Beta vulgaris NC-7 Collection as a Source of High Sucrose Germplasm

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ABSTRACT

Among the major problems facing sugarbeet breeders are lack of genetic diversity and the negative association between root yield and sucrose concentration. The USDA-ARS *Beta* collection contains a wide array of material that has not been utilized fully. In this study 167 accessions of the NC-7 collection were evaluated for sucrose concentration on an individual root basis. A breeding population was formed by interpollinating 30 individuals with relatively high sucrose concentration. Seed from each plant were harvested separately and progeny were evaluated the following year in replicated field plots. Subsequent selection was based upon both individual and family performance. Selected plants were interpollinated, seed were harvested again from individual plants and the progenies were evaluated as a family. This procedure was repeated in each of five selection cycles. After the second cycle it was apparent that root weight was decreasing drastically, so individual root weight was added to the selection criteria. The average sucrose concentration of fifth-cycle families was increased to 113% of Ultramono. Five families combined high sucrose concentration with average root yield in the fourth and fifth selection cycles. This research indicates that germplasm collections of the USDA can be used for improving yield and quality of sugarbeet and for widening the genetic base of the sugarbeet crop.

Additional Key Words: Sugarbeet, genetic diversity, yield

The generally negative association between sucrose concentration and root yield has been a persistent problem in sugarbeet (*Beet vulgaris* L.) improvement. The classification of earlier varieties as yield- or sugar-types (8,12) indicates that this relationship has been recognized for some time. Pack (11) reported a correlation between sucrose concentration and root weight of -0.40 with a range from -0.53 to -0.27 for different lines. Correlation coefficients between sucrose concentration and root yield were approximately -0.60 in trials involving numerous commercial cultivars grown throughout the Red River Valley of North Dakota and Minnestoa (1,2). Doney et al. (6) presented evidence which indicated that the relationship between sucrose concentration and root yield was a reflection of cell size and cell number. Large cells were associated with high root yields and low sucrose concentration. Doney and Theurer (5) found that heterosis for root yield was due to greater cell number and not increased cell size. They recommended that breeders develop lines with small cells that exhibit heterosis for cell number. Carter (3) discussed the relationships between water concentration and cation concentration and their effects on root yield and sucrose. Most studies have indicated that sugar production per unit area can be maximized by giving prime consideration to increased root yield (2,8,11). However, because of the premiums paid production per unit area does not necessarily result in maximum financial return to growers.

Sugarbeet breeders constantly are seeking germplasm which will increase sucrose concentration without adversely affecting root yield. Also, since heterosis is generally enhanced by increasing the genetic diversity of the parents (7), desirable germplasm from previously unused sources be useful in commercial hybrid breeding programs. The USDA *B. vulgaris* collection apparently has not been used extensively in breeding programs and, thus, may provide unique genetic combinations for increased yield and sugar concentration as well as increased genetic diversity. This collection was used as a source population in a selection program with the objective of extracting agronomically desirable germplasm from previously untapped sources. The results of five selection cycles are reported in this paper.

MATERIALS AND METHODS

One hundred sixty-seven accessions of the *B. vulgaris* collection (NC-7) maintained by USDA-ARS at Ames, Iowa, were evaluated for sucrose concentration. All accessions exhibited biennial growth habit and some were non-sugarbeet types or mixtures. The choice of accessions was limited to entries with sufficient seed for field planting. The sucrose concentration of each root was determined on a tissue sample obtained by diagonally drilling a 3.2-cm diameter core in the taproot with a power drill. Samples were frozen immediately and subsequently analyzed for sucrose concentration using standard tare laboratory procedures (10). Because of limited seed supplies, the original accessions were evaluated in unreplicated field plots with a check (ACH-14) in every fifth plot (Fig. 1). Thirty individual plants with relatively high sucrose, compared to other plants in the same plot and nearby check plots, were identified and randomly interpollinated to form the base population (Table 1). Seed were harvested from each plant separately and evaluated the following year as a family in replicated field trials. Subsequent selection was based upon both individual and family performance. Selected plants were interpollinated, seed were again harvested from individual plants, and the progenies of each plant were evaluated as a family. Individuals with the desired traits were selected from most families to maintain genetic diversity; however, the number of selections per family was proportionate to family performance. This process was repeated in each of the five selection cycles. Because of erratic stand, fourth-cycle selection was based solely upon family performance and a random sample of 57 individuals from selected families provided seed for the fifth selection cycle. The mating procedure did not allow for determination if, or to what extent, self-pollination occurred. In each selection cycle, 27 to 57 plants were selected for interpollination. Visual selection eliminated severely sprangled or colored beets. After the second cycle it became apparent that root size (weight) was decreasing drastically, so individual root weight was added as a selection criterion. In subsequent selection cycles, the average weight of selected beets was approximately equal to the average weight of the commercial hybrid checks.

