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The Sunflower Crop and Disease: Progress, Problems, and Prospects

Sunflowers were practically unknown as a commercial crop in North America prior to 1940, although they were grown on a large scale in the USSR and adjacent countries and in South America. Worldwide interest in the crop was aroused during the 1960s, and by 1980 sunflowers were the second most important source of edible vegetable oil in the world. Skyrocketing prices for petroleum in the 1970s led to experimentation with sunflower oil as fuel for diesel engines. The results are encouraging and may trigger an additional surge in sunflower production for nonfood uses.

Details on the history, production, breeding, diseases and pests, and technology of sunflowers compiled by numerous experts are given in a recent book (1). The original papers documenting many of the statements made in this article are cited there.

From Curiosity to Crop

Various food plants—such as beans, chili peppers, maize, peanuts, potatoes, squash, and tomatoes—that are now staples in many parts of the world originated in South and Central America. Sunflower is the only food plant now grown worldwide that originated in temperate North America. The European explorers who came to the Americas in the fifteenth and sixteenth centuries sent samples of all these plants home. Many of them were rapidly adopted as food throughout Europe, Africa, and Asia. Sunflowers, however, which were used by American Indians as a source of food, oil, and dye, were grown largely as curiosities and ornamentals in European gardens until the nineteenth century (3).

Early in that century the plant reached the farmlands of Russia and found favor as a source of food and edible oil. Its success there and later in eastern Europe led to the introduction and trial of sunflower as a crop in north and south Africa, India, China, Australia, and North and South America. It became established in Argentina, occupying 1–2 million ha, second only to the USSR, where it is grown on 4–5 million ha (Fig. 1). In the United States, sunflowers were tried first as a forage crop, but until the 1960s they were grown mainly to produce seed for feeding to wild birds.

Work on sunflowers began in Manitoba in earnest about 20 years earlier than in the United States. Mennonite immigrants from Russia to the prairies of Canada late in the nineteenth century grew sunflowers in farm gardens to roast and eat the seed. Commercial production started in Canada with government support in 1943 on about 2,000 ha to relieve the wartime shortage of edible oils. Mennonite farmers in southern Manitoba formed a producer's cooperative to build a processing plant, which started operations in 1946. It was successful. By 1949 the crop occupied about 25,000 ha, roughly 10% of the total area in 30 townships; on many farms it was repeated in the same fields for several years.

Seven or eight of the more than 60 annual and perennial species of *Helianthus*, including the wild sunflower (*H. annuus* L.), occur naturally in Manitoba. It could be predicted that diseases would become conspicuous on a native plant grown intensively on a relatively large scale. Various diseases were encountered in 1948, when systematic disease surveys of sunflower fields in Manitoba were initiated (12). Rust was the first to attract serious attention. Descriptions of rust and all the diseases discussed are given by Zimmer and Hoes (17).

Rust

Rust (*Puccinia helianthi* Schw.) was the most prevalent disease observed in 1948 but caused little injury in commercial fields. In 1951, rust appeared early and losses were severe; yields averaged only 300 kg/ha, compared with the 650–800 expected. The sunflower area dropped to about 1,500 ha in 1952 as a result. The situation in Canada was not unique. Described first from the southeastern United States in 1822, rust occurs everywhere in the world where sunflowers are grown; severe losses have been reported in many countries for many years (Fig. 2). Fungicide control of rust is possible but usually not economical. The only practical way to control sunflower rust is with resistant varieties. Unfortunately, all the varieties available from Europe and South America were susceptible.

In 1949, one plant resistant to rust was found in an experimental plot at Altona, Manitoba; a second was found at

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Fig. 1. World distribution of sunflowers: ★ Primary center of evolution of *Helianthus annuus* in North America and secondary center of evolution of sunflowers with high oil content in USSR. ⋆ Primary centers of world-significant sunflower research. ✱ Major sunflower-producing areas.

Morden, Manitoba, in 1950 and a third, at Altona in 1952. All three originated from seed produced by open-pollinated plants grown as a winter generation at the Texas Research Foundation, Renner, by scientists cooperating in the Canadian plant breeding program. Characteristics of the three resistant individuals indicated that all resulted from accidental outcrossing with wild *H. annuus*, the only annual sunflower growing wild near Renner. An intensive program of plant breeding and testing of rust reactions in Canada and of winter increases in Texas, Peru, and Chile of progenies of the 1949 discovery resulted in the production of a synthetic variety, released in Manitoba in 1956 as 'Beacon', the first rust-resistant variety of sunflowers ever to be made available to growers (10).

