Breeding of Synthetic Varieties of Sugar Beet With Maternally Selected Strains

By FUMIHIRO FUJIMOTO

5th Laboratory, Division of Genetics, National Institute of Agricultural Sciences (Hiratsuka)

Synthetic varieties have been mainly used in the breeding of cross-pollinated crops, especially in the heterosis breeding program in which seed production of hybrid varieties is commercially difficult.

In corn breeding, moreover, questions have recently been raised as to whether the standard system of inbreeding and use of F_1 hybrid was the most efficient, and re-evaluation of breeding methods including synthetic varieties has come under careful scrutiny.

In sugar beet breeding, synthetic varieties which are composed of maternally selected strains have been widely used in Europe. But few basic researches on breeding methods have been reported, as the breeding work has been mainly carried out in sugar companies or seed companies.

At the Branch of the Japan Sugar Beet Institute (Br. J.S.B.I.) in Kumamoto, several synthetic varieties were developed in the short period of eight years from 1961 to 1969. They exhibited excellent performance in producing higher sugar yield not only in the warmer region of Japan (Shikoku and Kyushu) but also in the cooler region (Hokkaido).

The author took part in breeding these varieties and in this report the genetic basis of this success of sugar beet breeding work is elucidated; it may provide some evidences for re-evaluating breeding methods of cross-pollinated crops.

Effects of maternal line selection

Changes of the root weight and sugar percent of the maternal line BC group which was related to the synthetic variety "Hazuki" and those of B51 which was related to another variety "Harumasari" are shown in Fig. 1. From the original population, individuals with phenotypically superior roots were selected by mass selection but its effect was hardly recognized.

In the first generation, performance of maternal lines was tested by replicated tests and superior maternal lines were selected. After this selection, the root weight was clearly increased in both groups. In the BC group, effect of maternal line selection was decreased in later generations, whereas in the B51 group both the root weight and the sugar percent continued to increase up to the sixth generation.

The effectiveness of the maternal line selection towards increasing the root weight, accompanied by gradual increase of the sugar percent, is evident from these results. It is likely that one of the important reasons for the effectiveness of the maternal line selection is the fact that the selection was made on the basis of replicated performance tests, by which superior genotypes could be distinguished.

The disappearance of effects of the maternal line selection in the BC group in advanced generations was considered to be due to inbreeding depression. The BC group was

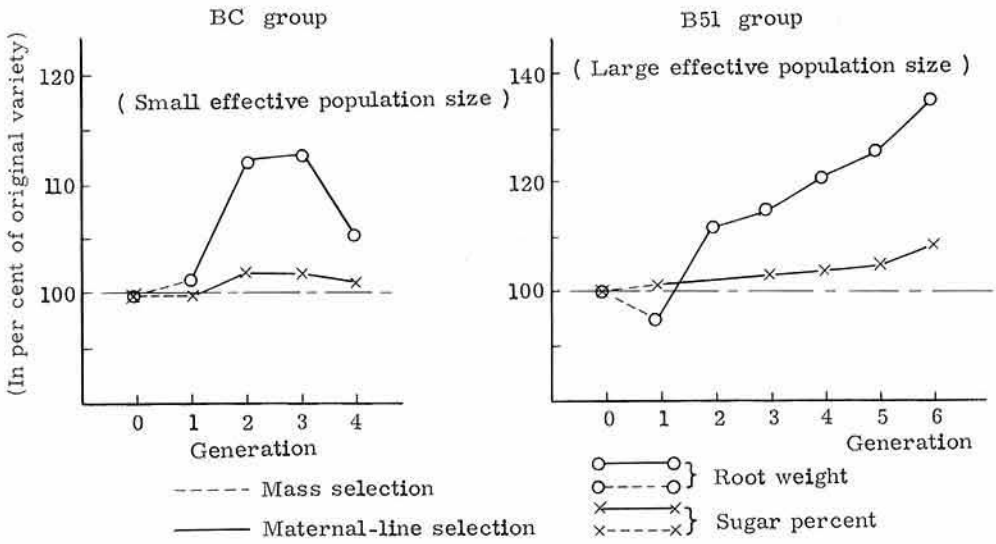

Fig. 1. Effects of maternal line selection in root weight and sugar percent as generations advanced

developed by grouping two to three maternal lines, whereas B51 was developed by grouping 6~40 maternal lines.

