Selective Fertilization Studies and Recovery of Self-sterile from Self-fertile Races of Monogerm Sugar Beets

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Introduction

All contemporary sugar-beet varieties are self-sterile. Introduction of self-fertile monogerm races into self-sterile populations may lead, in greater or less degree, to selfing within the hybrid populations and will result in a decrease in vigor and productivity. Obtaining self-sterile monogerm races makes it possible to develop monogerm varieties by the simplest method, namely, the crossing of the best commercial self-sterile varieties with self-sterile monogerm races.

Selective Fertilization in SLC 101

The original monogerm race SLC 101 is self-fertile. Selective fertilization favors the plant's own pollen. There was an average of 17.08 percent hybridization under open-pollination when single plants of SLC 101 were grown within large multigerm populations at Salt Lake City, Utah, (Table 1) . Deviations were observed from 3 to 28 percent in separate cases. Selective fertilization with respect to the plant's own pollen was also observed in field plantings in Oregon and California (22.81 percent hybridization) and also when these monogerm plants were grown in greenhouses (15.52 percent hybridization) . In a total of 5,904 plants, 953 hybrids (16.14 percent) were observed.

When the self-fertile monogerm race SLC 101 was crossed with self-sterile multigerm varieties, all F_t plants were observed to be self-fertile. In agreement with the oppositional hypothesis (1)[2] F_2 hybrids were also self-fertile when derived from F_1 plants by selfing under paper bags. Of about 300 monogerm F_2 plants derived from controlled self-pollination of F_1 plants, only two were self-sterile (it is questionable whether the apparent self-sterility of these plants was due to their genotype or to some other cause) . All F_3 monogerm plans also appeared self-fertile. Attempts to obtain self-sterile monogerm beets without preliminary selection for self-sterility were unsuccessful.

Outline of Methods of Obtaining Self-Sterile Monogerm Races.

The method of obtaining self-sterile monogerm races was based upon genetic studies and upon embryological investigations. (A) . It was necessary to produce backcross generations (multigerm self-sterile plants x F_1) to obtain segregation for self-sterility and self-fertility. (B.) It was necessary to select self-sterile plants from the first backcross generation (b_1) and monogerm plants in the succeeding generation $(b_1)_2$. (C.) It was necessary to distinguish self-sterile plants from self-fertile plants on the basis of fruit and ovule development at the time of flowering (2) .

If self-sterility versus self-fertility is controlled by one allelic series of genes (1) and the multigerm versus monogerm characters by another independent pair of genes (3) , then the b_1 progeny must consist of four genotypes: $MM\ SfS^1$, $Mm\ SfS^1$,$MM\ S^1S^2$, and $Mm\ S^1S^2$ (S^1 and S^2 indicating

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[2] Numbers in parentheses refer to literature cited.

allelic genes for self-sterility). All plants in b_1 must be multigerm; 50 percent of them are expected to be self-sterile and 50 percent self-fertile. The self-sterile and self-fertile groups will both segregate in the next generation for monogerm plants.

Table 1.—Percent Hybridization in Offspring from SLC 101 Grown Under Open-polination With Other Varieties.

Location of seed isolation	Lines studied	Plants	Hybrids
	Number	Number	Percent
SALT LAKE COUNTY			
Bateman	2	405	27.91
Shaw	4	551	21.63
Turner	2	509	20.23
Jordan	2	288	20.48
Hastings	2	134	19.40
Atkinson	2	421	15.67
Young	2	333	12.31
Hamblin	2	493	9.54
Christensen	2	456	7.45
D.Turner	2	279	3.22
Total	22	3,869	17.08
GREENHOUSES IN UTAH			
Ogden	6	463	23.97
Intermountain	2	108	27.77
Sugarhouse	5	762	8.66
Total	13	1,333	15.52
OTHER LOCATIONS			
Ogden, Utah	7	222	16.21
Salem, Oregon	3	174	38.50
Salinas, California	6	306	13.72
Total	16	702	22.81
Grand total	59	5,904	16.14