Genetic studies indicated that resistance was controlled by two nonallelic dominant genes: R_1 in the plant discovered in 1950 and R_2 in those discovered in 1949 and 1952 (10,11). The presence of two genes for rust resistance made it possible to differentiate four "races" or race groups of rust (13). Use of these races, in turn, made it possible to identify the resistance genes present in various sunflower lines and progenies.

All four races were present in farm fields or plant breeding plots in Manitoba in 1955, a year before the first resistant variety was widely grown by farmers. R_1 in particular and R_2 to a lesser extent have since been incorporated into sunflower varieties, inbred lines, and hybrids around the world. Appropriate races or virulence genotypes might have been expected to increase and render these resistance genes useless in a relatively short time. This has not yet occurred, although it may be happening in Argentina (A. Luciano, *personal communication*) and Australia (J. Kochman, *personal communication*).

The long-lasting success of breeding for rust resistance may have engendered mistaken complacency in some. It was obvious very early that the apparently simple situation of two nonallelic genes for resistance and four races was much more complex; both host and pathogen have undescribed gene pools, and the inheritance of resistance and of pathogenicity may not be as uncomplicated as it first seemed.

Verticillium Wilt (Leaf Mottle)

Verticillium wilt (*V. dahliae* Kleb.) (Fig. 3) was described in the 1948 survey as "leaf mottle" and was attributed in 1956 to *V. albo-atrum* Reinke and Berth., new on sunflowers in North America (16). It was prevalent in 1954, reducing yields by 50% or more in severely affected fields. It is known to be present in most major sunflower-producing areas of the world (17) and continues to extend its geographic range (*personal observations*). Although considered one of the most serious diseases in Manitoba and North Dakota in the 1960s and early 1970s and a major disease in parts of Europe, it is now regarded as relatively minor elsewhere.

The pathogen almost certainly achieved worldwide distribution in infected seed. Once introduced, the pathogen is soilborne and persistent. Strains attacking sunflowers appear specialized but can infect other hosts. Growing sunflowers repeatedly or in short rotations markedly increases inoculum levels and may result in severe outbreaks of Verticillium wilt, but longer rotations do not guarantee freedom from the disease.

Resistance reported in Canadian breeding material in 1958 appeared to be under various forms of genetic control. Dominant monogenic resistance, dominant susceptibility, lack of dominance, and heterosis for resistance were all evident (9). Resistance to *Verticillium* was found to be common and widespread in wild annual sunflowers, particularly near their reputed evolutionary center of origin in the south central Great Plains of the United States.

While the Canadian sunflower breeding program was incorporating disease resistance and selecting lines with approximately 30% oil content in the seed, remarkable advances were being made in the USSR. V. S. Pustovoit, working at Krasnodar in southern Russia, broke through the 33% oil content "barrier" in about 1940. For the next 20 years he increased oil content by about 1% per year on the average, while maintaining or improving seed yield and agronomic type (8). The high-yielding, high-oil Russian varieties spread into the socialist bloc countries in the late 1950s and to western Europe and North America in the 1960s. In the 1950s, average yields of 700–1,000 kg/ha for Manitoba were considered good; in 1975, disease-free fields of the new varieties ranged from 900 to 2,000 and averaged 1,350 kg/ha. Sunflowers had become economically attractive.

Although seedlings of Russian oilseed varieties available in 1963 were susceptible to Verticillium wilt, varieties tested in the field in the 1970s were less susceptible than American nonoilseed types. Resistance in selected inbred lines appeared to be conditioned by a single dominant gene. Its relationship to the dominant gene for resistance encountered earlier in Canada is not known (2). If and when the pathogen changes, causing the resistance to "break down," the gene pool in the wild annual species can be drawn on for new sources of resistance.

Downy Mildew

Downy mildew (*Plasmopara halstedii* [Farl.] Berl. et de Toni) was described in the northeastern United States in 1882. Its potential for destructiveness when moisture is adequate after sowing (50–95% of plants in severely affected fields) has made downy mildew one of the major diseases of sunflowers in many parts of the world (14,17). The pathogen has been found in most areas where sunflowers are widely grown except Australia and possibly South Africa. The pathogen is seedborne, but most infection arises from soilborne inoculum (7).

Resistance to downy mildew in lines produced at Morden was reported in Canada in 1964. Vranceanu and Stoenescu in Romania identified a single dominant gene for mildew resistance (later designated Pl_1) derived from Canadian material. It appeared to be closely linked to the R_1 rust-resistance gene (17). A line derived by Kinman in Texas from Canadian material with the R_2 rust-resistance gene proved resistant to mildew in tests in North Dakota, in which lines with Pl_1 were susceptible. Resistance to the "Red River" race of mildew, also effective in Europe, was attributed to a single dominant gene, Pl_2, inherited independently of R_2. Genes Pl_3 and Pl_4, identified later by workers in France, behave like Pl_1 and Pl_2, respectively (17).