Hence, the effective population size was much smaller in the BC group than in the B51 group. These facts indicated that even in the maternal line selection, gains by selection in advanced generations were invalidated by the inbreeding depression if the effective size of the selected population was small. When inbreeding depression begins to appear, the breeding procedures should be changed to heterosis breeding.

Combining ability of maternally selected strains

Combining ability of strains of the BC group was tested by polycross and it was clarified that the correlation between general combining ability and parental performance was high (Fig. 2, upper half).

In order to study this correlation in relation to the selection methods, the general combining ability of strains bred by the maternal line selection (BZF-L group) from the hybridized progeny populations was compared with that of strains bred by the mass selection (BZF-M group).

A similarly high correlation was obtained in the BZF-L group but the correlation was low in the BZF-M group (Fig. 2, lower half). These results demonstrated that strains bred by the maternal line selection had high combining ability in addition to high yielding ability.

Furthermore, a comparison of the frequency distribution of sugar yield in single crosses among the inbred lines derived from maternally selected strains (L) and mass selected strains (M) suggested that genes for high combining ability were concentrated in the maternally selected strains (Fig. 3).

According to KNAPP (1958), "Beginning of evaluating the breeding value of each plant based on progeny tests meant an essential progress for the sugar beet breeding. In cross-pollinated Beta-roots, it was carried out as selection of mothers. Sugar yield in Germany was 1.86 ton/ha in the years 1850–1859, and increased rapidly to 4.00 ton/ha in the years 1890–1899. This progress would be ascribed to the use of breeding method of individual progeny testing."

The effectiveness of the maternal line selection in increasing sugar yield has thus been

