the southern USA with a generally warmer climate has a higher oleic acid percentage, but rarely do these percentages exceed 40.

Recently, sunflower lines have been identified that produce oleic acid percentages of ca. 80% and as high as 90% on an individual plant basis. The high oleic lines do not appear to be temperature-sensitive, as oleic acid percentages fluctuated only 3-4 percentage units when grown in widely varying climates.

The high oleic oil from these hybrids should help create new markets for sunflower oil especially in the deep-fat frying industry, as a substitute oil in export channels, and for chemical and industrial purposes. Limited production of high oleic hybrids is expected as early as 1983.

Disease Problems of Sunflowers

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ABSTRACT

Sunflower, the second most important oilseed crop in the world, was developed as a crop in eastern Europe, but is a native of North America. The pathogens causing many of its major diseases are also native to North America. Although a profitable crop, sunflowers have fairly low value per hectare. Disease control must, therefore, be inexpensive, by resistant varieties or seed treatment or cultural practices, rather than repeated field application of chemicals. Rust, a limiting factor in many countries, has been successfully controlled everywhere by resistance from wild sunflowers discovered in Canada about 1950. New races are posing problems in Argentina and Australia, but new resistance may be available. Verticillium wilt has been destructive in some areas but resistance is available from wild sunflowers and Russian high-oil varieties. Downy mildew, highly destructive in many countries, has been effectively controlled by two genes from the original rust-resistant material. A new race attacking this resistance was discovered in 1980: resistance to it appears to be available. Sclerotinia stalk rot and head rot, caused by a pathogen with wide host range, is much harder to control by breeding. Leaf spot diseases have long been a limiting factor in some European countries and elsewhere, but were considered minor in North America until recently. Broom rape, a root parasite which almost destroyed the crop in the USSR and elsewhere in eastern Europe, does not attack it in North America. It is controlled by resistant varieties.

INTRODUCTION

Sunflowers (*Helianthus annuus*) are native to North America; many wild species occur from Canada to Northern Mexico. Taken back to Europe by the first explorers and conquerors, sunflowers were long considered merely ornamental until they were developed as a source of edible oil in Russia in the 19th century. The crop spread from there to eastern Europe, Argentina, and limited areas elsewhere (1). After the release of high-oil varieties by the USSR, sunflower growing began or increased in many countries. After the discovery of cytoplasmic male sterility (2) and restorers (3) which made production of hybrid sunflowers practical, the crop rapidly assumed major importance worldwide, second only to soybeans among the annual oilseeds (4, 5).

Sunflowers are highly adaptable and can yield well from beyond 50° north of the equator to 40° south of it. Any crop grown over such a range will encounter tremendous variability in soil, climate and weather. Even where environmental conditions are favorable, there may be hazards. These include market and other economic factors, bird and insect predation, weeds and diseases.

DISEASES: CAUSES AND CONTROLS

Disease of plants may be caused by such diverse agencies as environmental factors, fungi, bacteria, viruses, nematodes and parasitic higher plants. Fungi cause most of the diseases which have been destructive on sunflowers in various countries (6). Like sunflowers, many of their fungal pathogens appear to be native to North America. Unfortunately, some of the most destructive have spread with seed or by other means and now affect sunflowers almost everywhere that they are grown. Some diseases which are destructive in other parts of the world have not yet attacked sunflowers in North America, but at least one of them has appeared here recently (6, 7).

New or foreign diseases may sometimes be kept out of a country, or their introduction may be delayed, by well designed quarantines or embargoes. Control of diseases present in the country may be attempted by cultural practices, such as crop rotation; by the use of appropriate chemicals; and by breeding resistant varieties. The choice of control measure may be dictated not only by what is biologically possible, but also by what is agronomically desirable, or economically feasible.

Sunflowers have been a profitable crop for many growers in the last ten years, but their value per unit area is relatively low. Average production costs and average yields under good management were calculated for 1978 for North Dakota (8). Using those values and average prices received by US farmers from 1977/78 to 1981/82 (4), the net returns during those five years varied from ca. $15 to $75 per hectare. Because of such narrow profit margins, sunflower growers cannot consider the repeated applications of chemicals to control disease which are normal in growing crops such as potatoes or apples. They must depend on other means of disease control.