Pl_2 is being used to give mildew resistance in breeding programs in many parts of the world. The Red River race, or a comparable one, has been reported in southern Russia, Romania, and Italy, originating either from imported seed or by mutation. If a mutation in the Red River or comparable races enabled them to overcome the Pl_2 gene, sunflowers everywhere would be potentially susceptible to downy mildew. What appears to be such a mutation was encountered in one location in Minnesota and one in South Dakota in 1980 (G. N. Fick, *personal communication*).

A pool of undiscovered genes for resistance to downy mildew may exist in the numerous wild species of *Helianthus* in North America. All tests so far have been limited to a few individuals of any species. Working with adequate numbers of many species and making the appropriate genetic studies on an adequate scale would be a time-consuming and expensive undertaking but is essential to find resistance to downy mildew and various other sunflower diseases. A quarantine facility would be required to study reactions to isolates from various areas.

Various fungicides have been tested for controlling downy mildew. None tried before 1978 was effective against seedling infection. The new systemic metalaxyl gave excellent control as a seed treatment and "cured" infected plants in the laboratory and in field plots (15) (Fig. 4). Resistance to metalaxyl has developed in several pathogens; it may take longer to arise against a soilborne pathogen with only one effective generation in most seasons.

Sclerotinia Wilt and Rot

Sclerotinia sclerotiorum (Lib.) de Bary causes root and basal stem rot and wilt of sunflowers and also head rot (Fig. 5). Basal stem rot and wilt, found in some fields every year of the survey in Manitoba, usually affected less than 1% of the plants; in one or two fields each year, however, from 10 to 25%, and occasionally up to 50%, of the plants were affected. In the 1970s (17), up to 95% of plants had basal rot and wilt and some had head rot.

Sclerotinia infection is now considered the most dangerous disease of sunflowers in northern North America. It has long been a major disease in European countries with plentiful rainfall and high yields (14). Under particularly favorable conditions, head rot may affect 80% or more of the plants in parts of France and in late-sown crops in Chile and Uruguay. *Botrytis cinerea* induces the same type of head rot as *Sclerotinia* under similar conditions and is also a major pathogen in some parts of Europe (14).

The wide host range and lack of specialization of the pathogen make it difficult to control by crop rotation. The probability of selecting resistant strains within a host species is also reduced. Differences in susceptibility among breeding lines have been demonstrated in France and in Yugoslavia, however, and are being exploited in breeding programs. The possibility of biological control using hyperparasitic fungi is being investigated at Morden.

Fig. 2. Sunflowers killed by rust in the field. (Inset) Severe rust infection on sunflower leaves in the field.

Plant pathogens, like many other organisms, tend to occupy available ecological niches for which they are adapted. *Sclerotinia* and *Botrytis* head rots are rarely if ever encountered in warm, arid regions or seasons. Head rot does occur under such conditions, and in North and South America, the Mediterranean basin, and Australia, the pathogen responsible is usually some species of *Rhizopus*. Effective and economical control of Rhizopus head rot of sunflowers grown under irrigation by spraying with fungicides has been reported in Israel, but the method is not in general use elsewhere.

Charcoal Rot

Charcoal rot (*Macrophomina phaseolina* [Tassi] Goid.) is the major component of the complex known as *peste negra* in Argentina and Uruguay (Fig. 6). Elsewhere it is a major cause of so-called premature ripening in hot dry areas or seasons, although this condition also is a complex with different causes in different areas.

M. phaseolina grows best and attacks the species in its very wide host range best at temperatures near or above 30 C. The pathogen is present in the soil in most warm countries of the world and attacks the roots and basal stems of host plants. Although seedlings can be killed rapidly under suitable experimental conditions and in the field, the pathogen's effects are not usually evident until plants are beginning to mature. If moisture supplies are adequate, sunflowers may not show symptoms of charcoal rot even if the pathogen is on and in the roots. Plants that suffer drought stress and high temperatures may ripen prematurely, with small heads, poorly filled seed, and much reduced yields.

Not a factor in northern North America, the disease can be significant in the southern United States and is extremely destructive during some seasons in Argentina and Uruguay. The pathogen was found on sunflowers in the USSR in the 1930s but was first recognized in Yugoslavia after 1960 and in various Mediterranean countries after 1970, as sunflower growing expanded and pathologists began devoting attention to the crop (14). The disease is significant in Australia and in South Africa.

