Impurity Index Selections on Individual Sugarbeets[1]

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Received for publication August 3, 1970

There are numerous references on breeding procedures used to improve the quality of the sugarbeet. Many of these studies begin with mass selection for yield from a large number of individual sugarbeets of a specific variety (1,2,3,6,7,13,20,21).[3] Other studies have involved selection for various chemical constituents, including sugar, purity, Na, K, and amino N (5,8,10,11,12).

Powers and others (14,15,16,17) have described methods to identify genetically superior beets in weight and sucrose, but these methods require large populations. Individual beet selection methods, utilizing mathematical transformations of beet weight and sugar percentage, have been devised for small samples by some breeders (9,10).

The merit of individual beet selection as a method of improving sugar, yield, and quality has not been well established. There is no doubt that when material has a very broad genetic base, large improvements or changes can be made (18). However, procedures for reasonably easy and economic selection from individual beets has not been investigated to a great extent. The use of an impurity index as a breeding tool for making selections is presented herein.

Material and Methods

Strip plantings of two varieties, 030 and 0461, of diversified origin and heterogyzous for genetic male sterility *(aa)* were planted on the Greenville experimental farm of Utah State University in 1963.

At harvest, individual roots selected in the field for large size and good shape were plugged and analyzed for sugar, amino N, Na, and K in our laboratory according to methods described by Stout (19). The impurity index ratio was calculated as:

$$\frac{10 \times \text{PPM N} + 3.5 \times \text{PPM Na} + 2.5 \times \text{PPM K}}{\text{sugar percentage}}$$

which is a modification of the formula suggested by Carruthers *et al.* (4).

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[1] Cooperative investigations of the Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture; the Beet Sugar Development Foundation; and the Utah Agricultural Experiment Station approved as journal paper no 1052 Utah Agricultural Experiment Station, Logan, Utah.

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[3] Numbers in parentheses refer to literature cited.

Selfed progenies of selected individual roots were planted in the spring for further selection. Selections were made from these selfed progenies within each variety for (A) high sugar percentage, (B) high impurity index, and (C) low impurity index. These selections were grouped into the above three selection categories for each variety and were planted in isolated plastic chambers in the greenhouse. Sufficient seed was obtained for four replications of a randomized block planting.

This planting consisted of two varieties and the three selections from each parent. Plots were two 32-foot rows, 22 inches apart with beets 10 to 12 inches within the row. Individual beet analyses were obtained for all beets in each plot and impurity indices were calculated as cited above. Reselections were made for (A) high sugar percentage, (B) low sugar percentage, (C) high impurity index, and (D) low impurity index within each previously selected group. Beets of each group were planted in 4 $\times$ 4 foot isolation chambers for seed production. Because of the limitation of the chambers it was necessary to subdivide some of the selected groups. In these cases the roots having the highest sugar percentage were grouped and labeled high sugar #1, the second high as high sugar #2, the lowest index roots were labeled low index #1 etc. All male-sterile plants in each group were tagged and seed for the sibbed progeny was harvested separately . In 1967 a randomized block test was planted to compare the two cycles of selection from composite selfed progeny and composite sibbed progeny.

In 1966 a block planting at Farmington, Utah, was utilized for initiating another study for individual beet selection. Twenty rows 22 inches apart and 35 feet long were planted with a promising high sugar *Aa* hybrid, 4702. Forty-four rows of the same length were planted with 2224, a four-way *Aa* hybrid of diverse parentage. Individual roots of the center 20 feet of each row were consecutively numbered and each row was harvested separately.

A total of 449 beets for variety 4702 and 1155 beets for 2224 were weighed and analyzed by the plug method. Individual beets were selected for future selfed progeny and recurrent selection in the following categories: (A) low impurity index, (B) high impurity index, (C) high sugar—not included in the low index group, and (D) low sugar—not included in the high impurity index group. Only beets which were above or below the mean in impurity index or sugar percent by at least one standard deviation, and those that were better than the mean in beet weight, were selected in each group. These selections were grown in isolation seed plots and plants were again harvested individually. All *aa* plants within each group were tagged at the time of flowering so that they could be identified at harvest. These individual beet progenies were consecutively numbered and were evaluated in a 1968 replicated variety test. A sample of pulp from a 10-beet sample from each row of a two-row plot was used for laboratory analysis. All tests were planted in a randomized block planting with four to six replications.