Field plots were 10.6 m^2 and consisted of two rows 56 cm

Table 1. Accession numbers (PI nos.) and sources of the parents used to form the base population.

Country of Origin	PI No.	Country of Origin	PI No.
Turkey	169025	Poland	286501
	179174		274393*
	169020		266100
	174058		266102
	169014		296538
	175594		
	344064	Iran	140354
	171515		222970
	120705		
	165013	Afghanistan	220506
			220645
U.S.S.R.	355963		
	355960	Ethiopia	193457
	355959		
	355962*	Burma	224684
	355966		
	355958		
	355964		

apart. All evaluations were conducted at Fargo, North Dakota, between the years of 1980 and 1986. No disease symptoms were observed in the plots at any time. Roots were harvested manually, weighed, and washed before sampling for sucrose, purity, and dry matter determinations. Sucrose concentration was determined polarimetrically (10). Clear juice purity was calculated using procedures described by Dexter et al. (4). Twenty-gram brei samples were oven dried at 80°C to determine dry matter concentration. Root yield and sucrose concentration were expressed on a fresh weight basis.

RESULTS AND DISCUSSION

The third selection cycle produced families with an average sucrose concentration 4% below that of the commercial hybrid Ultramono (Table 2). The average sucrose concentration of the selected families increased in the fourth cycle and exceeded Ul-

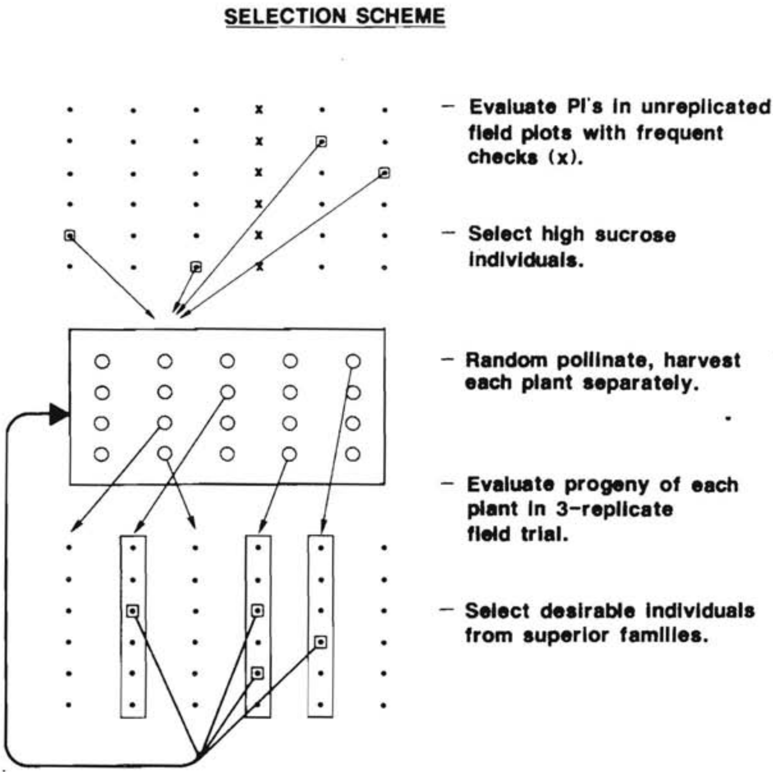

Figure 1. Selection scheme for the development of high sucrose germplasm.

tramono by 13% in the fifth cycle. Average root yield of the selected families was approximately 80 to 90% of the yield of Ultramono. These results indicated that selection for individual root weight was effective in maintaining root yield. Average sucrose yield per unit area, clear juice purity, and dry matter concentration were slightly higher than Ultramono. Apparently purity increased as sucrose concentration was improved. These results and those of others (3,9) confirm that sucrose concentration and purity can be improved simultaneously with little difficulty. A small increase in dry matter concentration appeared to be associated with increased sucrose concentration. However, sugar yield per unit area (Table 2) indicated that increased sucrose concentration was not due solely to decreased water content. Significant differences for sucrose concentration between fourth or fifth cycle families were infrequent, suggesting that further improvement may be limited to small increments with the selection scheme used in this study.

