Threats to Soybean Production in the Tropics: Red Leaf Blotch and Leaf Rust

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U.S. agriculture, as well as that of other countries, is continually threatened by the introduction of destructive pathogens that are not established in the area. A classic example from U.S. agricultural history is the introduction and eradication, then reintroduction in 1984, of *Xanthomonas campestris* pv. *citri* (Hasse) Dye, the causal bacterium of citrus canker in *Citrus* and other species (16,17). Another example is the introduction into the United States in 1979 of *Puccinia melanocephala* H. & P. Sydow, causal fungus of sugarcane rust in interspecific hybrids of *Saccharum* (15). The devastation caused by these pathogens and others is legendary. Many other examples could be given.

Two primarily foliar diseases of soybeans (*Glycine max* (L.) Merr.) do not occur in the United States: red leaf blotch (Pyrenochaeta leaf spot, Dactuliophora leaf spot), caused by *Dactuliochaeta glycines* Hartman & Sinclair [syn. *Pyrenochaeta glycines* Stewart] (=*Dactuliophora glycines* Leakey), and leaf rust, caused by *Phakopsora pachyrhizi* Sydow (8,18). Both pathogens are indigenous on wild hosts in the tropics and subtropics, where soybeans were introduced as a new host. Both diseases cause yield losses by premature defoliation. Neither pathogen appears to be seedborne in soybeans. Introduction of either pathogen into the United States or any country where it does not occur could threaten soybean crops and perhaps, in the case of leaf rust, other wild and cultivated legumes (11).

Red Leaf Blotch

The disease and causal fungus were first described on soybeans in 1957 by Stewart (19). In 1964 Leakey (13) described the sclerotial state, *Dactuliophora glycines*, and in 1986 Datnoff et al (2) showed that *Dactuliophora glycines* was a sclerotial state of *P. glycines*. The disease and its causal fungus have been reported on a perennial relative of soybeans, *Neonotonia wightii* (Arnott) Lackey (12), in Ethiopia, Zambia, and Zimbabwe; *N. wightii* also is an alternative host of the soybean leaf rust pathogen. Red leaf blotch has been reported on soybeans from Cameroon, Ethiopia, Malawi, Ruwanda, Uganda, Zaire, Zambia, and Zimbabwe (7,18), and there is an unconfirmed report from Nigeria. The only record of *Dactuliochaeta glycines* on soybeans outside of Africa is among mycological leaf collections from Bolivia made by Waller in 1982, now at the Commonwealth Mycological Institute Herbarium, Kew, Surrey, England. Hartman et al (7) and Hartman and Sinclair (8) have reviewed the literature and research concerned with the disease on soybeans through 1988.

The occurrence of the disease has increased concomitantly with the increased production of soybeans in southern Africa since the early 1970s, particularly in Zambia and Zimbabwe. In 1985, soybean production was approximately 26,000 t on 15,000 ha in Zambia and 84,000 t on 42,000 ha in Zimbabwe. The disease causes severe leaf blotching and defoliation. In 1977, a 50% reduction in yield caused by the disease was reported from Zambia, and in 1985, a 34% reduction in yield over approximately 24% of the growing area was recorded (3,7,8). In Zimbabwe, losses ranged from 10 to 50% in Harare and Mashonaland provinces (7,8).

Red leaf blotch appears as lesions on the foliage, petioles, pods, and stems of soybeans during the November–April growing season in Zambia and Zimbabwe. Lesions appear initially on the unifoliolate leaves associated with primary leaf veins. Lesions develop on trifoliolate leaves as dark red spots on the upper leaf surface (Fig. 1A), with similar spots with reddish brown and dark borders on the lower leaf surface.

The disease cycle caused by *D. glycines* has not been fully characterized on either soybeans or *N. wightii*. Soilborne sclerotia may be spread by splashing rain onto leaf surfaces, where germination and infection occur (7). Sclerotia may give rise to mycelium, which in turn produces pycnidia, or pycnidia may develop directly on sclerotia; or a secondary sclerotium may develop on a sclerotium in culture. A similar process may take place in the soil and on leaf surfaces. Pycnidia and sclerotia develop in lesions resulting from infection by *D. glycines*. Heavily diseased leaves drop prematurely, and eventually all the foliage from a diseased plant will drop, releasing the sclerotia back into the soil. These sclerotia probably overseason, providing initial inoculum for the next season. Abundant rainfall and high humidity promote disease development. Yield losses result from reduced seed size and weight (7,8).

