Introgressive Hybridization as a Breeding Method in *Beta Vulgaris*

R. K. OLDEMEYER[1]

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Combining the root yield of fodder beets and the sugar content of sugarbeets would be a major advancement in sugarbeet breeding. Few, if any, attempts have been made in recent years to combine the characteristics of the two types of beet.

Colin and Bougy, (2)[2] during the 1930's, made rather extensive hybridization studies involving sugar and fodder beets. They observed that sugar content of the F_1 hybrid was intermediate between the parents, but nearer the sugarbeet, indicating some degree of heterosis for sugar content. In the F_2 generation, segregants shaped like sugarbeets had the highest sugar content. Segregants with red or yellow skin had larger roots and a lower sugar content than white-skinned segregants. These relationships indicate a genetic linkage exists between the characteristics which made a plant a fodder beet or a sugarbeet.

Anderson presented his genetic theory of introgressive hybridization in 1949 (1) in which he described the distribution of segregants from hybrids between parents which differ widely in the characteristics which distinguish them. In the distribution of individuals in segregating generations, individuals rarely, if ever, appear which combine the characteristics of both parents, but are generally like either of the parents or the F_1 hybrid. This results in a narrow re-combination spindle of the scatter diagram and could explain the problems others have had in combining sugar content of sugarbeets with yield of fodder beets by selecting in successive filial generations.

It was against this background that a breeding plan was designed for possibly combining the yield of a fodder beet variety and the sugar content of a sugarbeet variety.

Materials and Methods

Otofte Nova II, a mangel type fodder beet variety which is yellow, sits high in the ground, and is high yielding but low in dry matter was chosen as the fodder beet parent. GW674, which has a very broad genetic base and is *Cercospora* leafspot resistant, was chosen as the sugarbeet parent. The genotype of the two marker loci is YYrr (yellow skinned root, green hypocotyl) for the fodder beet and yyRR, yyRr or yyrr (white-skinned root with red or green hypocotyl) for the sugarbeet.

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[1]Manager, Variety Development, The Great Western Sugar Co., Longmont, Colorado 80501.
[2]Numbers in parentheses refer to literature cited.

A breeding plan was designed to counter a theoretically narrow recombination spindle. Selection was utilized for retention of the fodder beet yield of roots while backcrossing to sugarbeet was used for incorporation of sugar content. The plan was to introgress sugar content into the fodder beet.

Two consecutive mass selections were made in the segregating generations before each backcross to allow as much recombination as possible so that there would be a greater chance for genotypes approximating those of fodder beets to exist.

The original F_1 hybrid was made by interplanting fodder beet plants with green hypocotyl sugarbeets. Yellow rooted plants in the progeny of sugarbeets were hybrid. About 100 hybrid plants were grown for production of seed of the F_2 generation.

Two methods of selection were used. The segregating generations, F_2, F_3, F_2B_1 and F_3B_1 were mass selected with local block control as follows: The area which was planted with seed from a segregating generation was divided into blocks 12 rows × 25 feet. The largest beets having full competition were selected and marked according to the block from which they came. Sugar analysis was made on each root selected from the field. Final selection consisted of about equal portions of roots from each selection block—the selected roots being the heaviest in the block after elimination of roots with the very lowest sugar content.

The other method of selection was a combined backcross and progeny test. Selected roots of F_3 and F_3B_1 generations having green hypocotyl (rr) chosen as described above were interplanted with red hypocotyl (RR and Rr) sugarbeet plants. Seed from each green hypocotyl plant was harvested separately. Seed of about 150 individual progenies was planted in standard replicated production trials. By selectively thinning all plants to red hypocotyl, plants with pure stands of hybrids were established for determination of yield, sugar content and laboratory thin juice purity. Hybrid stecklings (Rr) grown from remnant seed of the hybrid families having the greatest yield of roots and/or yield of sugar were used for production of seed of the F_2B_1 and F_2B_2 generations.

Production of the F_2B_2 generation was from hybrid roots of families showing the greatest sugar production.

Approximate selection pressure was 200 of 5,000 in mass selecting of F_2, F_3, F_2B_1 and F_3B_1 generations, and in the progeny test of roots in the F_3 and F_3B_1 generations, about 15 families of 150 progenies tested. Twenty to 25 stecklings of each of the 15 selected progeny were used for production of F_2B_1 and F_2B_2 generations.

To determine the progress of introgression, a performance trial involving varieties representing each generation was conducted at Longmont, Colorado, and Gering, Nebraska. Both trials consisted of six replications of each variety planted in plots six rows × 25 feet. Six rows × 18 feet were harvested to determine yield of roots. Sugar content and laboratory thin juice purity was determined on roots from two of the rows, harvested as two samples. Soluble non-sugar on beet was calculated as follows:

$$\frac{\text{Sugar Content on Beet}}{\text{Purity Percent}} - \text{Sugar Content on Beet} = \text{Residual Soluble Non-Sugars on Beet.}$$

Seed for testing the F_1 generation was produced by allowing fodder beet plants (YYrr) to interpollinate with red hypocotyl (yyRR) sugarbeet plants and harvesting seed from the fodder beets. Plots planted to this seed and thinned to red hypocotyl (Rr) plants were totally hybrid.

Results and Discussion

A hypothetical model of how the population spindles of successive generations under maximum selection might appear from a fodder beet × sugarbeet cross is presented in Figure 1. The horizontal axis is sugar content and the vertical axis is root yield, both in percent of the sugarbeet parent. The sugarbeet parent is represented by the lower right corner while the fodder beet parent is in the upper left corner.

The effect of backcrossing is to move the mean yield of roots and sugar content toward the mean of the sugarbeet parent. Selection for yield of roots (hatched area) will move the yield of roots and sugar content toward the mean of the fodder beet parent.