Agronomic practices may be very useful in reducing damage from some diseases. Appropriate date of seeding, depth of seeding, etc., may help reduce disease losses. Rotation with appropriate nonhost crops can give good control of some pathogens. Seed treatment with chemicals is much cheaper and easier than field applications of chemicals, and can be useful in some cases. A single well timed field application of fungicide may be economic in some instances. The most desirable control, and cheapest and easiest for the growers, is the use of resistant varieties where possible.

Close to 100 species of microorganisms and viruses have been reported on sunflowers throughout the world, and about 30 in North America (9). Ten to twelve diseases are described as major problems in various countries (10); half of them are important in North America. As the first commercial production of sunflowers for edible oil in North America started in Canada, in Southern Manitoba, and sunflower breeding and disease research programs were established there, I shall discuss diseases in the order in which they assumed priority in those programs, then add some of major interest elsewhere. All but the last disease to be discussed are caused by fungi.

Rust

Rust, caused by *Puccinia helianthi,* occurs almost everywhere in the world that sunflowers are grown and has been extremely destructive in areas with adequate rainfall during the growing season (11). It destroys leaf tissues and can reduce yields very markedly. The pathogen spreads from plant to plant and field to field by spores which can be carried by wind for long distances. It also produces a special spore form which can overwinter on infected stems and other debris even in cold climates, and give rise to infections on seedlings the following spring. Crop rotation can reduce the danger of infection on young seedlings and delay the beginning of an epidemic. It cannot provide complete control. Rust can be controlled by repeated applications of fungicides, but this is usually uneconomic.

Rust almost destroyed the young sunflower industry in Manitoba in 1951. The timely discovery of resistance derived from wild sunflower species and release of the first rust-resistant varieties brought the disease under control (12). The two genes for resistance encountered in Manitoba (13) have been used in breeding programs throughout the world.

The identification of two genes for resistance made it possible to distinguish four rust populations or races differing in their ability to attack one or other of the genes (14). All four races were identified from the field soon after the resistance genes were discovered. It might have been expected that races attacking both genes would soon predominate in the field, as has occurred with rust diseases of various other crops. This has not yet happened. In recent years, significant rust damage has been observed on nominally rust-resistant hybrids in Canada (15), Australia (16), and in Argentina (A. Luciano, N. Luciani, personal communications). It is not yet clear if new races are increasing there, or if resistance genes from parents of the hybrids have been diluted or lost. New sources of resistance should be available in wild *Helianthus* species.

Verticillium Wilt

Verticillium wilt was described as "leaf mottle" in Manitoba and the causal agent was later identified as *Verticillium albo-atrum* (now corrected to *V. dahliae*) (17). It has since been found in many parts of the world. The fungus attacks sunflowers through the roots. It can survive in the soil for years, and can also be spread by infected seed (18). Although symptoms normally appear after the plants have flowered, the disease can affect and kill young plants in heavily infested soil, and can reduce yields markedly. It was at one time considered a possible limiting factor to sunflower production in Manitoba, and has been conspicuous and alarming in various other countries (10). Rotation with nonsusceptible crops such as cereals can reduce inoculum levels in the soil, but does not give complete control. Resistance derived from wild species has been incorporated into modern hybrids (19, 20), and high-oil sunflowers from the USSR have good levels of field resistance. A potentially dangerous new race attacking resistant hybrids has been encountered in Argentina (21), and in current work with *Verticillium* from various hosts (W.E. Sackston, unpublished). New sources of resistance should be available from wild *Helianthus* species.

Downy Mildew

Downy mildew, caused by *Plasmopara halstedii,* has been extremely destructive in many countries where moisture is plentiful in the two or three weeks during seed germination and emergence of the seedlings. Australia, the only sunflower-producing continent where the disease has not yet been found, maintains strict quarantine regulations to try to keep it out. Affected plants may die in the seedling stage, or may produce only empty, sterile seeds, or greatly reduce seed yield. The pathogen can survive for many years in infested soil. It may also be transmitted by seed, but as plants from infected seeds usually show no symptoms, such transmission is difficult to identify by simple routine methods. Two, or possibly three, distinct genes for resistance have been identified from wild *Helianthus* species. One or another of these genes has been incorporated into hybrid sunflowers in most parts of the world (22). A new race attacking previously resistant hybrids was found in the USA in 1980 and 1981; resistance to the new race has also been reported (23, 24). Seed treatment with a systemic fungicide was reported to protect seedlings against infection past the susceptible stage (25); it can also be used to control the disease in infected plants in the field, although such treatment is not economic (26).