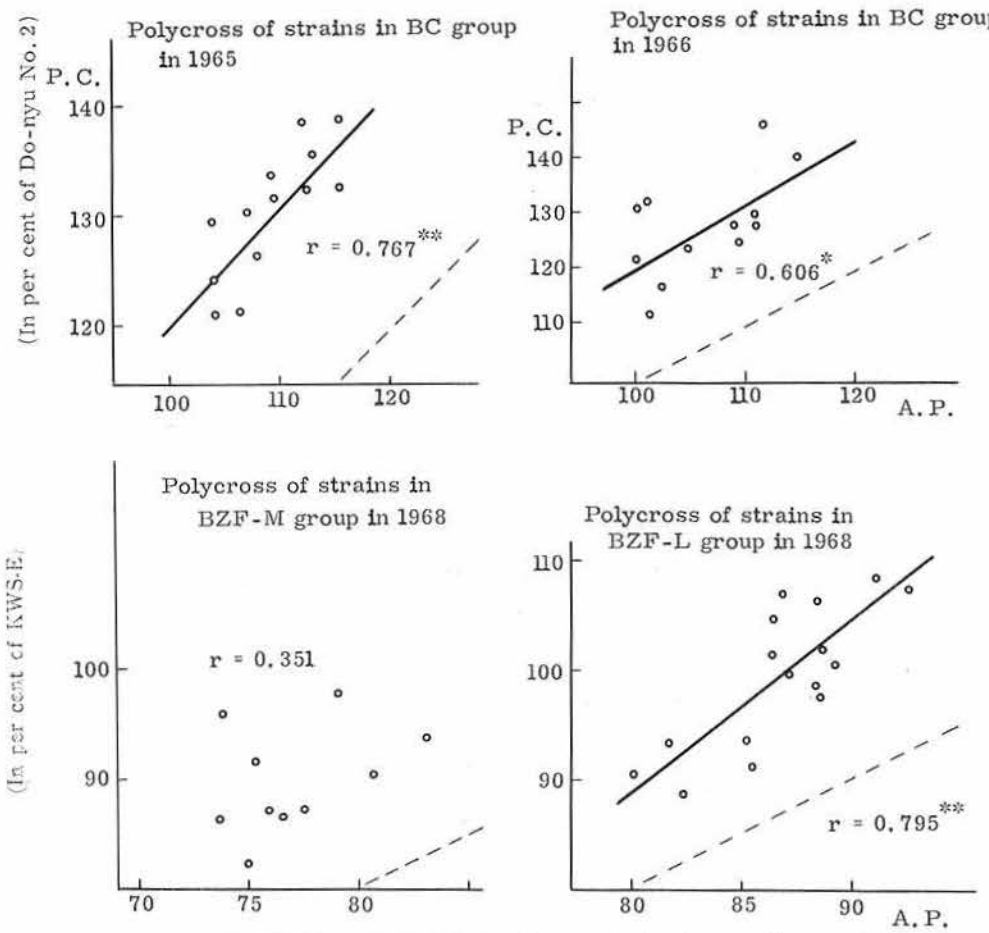

Fig. 2. Correlation between the performance of polycrossed progenies (P.C.) and average parents (A.P.) in sugar yield (Solid lines are regression lines and dotted lines are Y=X.)

recognized since old days, but it should now be noted, from the experimental results reported in this paper, that the important basis for the success of the maternal line selection was ascribed to the fact that development of high yielding maternal lines was connected directly to the development of strains with high combining ability.

Combining ability in sugar yield and breakup of the correlation between root weight and sugar percent

Sugar yield consists of two constituent characters, that is, root weight and sugar percent. Process of concentrating genes for high combining ability in sugar yield was studied from the viewpoint of the breakup of the negative correlation between root weight and sugar percent. Change of correlation coefficients between these two characters during the course of the breeding work in Br. J.S.B.I. is shown in Fig. 4.

A very high negative correlation coefficient was obtained between them in the original varieties but it was lowered through the maternal line selection and crosses. In mass selection, the degree of lowering of negative correlation was very small. These results indicated that the negative genetic correlation

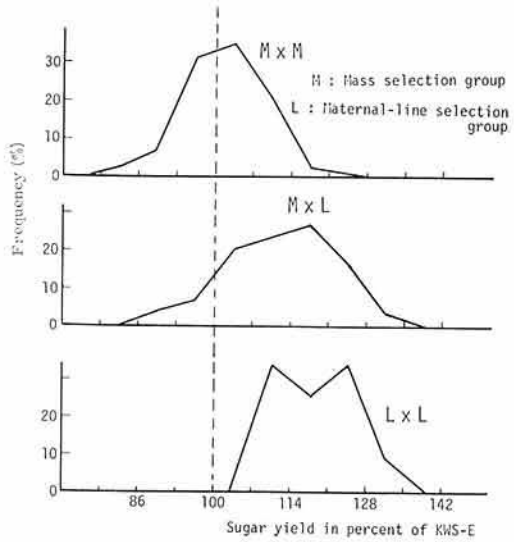

Fig. 3. Comparison of frequency distributions of single cross sugar yield grouped by selection method

to its accuracy in distinguishing superior genotypes by replicated performance tests. Most of these genotypes superior in sugar yield would be heterozygotes because heterosis was of the greatest importance.

In these selected heterozygotes, effective crossing-over would occur more frequently than in homozygotes. They were intercrossed and formed new maternal lines on which the next cycle of selection was practised.

It is most likely that recurrent maternal line selection increased the superior genotypes in which genes were in new favorable combinations—high root weight with high sugar percent—which had not existed in the original population.

