SUNFLOWER BREEDING IN CANADA

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The Canadian sunflower breeding program may be divided into three phases; first, the early work primarily at Saskatoon, resulting in the licensing of the variety Sunrise and the hybrid Advance; second, the 1950 decade in which high priority was given to breeding for resistance to rust and to a lesser extent for resistance to Verticillium; and third, the 1960's in which more attention is being given to methods for utilizing heterosis and to breeding for oil content. The work might also be classified as the pre-Russian and post-Russian eras, hinging on the introduction in 1960 of Russian varieties which are much higher in oil content than any material previously available. One of these varieties, Peredovik, has been recently licensed in Canada. It is doubtful that any of the earlier material will remain acceptable to the commercial producer of oilseed even though some of it is being continued in the breeding program. Its main contribution to the program in the future will be resistance to disease.

The Early Work

The program was founded at Saskatoon in 1937 on the progenies, from open-pollinated seed, of about 400 single plants of the variety Mennonite selected from farmers' gardens in the vicinity of Rostern, Saskatchewan. In addition, approximately one dozen introductions were available from Russia. Inbreeding commenced in this material. One Russian introduction proved uniform for dwarf, desirable agronomic type and had the best oil content. It was licensed as the variety Sunrise in 1942, partly in response to wartime pressure for domestic production of vegetable oils.

As part of the program, the percentage of natural crossing that occurred in the crop was investigated using pairs of inbred lines with contrasting characters in small isolated plots. It soon became evident that some lines crossed better than others and that the F_1 hybrids had high vigor and yield. This led to the idea of commercial hybrids and the release, in 1946, of the hybrid Advance of the pedigree S-37-388 × Sunrise. Compared with Sunrise, Advance was superior in yield, similar in oil content, and about 5 days earlier.

The production of the crop soon centered in southern Manitoba and consequently the breeding program was transferred to Morden in 1945. From 1945 to 1950 the main work was on development of further inbreds from Mennonite and from crosses of the earlier lines. Combining ability tests were usually as topcrosses with Sunrise as the tester parent. A few of the lines in today's program stem directly from this work and others have either S-37-388 or Sunrise in their parentage.

Breeding for Disease Resistance

About 1948 it was apparent that rust was a major threat. In 1951 this disease reduced the yield from an estimated 800 pounds in early August to an actual figure of 325 at harvest. The crop declined from a high of 60,000 acres in 1949 to 3,500 in 1952. Rust resistance had been discovered in 1949 in a single plant of the progeny of the natural cross, Sunrise × Wild Annual from Texas. This resistance, termed the 88 source, was crossed with Sunrise, S-37-388 and two other promising inbred lines from Mennonite in 1950, and several threeway crosses and backcrosses to the commercial type were made in 1951. With the disastrous epidemic of 1951 a crash program to develop a "stop-gap" variety resistant to rust was undertaken and Beacon was licensed for distribution in December 1954. The initial seed of Beacon came from a polycross plot of 26 progenies grown in Chile. Other plants of the same progenies had been checked in the greenhouse for rust resistance in the seedling stage with three cultures of rust by Dr. W. E. Sackston. The progenies were in F_4 from the original crosses or S_2 from the backcrosses and threeway crosses. Beacon was equal to Advance in yield and slightly lower in oil content when rust infection was light but superior when rust infection was severe. Its main defects were late maturity and lack of uniformity.

During the development of Beacon, no clear qualitative inheritance of the 88 source of resistance was apparent in the field. However, in 1950 a plant in the progeny of the natural cross, California Oilseed × Wild Annual from Texas, had superior resistance to rust. A selection from its progeny, now termed the 22 source of resistance, showed a clear pattern of dominant monofactorial inheritance of resistance in the field. This discovery prompted a backcross program to produce S-37-388RR and culminated in the release of Advent, a rust resistant counterpart of Advance, in 1959. Admiral of the pedigree S-37-388RR (CM 5 × CM 27) providing slightly earlier maturity and slightly higher oil content followed in 1960.

The dominant single gene inheritance in the field of the 22 source of resistance still prevails, with minor exceptions, even though races of rust have existed, at least since 1955, which are virulent to it in the seedling stage in the greenhouse. It is still a main source of resistance in the program. It has been used to convert several inbred lines to resistant form and is presently in crosses with the high oil Russian varieties. Other sources from the wild annual pool of germ plasm from Texas are being used. Results of studies jointly with Dr. J. A. Hoes indicate that at least five genes for resistance are involved in this pool. We have also found evidence of resistance in wild material from Kansas, Nebraska and Manitoba and have studies underway to decide if it is controlled by additional genes. Dr. Sackston has reported gene pools for resistance in wild material from Chicago and from Dr. C. B. Heiser at Bloomington and in other material from Russia and Argentina. It seems that there is ample resistance to control this disease by breeding.