Experimental Results

Populations 030 and 0461. Comparison of selections in the selfed progeny of population 030 in percent of the parent is given in Table 1. In the first cycle the low index selection had 6% lower impurity index than the parent population. All of the second cycle low impurity index selections were lower than the parent; one selection (#1) showed a significant 25% decrease in impurity index. High impurity index selections had significantly lower quality (18 to 33%) than the parent population for both cycles of selection. The change in individual impurity components of Amino N, Na, and K was similar to that exhibited by the impurity index for each selection with the exception of the high index selection.

Table 1.—Yield and quality in percent of parent for two cycles of selection in composite selfed progenies of population 030, Logan, Utah, 1967.

Selection group	No. beets	Impurity index	PPM Amino N	PPM Na	PPM K	Percent sugar	Acre yield Gross sugar	Acre yield Tons/ acre
030 Parent		100	100	100	100	100	100	100
First cycle								
Low index	9	94	90	102	98	100	76	76
High-index	10	118	125	107	108	99	98	100
High sugar	7	99	115	85	102	105	92	87
Second cycle								
Low index #1	6	75	67	79	84	100	57	57
Low index #2	7	92	103	88	86	102	66	65
Low index #3	10	94	104	86	87	101	65	64
High index #1	9	129	127	107	125	95	77	81
High index #2	11	133	130	124	123	95	97	103
High sugar #1	12	84	84	78	93	103	80	78
High sugar #2	6	89	104	62	96	106	83	79
High sugar #3	7	99	108	84	93	100	69	69
High sugar #4	7	99	115	85	102	105	92	87
Mean in % of parent		104	109	94	101	100	81	81
LSD (5% point)		15.8	26.9	16.6	11.2	3.3	10.8	10.9

In the first cycle the high sugar selection had a significantly greater sugar percent than the parent population (105%). High sugar selection #2 and #4 showed superiority in the second cycle; however, the two other high sugar selections were no better for sugar percentage than their parent. All selections showed a decrease in tons per acre and yield of gross sugar.

The low impurity index selection in population 0461 was no different than the parent for index and sugar percentage in the first cycle, but low index #1 demonstrated significant improvement in impurity index in the second selection cycle (Table 2). Selections for low impurity index showed little difference in sugar percentage. High impurity selections were significantly higher (21 to 57%) in index value and slightly lower in sugar percent than the 0461 parent population in both cycles of selection. The high sugar selections exhibited no change from the parent population. All selections reduced the acre yield of gross sugar and tons of beet when selfing was involved.

Table 2.—Yield and quality in percent of parent for two cycles of selection in composite selfed progenies of population 0461, Logan, Utah, 1967.

Selection group	No. beets	Impurity index	PPM Amino N	PPM Na	PPM K	Percent sugar	Acre yield Gross sugar	Acre yield Tons/acre
0461 Parent		100	100	100	100	100	100	100
First cycle								
Low index	11	103	100	128	99	99	92	93
High index	12	130	131	136	110	97	79	82
High sugar	14	97	92	109	102	100	88	88
Second cycle								
Low index #1	11	77	68	109	95	103	82	80
Low index #2	13	94	89	103	106	100	77	77
High index #1	4	121	104	181	123	96	91	96
High index #2	9	157	145	206	124	92	87	95
High sugar #1	10	92	86	115	99	100	72	72
High sugar #2	14	93	84	115	106	100	70	70
High sugar #3	11	99	96	96	99	97	73	74
Mean in % of parent		106	99	127	106	98	83	84
LSD (5% point)		17.9	23.2	31.9	10.5	3.7	15.1	14.6

Results of modified recurrent selection with use of open-pollinated seed harvested from *aa* beets of each selection group are given in Table 3. The low index selection of 030 was consistently lower in impurity index, amino N, Na, and K than the parent. All three selections from 030 were significantly better

Table 3.—Yield and quality of recurrent selections of composite Mendelian male sterile populations in percent of parent, Logan, Utah, 1967.