These new combinations might presumably be the cause of the high combining ability and high yielding ability in sugar yield.

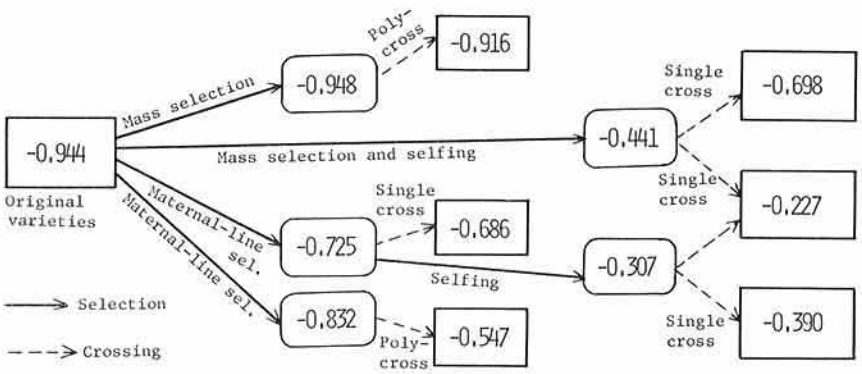

Fig. 4. Diagram showing changes of correlation coefficients between root weight and sugar percent as breeding proceeded

between root weight and sugar percent was caused by linkage and could be broken up by recombination.

The reason for the effectiveness of the maternal line selection in decreasing the negative correlation can be inferred as follows:

Many experimental results including those by the author proved that heterosis was very important in increasing root weight and sugar yield. As mentioned above, effectiveness of the maternal line selection can be ascribed

This study suggests that the maternal line selection is important as a breeding method that fully utilizes recombination of genes by recurrent selection of heterozygotes.

Yield prediction of synthetic varieties and number of component strains

According to ALLARD (1960), "The yield level of a synthetic variety can be increased by any one or a combination of the following:

(1) increasing the number of lines, (2) increasing mean F_1 yields, (3) increasing the mean yield of the parents."

In general, a larger number of component strains is desirable from the viewpoint of utilization of heterosis whereas a small number is desirable from the standpoint of superiority of strains. The optimum number of component strains in a synthetic variety should be determined with consideration on these factors.

In Br. J.S.B.I., 16 strains of the BC group which had been developed by the maternal line selection were used to produce eight synthetic varieties. The number of their component strains ranged from two to 16. Sugar yields of these synthetic varieties were predicted from the combining ability of component strains and actual yields were compared with prediction (Fig. 5).

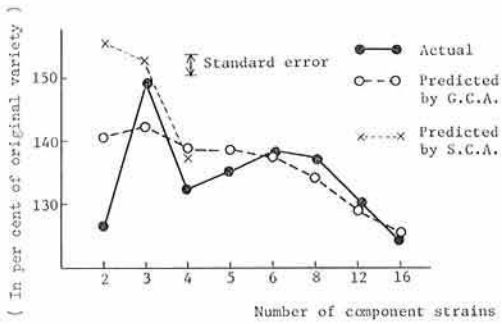

Fig. 5. Actual and predicted sugar yield in Syn_1 generation synthetic varieties (1967)

When the number of component strains were below five, the actual yield was lower than the predicted yield with an exception of the three-strain synthetic variety. Frequency of inter-strains crossing must have been low due to the small number of strains involved, which might have led to smaller effects of heterosis.

When the number of component strains was above six, the actual yield agreed well with its predicted value. As is shown in Fig. 5, however, the three-strain synthetic variety exhibited obviously a higher sugar yield than the prediction based on the general combining ability. If the prediction was made by specific combining abilitity, the actual yield agreed well with the prediction. This three-strain synthetic variety showed the highest sugar yield in Syn_2 generation, too (Fig. 6).