There is no experimental evidence that *D. glycines* is seedborne. Incidental transmission may possibly occur through seed lots contaminated with diseased plant debris and/or soil peds carrying sclerotia. Additional studies are needed to assess the importance of seed transmission of this pathogen.

At present, no control measures have been recommended. Over 2,500 lines, cultivars, accessions, and breeding lines were evaluated for resistance in field trials in Zambia and Zimbabwe between 1982 and 1984 (*unpublished*). All commercial cultivars from the United States in these trials were susceptible.

International cooperative research on red leaf blotch. When the ZAMARE Project (a cooperative effort between the Ministry of Agriculture and Water Development in Zambia, the University of Maryland–Eastern Shore, Southern Illinois University at Carbondale, and the University of Illinois at Urbana-Champaign [UIUC]) began in Zambia in 1981, red leaf blotch had been observed on soybeans in that country and in Zimbabwe. As soybean production increased in Zambia, red leaf blotch appeared as a potential threat to the successful establishment of soybeans in the region. A program of research on the disease was initiated that eventually involved the cooperation and collaboration of: 1) soybean breeders from the ZAMARE Project and from the public and private sectors of Zimbabwe, 2) faculty and Ph.D. students from the Department of Crop Science, University of Zimbabwe, and the Department of Plant Pathology, UIUC, and 3) researchers from the Mt. Makulu Research Station, Chilanga, Zambia. Hartman et al (7) summarized some of the research accomplished by these efforts.

International cooperation in studying this disease may eventually involve countries in South America, since the pathogen has been collected from Bolivia. Even though red leaf blotch is not known to occur on soybeans in Brazil or the United States, the pathogen may be introduced and become established

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because of favorable environmental conditions and the susceptibility of present-day cultivars. It is important that researchers in the countries where the disease occurs collaborate with agricultural scientists in countries where soybeans are grown extensively and in which the environment is suitable for establishment of the disease. Control methods developed in Africa and other areas where the fungus and the disease are found will be of significant use not only in those countries but also in countries where the disease may become established in the future.

Leaf Rust

Soybean leaf rust, first reported in Japan in 1903, now occurs in the tropics and subtropics of the Eastern and Western hemispheres. The disease is a major constraint to growing soybeans in the Eastern Hemisphere (1,4), being widely distributed in the Soviet Union to the north, in Australia to the south, and in India and Nepal to the west (1,9,11,14,18). It may be one of the reasons why soybeans have not been established as a major crop in the tropical areas of the Orient. The leaf rust fungus in the Western Hemisphere, although morphologically similar to that in the Eastern Hemisphere, is less virulent. It was first reported on soybeans in Puerto Rico in 1976 and later in Brazil and Colombia (1,22,25). It was known to occur on wild and cultivated hosts in the tropical areas of the region as early as 1913 (1,18,23). In Africa, *Phakopsora pachyrhizi* has been reported on legumes other than soybeans and may represent a forma specialis different from that found in eastern Asia and the Americas (1).

The host range of the pathogen includes at least 87 species in 35 genera, apparently restricted to papilionaceous legumes. Whether the fungus sporulates on all reported hosts needs confirmation, and the role of alternative hosts in soybean rust epidemics needs further investigation.

Soybean rust causes premature defoliation, early maturity, and reduced seed numbers and weight. Qualitative estimations of yield losses range from 3 to 5% in the Yangtze River region of the People's Republic of China, from 10 to 30% on local cultivars in Thailand (with complete losses on some imported cultivars), and from 23 to 80% in Taiwan (1). Experimental field losses in Australia average 23–68% (1).

The most commonly observed symptom of soybean rust is the sporulating lesions on the lower surface of the leaf, although lesions can appear on both leaf surfaces (Fig. 1B) and on petioles and small stems. Without the aid of a hand lens, early stages of lesion development may be confused with the pustules caused by *X. c.* pv. *glycines* (Nakano) Dye or, occasionally, with the brown spot lesions caused by *Septoria glycines* Hemmi. At the onset of the disease, chlorotic to gray-brown or reddish brown spots about 0.5 mm^2 appear on leaves and enlarge to 1 mm^2 or larger polygonal, tan or brown (sometimes reddish brown or purplish brown) lesions. Depending on the isolate of the pathogen and the soybean strain, either reddish brown (RB-type) or tan (TAN-type) lesions appear; both types may develop on the same leaflet of some cultivars (1,18,24).