Stalk Rot and Head Rot

Two distinct diseases, stalk rot or wilt, and head rot, may be induced by the fungus *Sclerotinia sclerotiorum,* in countries and in seasons with adequate moisture during the growing season. Under favorable conditions, losses can be devastating in individual fields, and severe over large regions. The pathogen can survive a year or more in the soil as specialized structures called sclerotia. As it has a wide host range, including many broad-leaved crops and weed plants, crop rotations must include cereals or grasses and be weed-free to be effective against the stalk rot disease. Head rot is induced by wind-borne spores of the fungus, produced on sclerotia at the soil surface. As sclerotia from a heavily infected crop may be numerous at the soil surface the following year even in a nonsusceptible cereal crop, crop rotation does not guarantee freedom from infection (27). Differences in varietal reactions have been reported (28, 29), but it has not yet been possible to produce resistant varieties. Interesting preliminary work has been reported on the possibility of biological control of sclerotia in the soil (30).

Leaf and Stem Spots

Leaf and stem spot diseases may be caused by a number of different fungi. Although sometimes conspicuous, they have not been considered of major importance in North America in the past. The situation is different in Europe, Australia and Argentina. Several leaf spot diseases constitute major problems in Yugoslavia (10). One of them, caused by *Alternaria helianthi,* is also of major concern in Australia and Argentina. Although not recognized in North America as late as 1978 (11), it was destructive in Florida in 1979 (V.E. Green, personal communication) and in the main sunflower area of the USA in 1980 (7). The pathogen is seed-borne, and can also survive over winter on residues from infected plants. Seed treatment and crop rotation are both recommended, but do not give complete protection as spores of the fungus may also be carried by wind. A single well timed application of fungicide when conditions favor an outbreak has been suggested as being economically feasible in Australia (31). Differences in varietal reactions have been observed, but resistant varieties are not yet available.

A new leaf and stem disease caused by *Diaporthe (Phomopsis) helianthi* was found in Yugoslavia in 1980 for the first time, and was destructive over a wide area in 1981 (32). There are indications of resistance in the progeny of crosses with wild *Helianthus* species.

Charcoal Rot

Charcoal rot caused by *Macrophomina phaseolina* may kill plants prematurely and reduce yield severely in crops suffering from high temperature and drought stress. The pathogen is widely distributed in the soil in warm areas, and affects a wide range of unrelated plants. It is particularly destructive on sunflowers in South America, and the Mediterranean basin of Europe and North Africa (11). It has been conspicuous in Texas, but is not a factor in the main sunflower area of the USA, possibly because of the low winter soil temperatures.

Broom Rape

Broom rapes (*Orobanche* species) are a group of higher plants which parasitize the roots of many plant species, including sunflowers. Broom rape has been a limiting factor in sunflower production in the USSR and other eastern European countries (10, 33). The disease has been controlled by the production of resistant varieties (33). New races of the parasite have appeared three times in this century. Each time a new source of resistance has been found. The disease has not yet been reported on sunflower in North America, although some species of *Orobanche* are known to parasitize various crops in the USA.

Helianthus Species Gene Bank

Most of the genes currently being used to control sunflower diseases have been derived from wild *Helianthus* species. As new races and new species of pathogens keep developing, new genes for resistance will be required. They too will have to come from the same sources. The potential 'gene bank' in wild *Helianthus* species is very large but has been inadequately exploited. Many individual populations of many species must be collected, maintained, and studied intensively by specialists in various locations and disciplines to determine their potential value. A start has been made; collections of wild species are being studied in the USA (34), the USSR (35), and Yugoslavia (36), and elsewhere. Much more effort and money must be invested in building the "gene bank account" to permit "withdrawals" to be made from it when necessary.