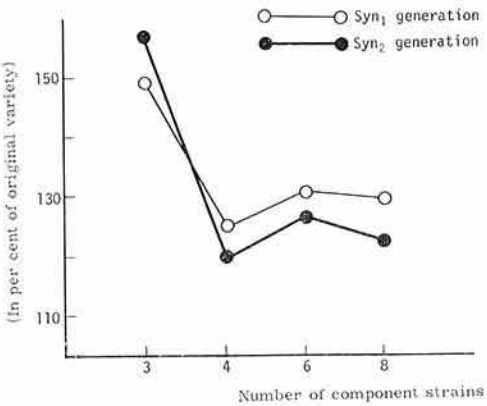

Fig. 6. Comparison of actual sugar yield of Syn_2 generation with Syn_1 generation (1968)

It is likely that the optimum number of component strains would be about six when we considered the utilization of the general combining ability of maternally selected strains, but there is a possibility that the specific combining ability may play an important role in the synthetic variety of a smaller number of component strains.

The conclusion, that yield of a synthetic variety can be easily predicted and that the optimum number of component strains can be determined with adequate considerations on combining ability, adds another advantage to the maternal line selection: the best synthetic variety can be found without testing the performance of a large number of synthetic varieties.

Superior strains bred by maternal line selection have the characteristics that they have high combining ability in addition to high yielding ability. This is the most desirable characteristic as the component strain of a synthetic variety and it is because of this characteristic that highly productive synthetic varieties were obtained with a small number

of component strains.

Maternal line selection and breeding of synthetic varieties discussed in this paper were applied to practical breeding programs at the Branch of the Japan Sugar Beet Institute.

The varieties bred by this method showed excellent performance at the Prefectural Agricultural Experiment Stations in the warmer region of Japan, and two of them, "Hazuki" and "Harumasari", were registered as new cultivars by the Ministry of Agriculture and Forestry in 1968.

Other cultivars, "Shi No. 6" and "Shi No. 7", showed extremely good performance in the northern and eastern districts of Hokkaido, Japan, in 1968, 1969 and 1970. They are expected to be released as new cultivars and to contribute to the sugar beet production in Hokkaido.

References

1) Allard, R. W.: Principles of Plant Breeding. 303–322. John Wiley & Sons, New York (1960).
2) Arashi, K.: Accomplishments of sugar beet breeding in warmer Japan. *Bull. Sugar Beet Res.* **7**, 1–95 (1969). [In Japanese with English summary.]
3) Arashi, K., Teshima, M. & Fujimoto, F.: Studies on the local adaptation of sugar beet varieties, especially new varieties bred by Branch of Japan Sugar Beet Institute. *Japan. J. Breeding* **21**, 219–226 (1971). [In Japanese with English summary.]
4) Fujimoto, F. & Matsumura, T.: Studies on the breeding method of synthetic varieties in sugar beet.
   I. Estimation of general combining ability of materially selected sugar beet strains by polycross. Japan. *J. Breeding* **20**, 223–229 (1970). [In Japanese with English summary]
   II. Estimation of general and specific combining ability by diallel cross. *Japan. J. Breeding* **20**, 293–300 (1970). [In Japanese with English summary.]
   III. Performance of synthetic varieties and number of component strains. *Japan J. Breeding* **20**, 359–364 (1970). [In Japanese with English summary.]
5) Fujimoto, F.: Studies on the evaluation of maternal line selection in sugar beet breeding. —In relation to the improvement of combining ability and breakup of the unfavorable correlation—*Bull. Sugar Beet Res.* **10**, 1–136 (1971). [In Japanese with English summary.]
6) Fujimoto, F., Matsumura, T. & Nishio, T.: On the effect of mother line selection in sugar beet. *Kyushu Agric. Res.* **29**, 91–92 (1967). [In Japanese.]
7) Knapp, E.: Beta Rüben, bes. Zuckerrüben. Handbuch der Pflanzenzüchtung **III**, 198–284 (1958).