In the advanced selection cycles, a negative association between sucrose concentration and root yield was not apparent due to generally nonsignificant differences between families for sucrose concentration. Root yield differences between families were large and more erratic than sucrose concentration, suggesting that considerable genetic variability exists for agronomic traits other than sucrose concentration. A few families with high sucrose concentrations had root yields equal to the commercial hybrids (Fig. 2).

Stability of yield and sucrose concentration were examined by comparing the performance of fifth-cycle families with the fourth-cycle families from which they originated (Fig. 3 and 4). Seventeen families had above average sucrose concentration in both cycles and ten families had above average root yield in both cycles (Table 3). Fourth-cycle families were evaluated in an environment (year) that produced considerably higher sucrose concentrations than the environment (year) in which the fifth-cycle families were grown. Five families combined average sucrose concentration with above average root yield (Table 3) in both the fourth and fifth cycles. These five families had average root yields

Table 2. Average performance of all selected families, expressed as a percent of Ultramono.

	Selection cycle mean		
	3rd	4th	5th
Sucrose concentration	96	108	113
Root yield	87	92	82
Sugar yield	—	—	105
Clear juice parity	—	—	102
Dry matter concentration	—	—	107

similar to the commercial hybrids, with an average sucrose concentration 17 g kg-1 greater than the hybrids. All families listed in Table 3 had clear juice purities exceeding the commercial hybrids. The heterogeneity remaining within the selected families suggested that they could provide unique germplasm for inclusion in population improvement programs. Combining ability studies are needed to determine the value of the germplasm when combined with currently used parental lines.

Table 3. Characterization of 22 fourth and fifth cycle families with relatively high sucrose concentration and/or root yield.[†]

Family	Sucrose			Root Yield		
	Cycle 4	Cycle 5	Mean	Cycle 4	Cycle 5	Mean
	g kg-1			Mg ha-1		
High sucrose families						
SA	173	133	153	32.5	43.5	38.0
SB	170	128	149	34.0	28.7	31.4
SC	171	128	150	35.8	40.5	38.2
SD	177	127	152	35.8	30.5	33.0
SE	174	124	149	35.8	24.6	30.2
SF	172	123	148	42.3	22.6	32.4
SG	172	123	147	34.5	22.2	28.4
SH	170	122	146	36.3	41.0	38.7
SI	170	122	146	42.1	17.5	29.8
SJ	172	122	148	42.3	28.9	35.6
SK	170	122	146	34.0	36.7	35.4
SL	171	122	146	35.8	42.8	39.3
Mean	172	125	148	36.8	31.6	34.2
High yield families						
YA	165	127	146	43.0	32.5	37.8
YB	167	127	147	37.6	41.7	39.7
YC	172	121	146	42.3	30.5	36.4
YD	167	120	144	41.0	30.5	35.8
YE	164	119	141	38.5	38.5	38.5
Mean	167	123	145	40.5	34.7	37.6
High sucrose and yield families						
CA	176	138	157	41.2	49.9	45.6
CB	176	136	156	41.2	30.9	36.0
CC	176	133	154	38.3	51.7	45.0
CD	170	129	150	39.6	35.4	37.5
CE	170	126	148	42.3	34.5	38.4
Mean	174	132	153	40.5	40.5	40.5
Commercial hybrids						
ACH 164	164	117	141	40.8	38.6	39.6
Beta 1230	158	109	134	41.2	47.7	44.4
Ultramono	157	112	134	39.4	33.6	36.5
Mean	160	113	136	40.5	39.9	40.2
LSD (0.05)[‡]	014	011	—	7.0	26.4	—

[†] Families with sucrose concentration, root yield, or both greater than the mean of all selected families in both the fourth and fifth selection cycles.

[‡] LSD included all families examined in each cycle and, therefore, can be used to compare applicable means in Figures 2, 3, and 4.