As with *Sclerotinia*, expecting resistance within a host species to a relatively unspecialized pathogen with an extremely wide host range may not seem logical. Differences in reaction have been observed among varieties, however, and some lines appear to have high resistance. Controlling the disease by plant breeding may prove possible.

Leaf Spots

Leaf spots have attracted some attention but have caused relatively little concern until recent years. *Septoria helianthi* Ell. and Kell. has been recorded in various parts of the world and reportedly can reduce yields.

Alternaria zinniae Pape was first described as a pathogen of sunflowers in Manitoba in 1963 and has since been found in most parts of the world, proving

Fig. 3. Verticillium wilt of sunflower in a disease nursery in Canada.

Fig. 4. Recovery of metalaxyl-treated sunflower plants naturally infected with downy mildew in a field in Spain; untreated plants in the foreground. (Inset) Typical stunting and leaf symptoms of downy mildew in the field.

Fig. 5. Severe Sclerotinia stem rot in the field. (Inset) Sclerotinia head rot in a breeding nursery in Canada.

destructive in some years. Bacterial leaf spots have been reported in Canada, Mexico, Japan, and other countries but have not been considered major problems so far.

Alternaria helianthi (Hansf.) Tubaki and Nishihara, the most recent leaf-, stem-, and head-spotting pathogen to attract attention, appears to be by far the most threatening (14). It is present in Asia, Australia, Argentina, and various countries in eastern Europe, being particularly destructive in Yugoslavia. Although the pathogen had not been reported in North America prior to 1978, Zimmer and Hoes pointed out that "seedborne inoculum from other continents is a potential danger to sunflower on this continent" (17). The potential became an actual danger in 1980. Damage by *A. helianthi* was sufficiently severe in humid north central (Wisconsin) and southeastern (Florida) areas of the United States that serious reservations were expressed about the crop's future.

Leaf spots of sunflower can be controlled by spraying with appropriate fungicides. The use of this control measure will be determined more by economic considerations than by its effectiveness. Differences in reaction to *A. helianthi* infection in plant breeders' lines have been reported (Fig. 7). No varieties or hybrids resistant to the disease have been released yet but almost certainly will be. Almost as surely, physiologic specialization will be encountered in the pathogen, and plant breeders and pathologists will start running on still another treadmill.

Conspicuous by Insignificance

Sunflower growers and breeders undoubtedly believe the crop has at least a fair share of serious diseases. Plant pathologists, aware that well over 20 species of fungi plus assorted bacteria and viruses were recorded on sunflowers in a 1960 U.S. checklist and a 1967 Canadian checklist and that a host index for the years 1921 to 1961 listed over 80 species worldwide, cannot help but wonder why more pathogens have not become important.

One particularly intriguing example is *Albugo tragopogonis* (Pers.) S. F. Gray, which induces white blister rust (Fig. 8). Recorded long ago on sunflowers in the United States, the disease has not been reported in the present area of commercial sunflower production in North America but is conspicuous some years in South America, Australia, and South Africa. *Albugo* requires free water and fairly cool temperatures for long periods to infect the leaves. Conditions must be suitable in at least some parts of the commercial sunflower area in the United States and Canada; *A. tragopogonis* has been reported on species of *Ambrosia*, a common weed, throughout both countries, so it may attack sunflowers eventually. High levels of resistance are available, however, and the disease may be controlled by breeding when and if necessary.

Virus diseases have been relatively inconspicuous in sunflower fields, although young plants have proved susceptible to a range of viruses in laboratory studies. The only virus disease reportedly causing severe losses, the *peste negra* in Argentina, later proved to be a case of mistaken identity. Reports of specific virus infections and of viruslike symptoms from a number of countries may indicate that pathologists and breeders alike should be watchful rather than complacent.

Broomrape (*Orobanche cumana* Wallr. and other species), a parasitic higher plant that infects sunflower roots (Fig. 9), has been a limiting factor in sunflower production in the USSR and other eastern European countries from time to time (14). Three times in this century, resistant varieties succumbed as new races of the parasite appeared and became widespread. Broomrape has not been reported on sunflowers in North America, although species of *Orobanche* are known to parasitize various wild plants as far north as Canada. Climatic conditions may prevent or limit the parasite's development in North America—or someday, like so many other weeds and pathogens, it may find a home on this continent.

Hybrid Sunflowers

Extremely important genetic discoveries were made concurrently with breeding for resistance. Leclercq in France reported in 1966 genetically controlled male sterility that could be used together with seedling marker genes to produce hybrid sunflowers. Leclercq's announcement in 1969 (6) of the discovery of cytoplasmic male sterility (Cms) was followed shortly by the discovery of fertility-restoring genes by workers in Canada and by Kinman in Texas (5).