If all fodder beet characteristics for size could be retained through selection, backcrossing to sugarbeet would result in the means of the

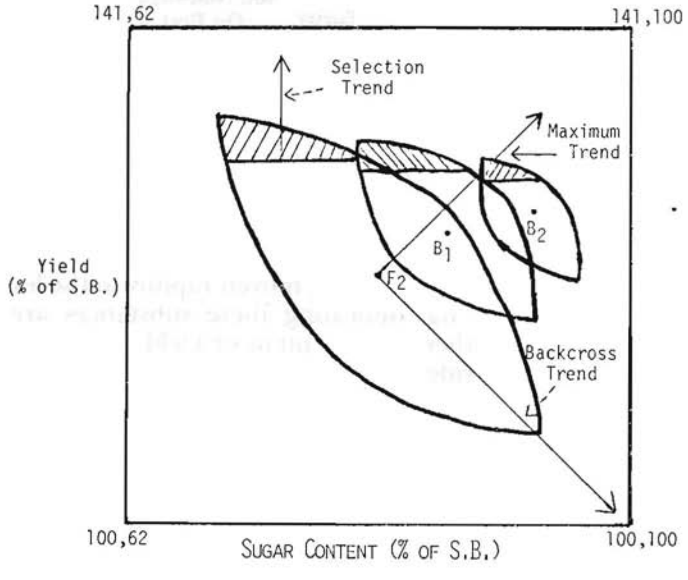

Figure 1.—Introgression theory applied to sugar content and yield.

products of successive cycles moving to the upper right, the result of the combining of characteristics of both parents. Somewhat less than perfect selection could be expected so the trend would be for the mean of successive cycles to move to the right, intersecting the vertical axis somewhere above the lower right hand corner.

Results of the performance trials of seed lots representing the various populations of the introgression are summarized in Table 1. No significant interaction, population × location, was observed for any character so the results from Longmont and Gering were combined.

Heterosis for yield of roots was observed in the F_1 hybrid. The yield of the hybrid, 139.9% of P_1, greatly exceeded the mean yields of the two parents, $\frac{100+141.1}{2} = 120.5\%$ of P_1. Little, if any, heterosis was observed for sugar content. Gross sugar production, the product of yield of roots and sugar content, definitely exhibited heterosis. Backcrossing, as expected, resulted in a major shift toward sugarbeet of yield of roots, sugar content and percent soluble non-sugars on beet. (See F_2B_1 and F_2B_2 populations as compared to the F_3 and F_3B_1 populations respectively.) Through simple mass selection, with great intensity, it was possible to retain most of the high yield of roots of the fodder beet (P_2); however, a major reduction in sugar content resulted. (See F_3 versus F_1 and F_3B_1 versus F_2B_1 populations.)

Table 1.—Performance trial of varieties representing generations of introgression, combined results from Longmont, Colorado, and Gering, Nebraska—1968.

	Wt.		Sugar %	Purity	Residual Sol. Non-sugars On Beet	Gross Sugar
	% P_1	% P_2	% P_1	% P_1	% of P_1	% P_1
P_1	100.0	71.0	100.0	100.0	100.0	100.0
P_2	141.0	100.0	62.0	94.8	143.4	87.4
F_1	139.9	99.1	83.2	97.8	127.6	116.4
F_3	138.2	98.2	74.2	97.2	125.0	102.5
F_2B_1	126.0	89.4	90.6	99.2	109.2	114.1
F_3B_1	137.3	97.6	86.7	98.6	117.1	119.1
F_2B_2	124.0	88.0	92.5	99.7	100.0	114.7

Residual soluble non-sugars on beet moved rapidly to the level of sugarbeet upon backcrossing, indicating these substances are not strongly associated with either sugar content or yield of roots.

These data do not provide evidence as to whether introgression of sugar content and yield of roots occurred. Considering the productivity of the F_3B_1 population, it might be concluded that some introgression is occurring. Yield of roots approaches the fodder beet parent (P_2) and its sugar content is substantially above the F_3 generation. Gross sugar production shows an increase over the F_2B_1 generation.

On the other hand, productivity of the F_2B_1 and F_2B_2 would indicate that no introgression was occurring. Two intensive mass selections in the F_2B_1 and F_3B_1 for size and a selection of high producing hybrid maternal lines produced no changes in productivity—114.1% of the P_1 in gross sugar per unit of area for the F_2B_1 versus 114.7% for the F_2B_2. There may have been a small gain in sugar content, but with loss in weight so that the productivity was not different. Selection at these stages appears only to maintain the heterosis observed in F_1. It was at this time the project was discontinued because other varieties were being developed which were superior to the material being developed in this program.

One explanation of the failure of appearance of pronounced evidence of introgression in this study could be that the two characters, yield of roots and sugar content, are physiologically dependent. Manipulation of one character always results in a corresponding change in the other character in the opposite direction. It appears that both are products of photosynthesis and without change in photosynthetic efficiency, no net change in productivity will occur.

Summary

A breeding plan using the theory of Anderson's introgressive hybridization was used in an attempt to combine the sugar content of sugarbeets with the yield of roots of fodderbeets. Selection and backcrossing appeared only to retain the advantage of the F_1 after two cycles.

Literature Cited

(1) Anderson, Edgar. 1949. Introgressive Hybridization. John Wiley and Sons, Inc. NYC. 109 pages.

(2) Colin, H. and E. Bougy. 1939. Les croissements de sucrieres et de fourrageres. Dissociation en F_2, de l'hybride Kuhn X mangold. Publication de L'Institut Belge pour L'Amelioration de la Betterave. 7: 2, 28-47.