Pimplelike uredia develop in the lesions and release uredospores through a central pore. More uredia develop on the lower surfaces of leaves than on the upper surfaces. Lesions with uredia increase over time on leaves. Under some conditions, groups of uredia form obvious lesions on tissues that are not discolored. Because the uredospores tend to stick together and form clumps, the disease is referred to as a sticky rust. Premature leaf yellowing and defoliation occur when lesion development is extensive.

Telia form subepidermally, mostly on the abaxial leaf surface among the uredia and at the edge of lesions. Telia are orange-brown or light brown when young, changing to dark brown or black with age. Telia are irregular to round, sparse to aggregated, and about 150–250 μm in diameter, with two to five irregular layers of teliospores. Germination of teliospores has been observed (10).

There is no experimental evidence that *P. pachyrhizi* is seedborne in soybean or other hosts. Incidental transmission may possibly occur through seed lots contaminated with infected plant debris, but this is doubtful because the uredospores are short-lived under dry conditions. Since teliospores have been observed to germinate, they are now considered a potential source of primary inoculum.

Bromfield (1) and Tschanz and Shanmugasundaram (20) reviewed the use of various control measures, host plant resistance, and pathogen specialization. The complex races of *P. pachyrhizi* are often compatible with a

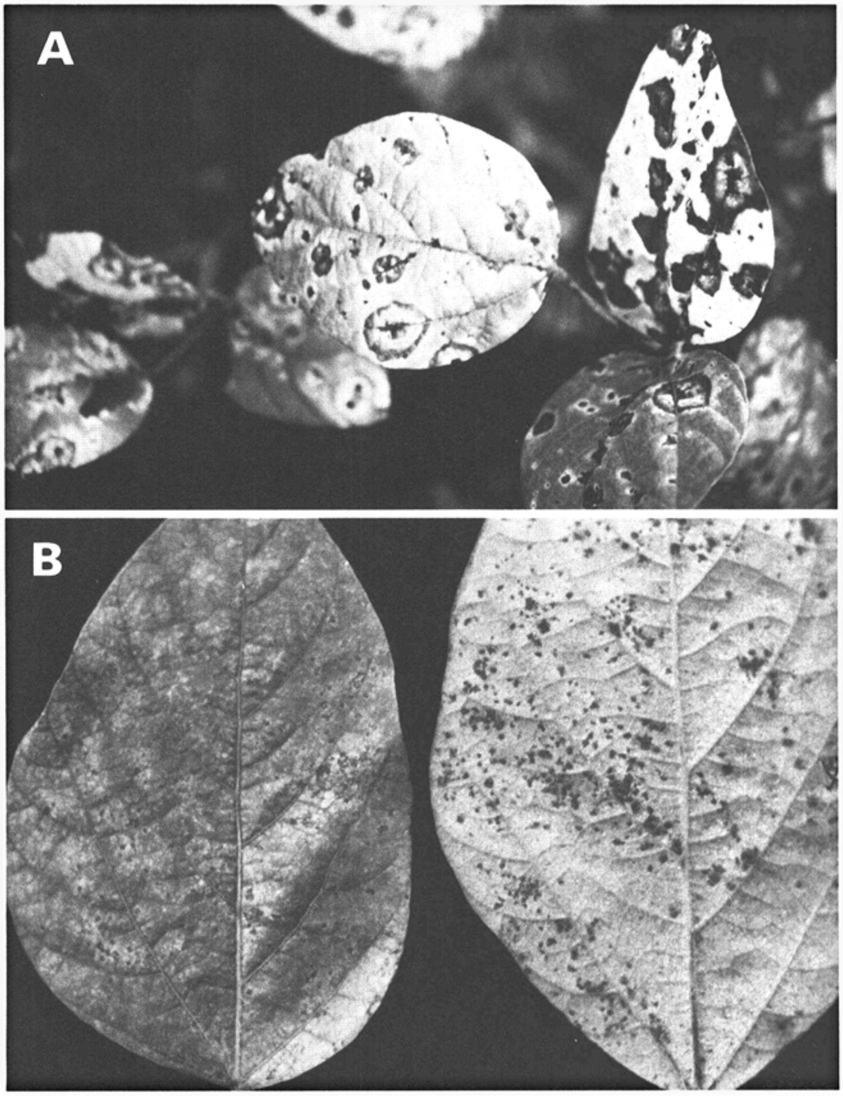

Fig. 1. (A) Symptoms of soybean red leaf blotch, caused by *Dactuliochaeta glycines*, on upper leaf surface. (Courtesy L. E. Datnoff) **(B)** Symptoms of soybean leaf rust, caused by *Phakopsora pachyrhizi*, on upper (left) and lower (right) leaf surface. (From Sinclair and Backman [18])