Selection group	No. *aa* seed beets	Impurity index	PPM Amino N	PPM Na	PPM K	Percent sugar	Acre yield Gross sugar	Acre yield Tons/acre
030 parent		100	100	100	100	100	100	100
Low index	7	73	68	91	89	107	100	94
High sugar #1	4	87	98	78	90	105	105	100
High sugar #2	1	87	106	60	89	109	96	89
0461 parent		100	100	100	100	100	100	100
Low index	7	97	88	128	99	98	102	103
LSD 030 (5% point)		15.8	18.2	25.8	NS	4.6	8.8	3.6
LSD 0461 (5% point)		14.9	14.0	38.9	NS	4.5	11.7	4.9

in sugar percent than the parental line. High sugar selection #1 had higher but non-significant gross sugar per acre than the parent. The low index composite of population 0461 showed no difference from the parent population.

Populations 4702 and 2224. The low sugar selection #2 from population 4702 was significantly lower than all other entries in the test for this character (Table 4). Low sugar selection #1 did not respond to selection pressure and produced a comparatively high sugar percentage and acre yield. High index selections 8, 9, and 10 were significantly the highest in impurity index values. Two of the high index selections (#1 and 2) were among the entries with the lowest indices. High sugar selection #1 had significantly greater sugar percentage and was significantly lower in impurity index than all other entries except low sugar #1. This high sugar line was the lowest in Na and K and slightly below the general mean in Amino N. Two other high sugar selections (#2 and 4) also tended to have higher sugar percentage. Sugar selection #3 failed to show results of the selection pressure.

Table 4.—Performance of individual beet selfed progenies from population 4702.

Selection group	Impurity index	PPM Amino N	PPM Na	PPM K	Percent sugar	Acre yield Gross sugar	Acre yield Tons/acre
Low sugar #1	599	248	404	1708	13.67	6635	24.24
Low sugar #2	838	254	480	1979	11.00	2202	9.98
High index #1	682	235	409	2070	13.25	6650	25.15
High index #2	688	287	460	1890	13.42	6594	24.52
High index #3	703	237	554	1924	13.05	5928	22.66
High index #4	714	374	435	1715	13.40	6631	24.75
High index #5	738	373	407	1828	13.29	7088	26.61
High index #6	761	388	411	1920	13.38	7114	26.56
High index #7	815	356	602	1860	12.72	5158	20.31
High index #8	881	405	333	2352	12.68	5556	21.89
High index #9	890	554	337	1952	13.04	5397	20.70
High index #10	955	647	383	1864	13.12	5146	19.60
High sugar #1	555	330	223	1608	14.67	5839	19.91
High sugar #2	696	299	374	2071	13.70	6658	24.30
High sugar #3	731	343	462	1856	13.38	4782	17.82
High sugar #4	753	447	329	1900	13.80	6653	24.07
Mean	750	361	413	1910	13.22	5877	22.07
LSD (5% point)	98	69	82	205	0.62	802	2.66

In the recurrent selection progeny of 4702, each entry from a single *aa* mother beet produced comparatively high acre yields of gross sugar and tons per acre (Table 5). The low index se-

Table 5.—Acre yield and qualiy of the first cycle of recurrent selection using seed from single Mendelian male sterile beets in population 4702, Farmington, Utah, 1968.

Selection group	Impurity index	PPM Amino N	PPM Na	PPM K	Percent sugar	Acre yield Gross sugar	Acre yield Tons/acre
Low index	535	316	386	1491	15.43	8,461	27.42
High index #1	865	449	777	2021	14.23	11,085	38.90
High index #2	960	337	1053	1915	12.63	9,437	37.53
High sugar #1	807	423	708	1988	14.48	10,704	36.91
High sugar #2	814	368	803	1916	13.94	10,588	37.93
Mean	796	38	746	1866	14.15	10,055	35.74
LSD (5% point)	105	71	122	135	0.68	864	2.86

lection was significantly better than all others in the test in sugar percentage, and was significantly better in quality, than all other lines as evidenced by the low values for impurity index, amino N, Na, and K. High sugar selection #1 showed improvement but high sugar selection #2 had less sugar than #1 high index selection.