REFERENCES

1. Heiser, C.B., Jr., in Sunflower Science and Technology, Agronomy 19, edited by J.F. Carter, Am. Soc. Agronomy, Madison, WI, 1978, pp. 31–53.
2. Leclercq, P., Ann. Amélior Plant. 19:99 (1969).
3. Kinman, M.L., in Proc. 4th Int. Sunflower Conf., Memphis, TN, 1970, pp. 181–183.
4. Doorn, J.J.L. van Waalwijk van, Keynote address, 10th Int. Sunflower Conf., Surfers Paradise, Australia, 1982, 10 pp.
5. Putt, E.D., in Sunflower Science and Technology, Agronomy 19, edited by J.F. Carter, Am. Soc. Agronomy, Madison, WI, 1978, pp. 1–20.
6. Sackston, W.E., Plant Dis. 65:643 (1981).
7. Sperbeck, J., Seedling Blight Found in Minnesota, Sunflower Oct/Nov:40, Sunflower Association of America, Fargo, ND, 1980.
8. Cobia, D.W., in Sunflower Science and Technology, Agronomy 19, edited by J.F. Carter, Am. Soc. Agronomy, Madison, WI, 1978, pp. 387–405.
9. Anon., Plant host-pathogen index: Review of Applied Mycology, Commonwealth Mycol. Inst. Kew, Surrey, England, 1968.
10. Sackston, W.E. in Proc. 8th Int. Sunflower Conf., Minneapolis, MN, 1978, pp. 7–29.
11. Zimmer, D.E., and J.A. Hoes, in Sunflower Science and Technology, Agronomy 19, edited by J.F. Carter, Am. Soc. Agronony, Madison, WI, 1978, pp. 225–262.
12. Putt, E.D., and W.E. Sackston, Can. J. Plant Sci. 37:43 (1957).
13. Putt, E.D., and W.E. Sackston, Ibid. 43:490 (1963).
14. Sackston, W.E., Can. J. Bot. 40:1449 (1962).
15. Hoes, J.A., in Proc. Sunflower Forum and Workshop, Sunflower Association of America, Fargo, ND, 1981, p. 15.
16. Kochman, J.K., and K.C. Goulter, in Proc. 10th Int. Sunflower Conf., Surfers Paradise, Australia, 1982, pp. 149–151.
17. Sackston, W.E.,W.C. McDonald and J. Martens, Plant Dis. Rep. 41:337 (1957).
18. Sackston, W.E., and J.W. Martens. Can. J. Bot. 37:759 (1959).
19. Fick, G.N., and D.E. Zimmer, Crop Sci. 14:895 (1974).
20. Putt, E.D., Crop Sci. 4:177 (1964).
21. Bertero, A.B., and A.N. Vazquez, in Proc. 10th Int. Sunflower Conf., Surfers Paradise, Australia, 1982, pp. 177–178.
22. Sackston, W.E., in The Downy Mildews, edited by D.M. Spencer, Academic Press, London, New York, San Francisco, 1981, pp. 545–575.
23. Fick, G.N., and G.E. Auwarter, in Proc. Sunflower Forum and Research Workshop, Sunflower Association of America, Fargo, ND, 1981, pp. 15–16.
24. Fick, G.N., and G.E. Auwarter, in Proc. 10th Int. Sunflower Conf., Surfers Paradise, Australia, 1982, pp. 175–177.
25. Sackston, W.E., The Sunflower Newsletter, International Sunflower Association, Zevenaar, Netherlands, 4(3):7 (1979).
26. Melero-Vara, J.M., C. Garcia-Baudin, C.J. Lopez-Herrera and R.M. Jimenez-Diaz, Plant Dis. 66:132 (1982).
27. Nelson, B., in Proc. Sunflower Forum and Research Workshop, Sunflower Association of America, Fargo, ND, 1981, p. 14.
28. Gulya, T., in Proc. Sunflower Forum and Research Workshop, Sunflower Association of America, Fargo, ND, 1981, pp. 13–14.
29. Huang, H.D., in Proc. Sunflower Forum and Research Workshop, Sunflower Association of America, Fargo, ND, 1981, p. 13.
30. Huang, H.C., Can. J. Bot. 55:289 (1977).
31. Allen, S.F., J.F. Brown and J.K. Kochman, in Proc. 10th Int. Sunflower Conf., Surfers Paradise, Australia, 1982, pp. 142–144.
32. Mihaljcevic, M., M. Muntanola-Cvetkovic and M. Petrov, in Proc. 10th Int. Sunflower Conf., Surfers Paradise, Australia, 1982, pp. 157–159.
33. Pustovoit, V.S., in Handbook of Selection and Seed Growing of Oil Plants, (translated from Russian), U.S. Dept. of Agriculture, Washington, DC, 1967, pp. 4–35.
34. Thompson, T.E., C.E. Rogers, D.C. Zimmerman, H.C. Huang, E.D.P. Whelan and J.F. Miller, in Proc. 8th Int. Sunflower Conf., Minneapolis, MN, 1978, pp. 501–509.
35. Pustovoit, G.V., in Proc. 2nd Int. Sunflower Conf., Morden, Canada, 1966, pp. 81–100.
36. Cuk, L., in Proc. 10th Int. Sunflower Conf., Surfers Paradise, Australia, 1982, p. 211.