In retrospect it appears the work on rust was overemphasized at the expense of other items, among which is the need for resistance to Verticillium. Even though a substantial portion of the Manitoba crop has been planted annually to the susceptible Mennonite for production of large seed, rust

has not seriously affected this variety since 1951. Leaf mottle, or Verticillium wilt, is likely causing greater losses than rust over a long term. It causes economic damage every year and in some seasons losses up to 90 percent occur in several fields. A number of inbred lines possess resistance to leaf mottle, the most promising being CM 144 from the variety Mennonite. It shows either very slight or no symptoms in the field and its resistance in crosses with lines of different degrees of susceptibility is controlled by a single dominant gene. It will likely be the main source of resistance in the immediate future. Other lines show no dominance and quantitative inheritance of resistance governed by relatively few genes. More detailed heritability studies with these lines are underway. A backcrossing program to produce a rust resistant form of CM 144 is nearing completion. Peredovik and the other Russian varieties have good tolerance to Verticillium in the field.

Dr. J. A. Hoes is developing a screening technique which can be applied in the seedling stage to material segregating for resistance to Verticillium. The most promising approach to date is to grow the material in inoculated Perlite. Resistant lines, particularly CM 144, show distinctly less symptoms of disease on the leaves and are stunted less than susceptible lines.

Other diseases which occur in Manitoba are downy mildew, aster yellows Septoria leaf spot, Sclerotinia basal stem rot, leaf and stem spot caused by Alternaria zinniae, and black stem due to Phoma oleracea. The most serious of these is downy mildew. Resistance to it is available but because the disease does not occur with any consistency from year to year a controlled breeding program depending on natural infections is not practical in Manitoba. This is a disease which merits more attention under controlled conditions than it has received to date. Aster yellows, first observed on sunflowers in Manitoba in 1953, caused significant damage in 1957, particularly in Beacon but has been either a minor factor or almost nonexistent in other seasons. The 1957 epidemic showed Sunrise and many lines related to Sunrise were highly susceptible, whereas S-37-388 was resistant and the resistance was dominant. The reaction of the newer Russian varieties is unknown. Here again work under controlled conditions is required because of the sporadic natural occurrence of the disease. Damage from the other diseases is not as well assessed, but is probably less serious than downy mildew. No breeding programs are underway against them or contemplated at present. Some field results indicate differences among lines in susceptibility to Sclerotinia and Dr. Hoes has evidence of differences among lines in reaction to Septoria.

Utilization of Heterosis

The maximum benefit of heterosis is not achieved in hybrids such as Advance and Advent because of the frequent low percentages of crossing, sometimes less than 20 percent, which occur on the female parent when the hybrid seed is produced commercially. Hybrids made by hand pollination, in which a high percentage of crossing is attained, consistently are the best performers in yield tests. Consequently, the ultimate for utilizing heterosis will be a means which will cause 100 percent crossing, or nearly

so, when inbred lines or other putative parents of hybrids are interplanted for natural cross-pollination. Two prospective means to achieve this ultimate are being investigated now. They are male sterility and partial male sterility.

Male sterile stocks have been discovered at Morden and by Dr. C. B. Heiser at Bloomington, Indiana. Each is controlled by a single recessive gene which functions in the male gametophyte when the sporophyte is heterozygous. There is considerable evidence that the responsible genes in the two stocks are different. A search is underway at present to locate a cytoplasm in which the gene controlling the Morden male sterility can be carried in the homozygous condition but not expressed. The stock has been crossed reciprocally with many inbred lines of different origin and with wild annual sunflowers from different locations on the continent. Similar crosses with the Bloomington stock are contemplated. If the desired cytoplasm is found then the simple method employed to produce hybrid sorghum can be applied to sunflowers.

The partial male sterility probably is a better immediate prospect for achieving nearly 100 percent crossing of inbred lines than the genetic-cytoplasmic interaction sought with male sterility. The partial male sterility occurs in two Morden lines, CM 30 and CM 90, both from the Mennonite variety. Within material descending from backcrossing programs of both lines it has been possible to select for low percentages of normal pollen or conversely high percentages of nonstaining and presumably abortive pollen. Plants with little normal pollen have produced seed when self-pollinated, the lines have been increased successfully in isolated plots and have yielded as well as other lines in replicated tests. Both lines cross well in naturally pollinated crossing plots. The F_1 of crosses between the two lines, and of crosses of each with normal lines and with the Morden male sterile are normal. The F_2 of these crosses, now growing, will provide additional information on inheritance of the character. If the character can be transferred to other lines, it should offer a solution to the problem of producing satisfactory hybrid seed. Lines possessing it would appear to be a practical counterpart of cytoplasmic male sterile lines in corn. They would have the advantage of requiring no fertile counterpart to maintain them and no fertility restoring genes would be required when they were used in hybrids.

Lines with high self-incompatability are another possibility of improving the percentage hybrids in commercial production of hybrid sunflower seed. Probably insufficient attention has been given to this character in the Canadian program. Mr. Luciano and Dr. Kinman have it under active investigation at College Station. Their results are being reported in this program.