In population 2224 selfed progenies, two low index progenies (#1 and 2) were significantly lower in impurity index than the parent population (Table 6). These same selections showed a 2 to 3% increase in sugar percent over the parent. Low index selection #7 did not demonstrate the effects of the selection pressure since it was second highest in impurity factors. There was as much as 42% increase over the parent for impurity index in the high index selections. We observed a decrease in gross sugar and tons of beets for all selections and a decrease in sugar percentage for all but three of the low index selections.

Table 6.—Performance of individual beet selfed progenies in percent of the parent population 2224, Logan, Utah, 1968.

Selection group	Impurity index	PPM Amino N	PPM Na	PPM K	Percent sugar	Acre yield Gross sugar	Acre yield Tons/ acre
2224 parent	100	100	100	100	100	100	100
Low index #1	86	81	110	86	103	85	83
Low index #2	86	119	83	79	102	80	78
Low index #3	92	84	99	86	97	70	72
Low index #4	93	98	84	93	100	89	89
Low index #5	106	121	81	101	98	70	71
Low index #6	109	106	165	81	93	73	78
Low index #7	126	128	156	102	94	83	89
High index #1	111	107	126	98	95	87	92
High index #2	113	81	143	101	97	86	88
High index #3	142	173	157	104	93	78	85
Mean in % of parent	106	112	119	94	97	82	84
LSD (5% point)	11.90	25.10	25.00	3.97	3.20	5.95	5.52

High impurity index sib progenies from population 2224 showed a 19 to 35% increase over the parent in impurity index with a corresponding increase in the other impurity measurements at Logan (Table 7). The composite Mendelian male-sterile progeny #1 selected for high sugar did not show improvement in sugar percentage at Farmington. The high index composite selection #6 gave a significant 19% increase over the parent in impurity index.

Discussion

Our data provide good evidence that selection response in selfed populations did not necessarily follow the direction of selection pressure. This may have been due to environmental variation or to the rapid fixation of genes by selfing. With all material, selection decreased individual root beet weight, a re-

Table 7.—Yield of selection using seed of single and composite Mendelian male sterile 2224 beets in percent of parent population at Logan and Farmington, Utah, 1968.

Selection group	No. *aa* seed beets	Impurity index	PPM Amino N	PPM Na	PPM K	Percent sugar	Acre yield Gross sugar	Acre yield Tons/acre
Logan								
2224 parent		100	100	100	100	100	100	100
High index #1	1	119	115	135	107	95	90	94
High index #2	1	119	130	127	98	94	90	95
High index #3	9*	122	129	126	112	97	81	84
High index #4	1	128	127	127	116	95	97	103
High index #5	1	135	131	149	118	94	89	95
Mean in % of parent		120	122	129	108	96	91	95
LSD		16	NS	19	10	4	6	4
Farmington								
2224 parent		100	100	100	100	100	100	100
High index #6	8*	119	100	129	99	92	90	98
High sugar #1	10*	107	100	113	100	96	91	93
Mean in % of parent		108	100	114	100	97	94	97
LSD		9.2	NS	14.6	NS	4.0	7.6	5.1

* composite progenies.

sult which was attributed to inbreeding. However, since the selected material would be used in hybrid combinations, this would not be a deterrent to the method. A combining ability test would be made to obtain the best yielding combinations with low impurities.

There was evidence that a high impurity index selection response could be maintained or increased. This may be why the tendency toward increased impurity has been a concern to the industry, since the advent of hybrid sugarbeet production.

Recurrent selections, with use of Mendelian male sterility as a crossing tool in the limited material tested, gave evidence that this method resulted in a positive selection response for higher sugar, low impurity, and high impurity. If individual plant progenies are kept separate, the selection response would be exhibited by a large part of the progenies. The more desirable ones could be retained for additional selection by using the genetic male sterile segregates as a means of accumulating more favorable genes.

Summary

The merit of utilizing an economical and easy method of individual sugarbeet selection for high and low sugar percentage and high and low impurity index was evaluated at Logan and Farmington, Utah.

Recurring selections, made by use of Mendelian male sterility as a crossing tool, resulted in positive selection pressure for all factors studied. Self-fertile progenies, selected on an individual beet basis, gave varied results, probably due to inbreeding and fixing of the genes.

Progress in the direction of low quality selection was easier to accomplish than was selection toward high quality. The impurity index was an effective breeding tool for improving the beet purity of a line, while maintaining high sugar percentage.

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