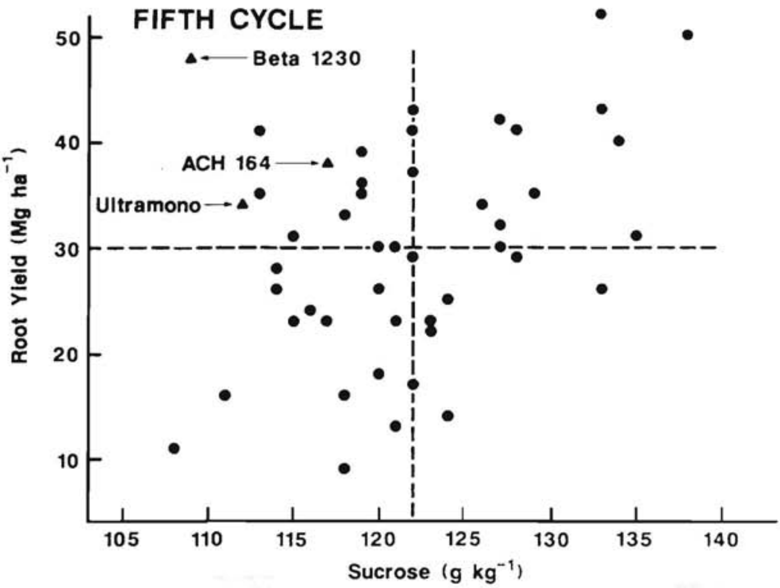

Figure 2. Root yield and sucrose concentration for fifth-cycle families. (Dashed lines are means of selected families; check hybrids are indicated by ▲.)

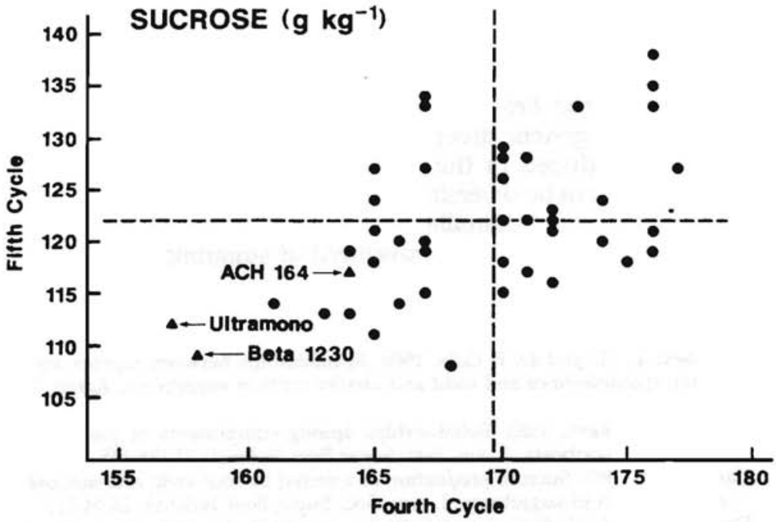

Figure 3. Sucrose concentration of fifth-cycle families compared to the fourth-cycle families from which they originated. (Dashed lines are means of selected families; check hybrids are indicated by ▲.)

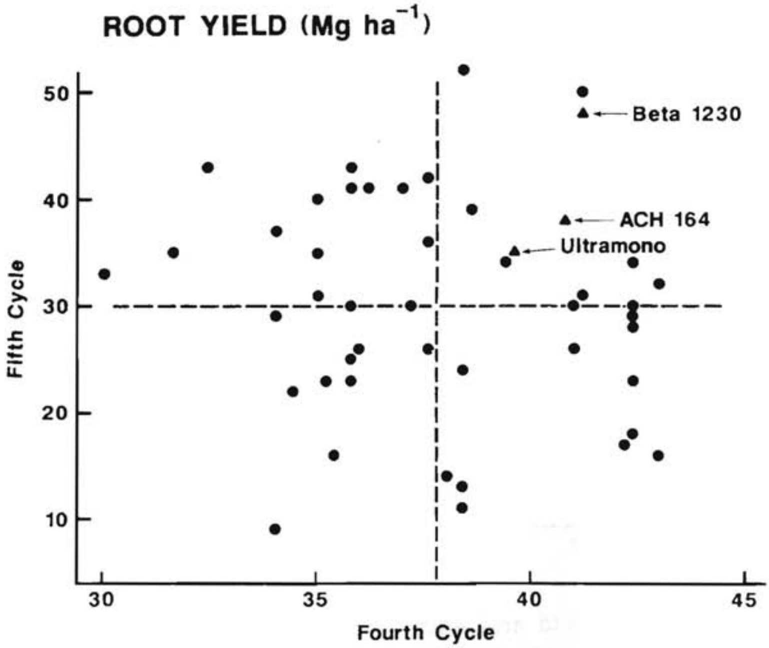

Figure 4. Root yield of fifth-cycle families compared to the fourth-cycle family from which they originated. (Dashed lines are means of selected families; check hybrids are indicated by ▲.)

The results reported in this paper demonstrate the potential value of the *Beta* collection and suggests that it can be used to increase genetic diversity in applied breeding programs. Germplasm produced in this study makes readily available a portion of the genetic diversity within the USDA NC-7 *Beta* collection. A few of the families are being increased as a new germplasm source for the improvement of sugarbeet.

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