If b_1 populations, consisting of self-sterile and self-fertile plants, are propagated under open pollination, we can expect (without much error) that all self-fertile plants will be selfed and all self-sterile plants will be pollinated by pollen from both self-sterile and self-fertile plants in proportion to the respective pollen production in the populations. In this case the genetic composition of the progeny in a large population will tend to approach the ratio 76 *MM*:40*Mm*:12*mm* (Table 2). In other words, 12 monogerm plants will occur to 116 multigerm. This gives 9.37 percent monogerm plants in the population. Of these monogerm plants 75 percent must be self-fertile and only 25 percent self-sterile. This means that only one self-sterile monogerm plant will appear to 41.6 other plants.

To increase the number of self-sterile monogerm plants in the $(b_1)_2$ generation, it is necessary to select self-sterile b_1 plants. For this purpose, part of the inflorescences of each b_1 plant must be enclosed in a paper bag. Two or three weeks later after initiating of flowering, depending on temperatures, the self-sterile plants can be distinguished and selected. Further work with self-sterile plants can be conducted in four different ways (Table 2)-

1. Propagation of b_1 self-sterile plants by crossing *inter se.*
   a. The group of selected self-sterile plants can be isolated and left

for open-pollination. All self-fertile plants must be discarded beforehand.

b. After the seed is harvested, the selected self-fertile plants can be saved for seed production in an isolated group the next year. They can also be propagated vegetatively and clones can be grown to produce seed under open-pollination. In all these variations of procedure, the groups of self-sterile plants are isolated from self-fertile plants in the population. Therefore, the genetic composition of the progeny in $(b_1)_2$ will differ from the preceding population. The composition of the population in this case will have a tendency to approach the ratio 9*MM*:6*Mm*:1*mm* (Table 2). The ratio of multigerm to monogerm plants will approach 15:1. Only 6.25 percent of the plants in the population will be monogerm, but all these will be self-fertile. No other method gives such possibilities.

c. If it is difficult to isolate the selected self-sterile plants as a whole group under open pollination, they can be crossed with each other by exchanging paper bags. By exchanging paper pollinating bags between self-sterile b_1 plants, 50 percent of the crosses will be lost as far as self-sterile monogerm offspring is concerned, because there is a 1:1 chance for self-sterile *MM* plants.

Table 2.—Recovery of Self-sterile Monogerm Beets from Hybrids from the Monogerm Race SLC 101 *(mm SfSf)*, Expected Segregation[1] in $(b_1)_2$ Generation.[2]

Utilization of 1st backcross—b_1	Genotypes *MM:Mm:mm*	Phenotypes *M:m*	*mm* segregates Total	Self-sterile to remainder		Crosses lost Self-sterile *Mm* hybridized under paper bags
	Ratio:	Ratio:	Percent	Percent	Ratio:	Percent
b_1 x b_1 (no discards)	76:40:12	116:12	9.37	25	1:41.6	
b_1 x b_1 (self-fertiles discarded)	9:6:1	15:1	6.25	100	1:15	50[3]
b_1 x F_1 *Mm* self-sterile	6:8:2	14:2	12.5	50	1:15	....
b_1 self-sterile x F_2 *mm*[5]	0:12:4	12:4	25.0	25	1:15	50[4]

[1] No linkage assumed between gene *Sf* for self fertility and gene *m* for monogerm fruits.

[2] b_1 = first backcross to multigerm *MM* ($MM\ SfS^1 + Mm\ SfS^1 + MM\ S^1S^2 + Mm\ S^1S^2$). $(b_1)_2$ = generation after b_1.

[3] Crosses considered lost which do not yield monogerm *mm* beets in the next generation.

[4] Crosses considered lost which do not yield self-sterile monogerm *mm* beets in the next generation.

[5] With regard to the gene *Sf* for self-fertility, 50 percent of the F_2 *mm* beets are homozygous and 50 percent are heterozygous.