Single-cross hybrids can give even higher yields and oil content than the USSR varieties. They can also be made disease resistant; dominant genes for resistance to rust, Verticillium wilt, and downy mildew have been incorporated into some of the inbred parent lines. Use of hybrids has led to an explosion of the area devoted to sunflowers. By 1979 the United States had over 2 million ha, second only to the USSR.

Leclercq's Cms gene and Kinman's fertility restorers have been used in most sunflower breeding programs in the world. New restorer lines have been found in various countries. The sources of Cms, just as the sources of downy mildew resistance, are very limited, creating the same sort of potentially dangerous situation that exists for various other crops (4).

What Does the Future Hold?

Sunflower is not the only crop to experience a tremendous "boom" in North America during the last 50 years, but it is the only native to go abroad, make good, and return home a hero, continuing to achieve new heights.

Prior to 1960, I was the only pathologist in North America—and one of two or three in the world—devoting a major part of his time to studying sunflower diseases. Now pathologists are working on sunflowers at experiment stations, at universities, and with private seed companies throughout the world. The results are predictable: New disease problems will be discovered and some of the existing and new problems will be resolved.

A critical question is: Will diseases become limiting factors in sunflower production on a wide scale? The answer is difficult, but some important considerations are obvious. If sunflower is treated as a speculative crop, to be grown year after year on the same fields while cash returns are good, the results almost certainly will be disastrous. If the desire for immediate gain is tempered by the realization that a range of reliable crops is worth having in the future as well as in the present, and if long rotations and other sound cultural practices are followed as a result, the long-term prospects for the crop may be good.

Advances in plant breeding often depend on the introduction of new germ plasm from other countries, with the possibility of importing new pathogens or new races with the seed. Establishment of a new crop usually involves importation of large quantities of seed from abroad. The proliferation of multinational seed companies, some with their own plant breeding programs, implies the transfer from one country to another of

Fig. 6. *Peste negra* (*Macrophomina phaseolina*) of sunflowers in a breeding nursery in Argentina; resistant lines in the background.

Fig. 7. Sunflowers defoliated by *Alternaria helianthi* in a breeding nursery in Australia; resistant lines in the background.

Fig. 8. Severe white blister rust infection on sunflower leaf in the field.

Fig. 9. Broomrape growing from roots of parasitized sunflowers in the field.

commercial lots of seed of new varieties, as well as of breeding materials. The attendant risks may be more obvious to pathologists than to company management—or even to some plant breeders. Strict and enforceable quarantines, based on well-documented information about pathogen biology, may help to protect the crop from some new diseases in some areas. A quarantine research facility outside any major sunflower area, where pathogens from various countries could be compared and critical breeding materials tested, would be a valuable asset.

Breeding programs to incorporate several genes effective against each disease important in specific areas may provide the best protection for the crop in some cases. The value of searching for resistance genes in wild populations near the center of host origin was pointed out long ago by Vavilov and has been confirmed by modern work with sunflowers. Only a small, hesitant start has been made at tapping the riches of the gene pool of wild *Helianthus* spp. in North America. A miniscule proportion of the sums spent in the search for nonrenewable mineral oil might yield vast riches if devoted to exploring for ways to assure and increase the production of renewable sources of sunflower oil, with its protein and other by-products.

What is the point of this superficial survey of the history and disease problems of one of the newest food crops to achieve prominence on a world scale? It can be stated simply: The current success of sunflowers was made possible only by the contributions of individuals in many countries. Without that international cooperation, sunflower would still be a minor crop in North America, significant in the USSR, eastern Europe, and Argentina because of local conditions, and a curiosity elsewhere. Because of that cooperation, sunflower is now the second most important source of edible vegetable oil in the world and may be on the threshold of expanded production for uses still in the planning stage or as yet undiscovered.

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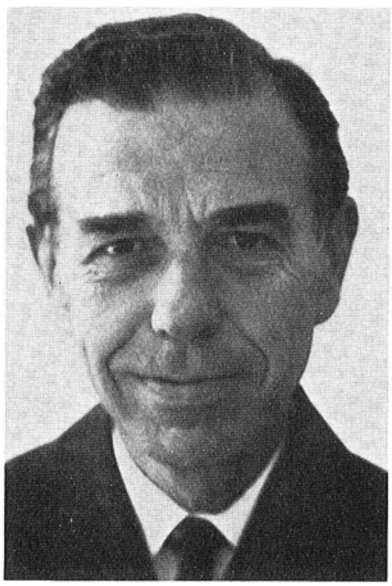

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