or effects that occurred due to this small set of testers also would be expected to occur in larger populations, hence, likely to be of practical importance to breeders.

Also important is the absence of a pollinator GCA effect for root yield, the major component of recoverable sucrose. These results indicate that GCA tests are unaffected by root size. This is an important finding because GCA testing is widely used by sugarbeet breeders, especially in the early stages of breeding line development. The information from this study will alleviate the concern of breeders that observed GCA differences may be related to the root size of their lines being tested.

The significant GCA effect of pollinators on sucrose content is also important. This indicates that the small- and large-root lines in this study were genetically different for sucrose content, even though the sucrose content of each line was not phenotypically different. The selection for constant sucrose content in the presence of small- and large-root genetic complexes apparently resulted in some different sucrose conditioning genes being sorted out which, in the end, resulted in the same phenotypic sucrose content. The pollinator GCA effects for sucrose apparently were not sufficient to cause a significant GCA component for recoverable sucrose.

The significant SCA effect for root yield (Table 4) indicates that the three pollinators combined differently with some of the females. Examination of the means in Table 3 reveals that the SCA variance primarily came from the test hybrids with the small-root and GW674 pollinators. Little of the SCA variance apparently was due to hybrids with the large-root male. This was confirmed by the analysis in Table 5 where the variance was partitioned into GCA and male X female effects. For root yield, only the interactions of small root X females and GW674 X females were significant. This was evidence that selection for small root discriminated against genes with additive effects, while large root selection favored additive genes. In theory, mass selection, as used in this study, should have had a direct effect only on genes with additive effects for root yield. However, discrimination against additive genes would allow nonadditive gene effects to have their full undiluted effect on variances.

Genetic interpretation of the analyses of sucrose content indicates that genes with additive effects conditioning sucrose tended to be accumulated in the small- root selection. However, the additive genes must have been both for lower and higher sucrose which offset each other to produce means of the small- and large- root populations that were not significantly different.

It also must be recognized that root yield and sucrose content are not totally independent, which surely has had some effect on the results of this experiment. This interdependence may be most reflected in the results shown in Table 5 where significant sucrose variances occurred for GCA pollinator and small root X females, yet these GCA effects were not reflected in the sucrose means.

The other characters in the study did not contribute to conclusions about root size and combining ability. No differences occurred for juice purity, and recoverable sucrose behaved as expected, since in this study it was entirely a function of root yield, sucrose, and purity. Among the juice characters, amino N declined with selection for large root, whereas small root selection had no effect on amino N. Potassium content was affected similarly. Sodium was not significantly affected by root size selection.

For purposes of sugarbeet breeding, the results of this study indicate that in the development of breeding lines with potentially high SCA, large roots should be avoided because large-root genotypes may have fewer nonadditive genes that contribute to SCA for root yield. Further, to the degree that SCA affects sucrose content, SCA effects may have a higher probability of occurrence in small roots than in large roots. If an analysis like this were made of similar female lines, it is logical to assume that they would be affected like the males in this study. Hence, the same conclusions should be applicable to the development of female (CMS) breeding lines.

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