2. The self-sterile plants selected in b_1 can be pollinated by pollen from F_1 hybrids derived from crosses of monogerm beets of SLC 101 with any valuable self-sterile multigerm variety. The genotypic composition of the progeny will approach 6*MM*:8*Mm*:2*mm* (Table 2) in the next generation. Multigerm to monogerm plants will occur in the ratio of 14:2. The percentage of monogerm plants will increase to 12.5 percent and of these monogerm plants 50 percent will be self-sterile and 50 percent will be self-fertile, but the self-fertile will be heterozygous for the genes controlling self-fertility and self-sterility. None of the crosses will be lost by using this method because the male parent is heterozygous for both genes.

3. Selected self-sterile b_1 plants can be pollinated by pollen from new monogerm plants derived from F_2 hybrids. These F_2 monogerm *mm* plants contain two genotypes: those heterozygous for self-fertility, SfS^1, SfS^2 etc., and homozygotes *SfSf.* Progenies derived from these crosses will segregate in the next generation with a ratio approaching 12Mm:4mm (Table 2) . Four monogerm plants will appear to 12 multigerm. The proportion of monogerm plants will increase to 25 percent, but three-fourths of these monogerm plants will be self-fertile because they carry the gene for self-fertility in the heterozygous condition and only one-fourth of them will be self-sterile. Of the crosses derived from self-sterile *Mm* b_1 plants 50 percent will be lost by pollination to F_2 *mm* pollinators because 50 percent of the male parents are homozygous for the gene 5/. The ratio of self-sterile monogerm plants to all other plants in the population will be 1:15, the same as by the first and second methods.

4. Another method of developing self-sterile monogerm races consists of crossing monogerm F_2 plants with multigerm self-steriles. The gametes expected from these monogerm F_2 plants will be 3m Sf: 1*m* S^1, (or S^2, S^3, etc.) . When plants from multigerm self-sterile varieties are pollinated by pollen from monogerm F_2 plants, 25 percent of the F_1 hybrids will be self-sterile and multigerm *Mm* (S^1S^2, S^2S^3 etc.) . Isolation and propagation under open-pollination of this group of self-sterile *Mm* plants in the next generation will produce 25 percent monogerm self-sterile plants.

Experimental Results

Plants in the first backcross generation (b_1) were bagged and checked for self-sterility versus self-fertility. Segregation for self-sterile and self-fertile plants followed a 1:1 ratio (80 self-steriles: 77 self-fertiles) . Self-sterile plants were selected. The most practical methods of obtaining progeny from selected self-sterile b_1 plans which produce a comparatively high percentage of self-sterile monogerm plants appeared to be as follows: 1. exchanging of paper bags on selected self-sterile plants, and 2. obtaining seed under open-pollination from other branches of these plants. Because of a larger amount of seed more self-sterile monogerm plants can be selected in the offspring from open pollinations.

Offspring obtained in 1950 from crosses between self-sterile b_1 plants with F_1 hybrids and from open pollination of self-sterile plants were transplanted in 1951 to the Amalgamated Sugar Company greenhouse at Ogden, Utah, and to the greenhouse at Salt Lake City and also to overwintering plantings. In all plantings multigerm segregates were discarded and all monogerm beets were bagged to determine whether they were self-fertile or self-sterile.

Progenies derived from open pollination of self-sterile *Mm* plants showed good results, which were equal to those obtained by pollination of these *Mm* plants by F_1 pollen. From progenies derived from open pollination at Salt Lake City there were 9 percent monogerm *mm* segregates of which 48 percent appeared to be self-sterile. From eight overwintered lines two produced a sufficient number of monogerm plants so that the segregation could be observed. In these lines the self-sterile monogerm beets accounted for 49.3 percent of all the monogerm segregates. From a total of 76 monogerm segregates 37 were self-sterile and 39 self-fertile.

A total of 78 self-sterile monogerm beets was selected from several thousand hybrid offspring in 1951. These self-sterile monogerm beets were crossed *inter se* by exchanging bags. Their progenies will be checked in 1952 to confirm whether or not they are self-sterile as expected. The first self-sterile monogerm elite seed will be obtained from this material.

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