Until a clearly satisfactory means of producing hybrid seed is developed synthetic varieties offer the best prospect of utilizing heterosis in sunflowers. At Morden, four synthetics, each composed of four lines, yielded as well as the best samples of commercially produced Advance. In these synthetics, no prior study had been made of the combining ability

of the constituent lines in relation to each other. More recently the yields of a diallel cross of 10 lines have been obtained. Using these results to predict the yield of synthetics that may be composed from the 10 lines shows that the synthetics have a potential yield of as much as 26 percent more oil per acre than the average of the yields from Advance, Advent and Admiral produced by hand-pollination or 10 percent more than Admiral which was the best single check. Three of the better synthetics have been prepared and the first generation is in yield tests this season.

Most single crosses in the above mentioned diallel cross showed heterosis for eight characters studied, including seed yield and oil content. Only five of the 45 single crosses failed to exceed the mid-parent value in yield and in 34 the difference was significant at P = .01. For oil content, the difference between the mean of all crosses and the mean of all parents was significant (P = .05) and the differences between seven individual crosses and the respective mid-parent values were also significant, six at P = .05 and one at P = .01. General combining ability effects for both yield and oil content were much greater than the specific combining ability effects. It was not encouraging to find that S-37-388, one of the key lines in the breeding program, had the lowest general combining ability and some others which were regarded highly also had rather low general combining ability. The best lines were two from the Beacon program and two from German introductions.

Use of the High Oil Russian Varieties

The first approach in using the high oil content of the Russian varieties is to cross them with different sources of resistance to rust and to Verticillium and to combine promising unrelated material of early generations into synthetics without any tests for combining ability. This is a "shot in the dark," but a method proved reasonably successful in the case of Beacon. Material is in F_4 from crosses with S-37-388RR and the first generation from single backcrosses involving three other rust resistant lines as well as the F_2 from crosses with the rust resistant and Verticillium resistant CM 144 is in this season's nursery. When inbred lines emerge from these crosses as well as from the original varieties, they will be tested for combining ability in top-crosses with Peredovik with objective of ultimately using them in hybrids or synthetics.

Early indications are that the heritability of the oil content in the Russian varieties is low. In 200 F_3 lines from the crosses with S-37-388RR only 19 had 39 percent oil or over when nine of 15 rows of VNIIMK 6540 in the same nursery had oil content over 39 percent. VNIIMK 6540 is one of the lower oil content Russian varieties. At least a single backcross to the high oil parent seems desirable to improve the chances of obtaining segregates with high oil content. In the few topcrosses of pre-Russian inbred lines × Peredovik that have been studied the oil content was similar to the low parent. However, two inbred lines from Smena, a high oil Russian variety, were crossed as females with Sunrise and in these crosses the oil content approached the high value of Smena. These results are suggestive of a maternal effect for oil content. There are now

several inbred lines out of the Russian varieties, some with over 50 percent oil. They will be used in crosses with low oil lines to investigate the heritability of oil content and maternal effects on it. Two types of crosses are contemplated; the first between two lines with similar maturity and the second involving a line 2 to 3 weeks earlier than the Russian lines. The second type should elucidate the possibility of combining high oil content with early maturity, a feature which does not appear to have been acheived with marked success to date.

The Russian varieties constitute populations which are virtually unrelated or at most very distantly related to earlier material in the program. Thus, they encourage the investigation of reciprocal recurrent selection in sunflowers. Peredovik has been set up with four of the pre-Russian synthetics in naturally pollinated crossing plots this season. If yield trials from the resulting seed show heterosis, Peredovik and the synthetic which combines best with it will be selfed, the S_1 topcrossed naturally with the opposite member of the pair, the topcrosses tested for yield and the results used to return to remnant seed of the better selfed plants to reconstitute the populations for a second cycle. It seems this approach should lead to two populations which cross well reciprocally and exhibit superior combining ability in their F1.

Breeding for Large Seed

The program on this type was started in 1956. The variety Commander was released this year. It was selected from Mennonite on the basis of replicated tests of S_1 lines and recombination of seed from the best parental plants. It is similar to Mennonite except that a larger portion of its seed passes over a No. 18 screen. Rust resistant forms of Mennonite are being tested at present as well as a few lines with large seed in topcrosses with Mennonite or Commander. One topcross in 1963 had the second highest total yield and yield over a No. 18 screen in a 13-entry test. It was 4 to 6 percentage points higher than other entries in percentage kernel to give the highest yield of large meats per acre. A few of the high oil lines from Russian varieties are being topcrossed this year with Commander to study their value for producing high yields of large meats. Selection for a Verticillium resistant Mennonite using the same procedure as in developing Commander is underway with the S_1 lines being grown this year and a similar program is being initiated in the rust resistant form of Mennonite.

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