wide range of known or suspected specific resistance genes in different soybean cultivars (21). These races limit the effectiveness of specific resistance, and there is a need to identify and characterize other forms of resistance or tolerance. However, levels of rust tolerance vary considerably among soybean cultivars with a range of 25–90% yield loss.

International cooperative research on leaf rust. The research and outreach efforts made on this disease are an excellent example of international cooperation. In recognition of the importance of soybean rust and the values gained by international efforts, the International Working Group on Soybean Rust (IWGSR) was formed during the regional soybean conference organized by the International Soybean Program (INTSOY) of UIUC (6), the Asian Vegetable Research and Development Center (AVRDC), Tainan, Taiwan, and the Royal Thai government and held 23–27 February 1976 at Chaingmai, Thailand (5). It was agreed that a systematic, coordinated research, training, and outreach program was needed for many of the Australasian countries where the disease limits soybean production. A year later, 28 February to 4 March 1977, the Asia-Oceania Soybean Rust Workshop was convened in Manila, Philippines, to organize such a program (4). The *Soybean Rust Newsletter* was initiated and is now published by the IWGSR through the Tropical Vegetable Information Service of AVRDC. This publication has become the primary means of disseminating worldwide the results of research and other information concerning soybean rust.

P. pachyrhizi was reported under a variety of synonyms on hosts other than soybeans in the tropics of the Americas and Caribbean Basin (1,18,23). It was reported on soybeans in Puerto Rico in 1913 and in Georgia in 1922 (unconfirmed). These reports were not appreciated until the summer of 1976, when the disease was found in experimental field plots in Puerto Rico (23). After the "rediscovery" of the disease in Puerto Rico, the U.S. Department of Agriculture (USDA) and the University of Puerto Rico, Mayaguez Campus, cosponsored the Workshop on Soybean Rust in the Western Hemisphere, 15–17 November 1976 (23). After the discovery of soybean rust in Brazil, cooperative research has been carried out at the National Soybean Research Center in Londrina, Puerto Rico, and the College of Agriculture of Lavras and the Federal University of Viçosa, Brazil (25).

Soybean leaf rust has not been reported in the United States since the unconfirmed report from Georgia, but to ignore the possibility of its entry and establishment would be unwise. In recognition of this, the USDA's Plant Disease Research Laboratory in Frederick, Maryland, began research on the pathogen and disease in containment facilities in 1971. Bromfield (1) summarized the research from this program, which involved formal cooperative agreements with the universities of Sydney and Queensland, Australia, and AVRDC.

INTSOY, AVRDC, and UIUC collaborated in the sponsorship of a postgraduate student from Taiwan to do a portion of his Ph.D. dissertation research on soybean rust in Taiwan (24). AVRDC and UIUC currently have a collaborative project on the introduction of genes for resistance to *P. pachyrhizi* from wild *Glycine* spp. into *G. max* through the use of biotechnology. A review of the research at AVRDC was published (22).

Collaborative research must be continued on population dynamics, environmental factors, and epidemiology.

Discussion

The examples of informal collaborative efforts among agricultural scientists throughout the world are too numerous to summarize in this short paper. This collaboration is continuing without formal documents or agreements.

Because of the threat imposed by the pathogens that cause leaf rust and red leaf blotch, both continue to be studied in cooperation and collaboration with agricultural scientists in the countries where they do occur. Such activities provide information for agriculturalists of the United States and other countries to use if either pathogen should ever be introduced. In turn, scientists from these countries have shared new technologies for plant disease control with scientists working in the countries where the diseases occur. The knowledge gained from this experience allows officials of the United States and other countries to make intelligent regulatory decisions.

Although the potential threat of these diseases to soybean production in countries where they do not occur has been emphasized, the threat may not be as serious as imagined. Whether or not either pathogen in its present form will move from the humid tropics into temperate regions is an open question. There is always the possibility that new forms will develop on soybeans as cultivation becomes more intense in the areas where the pathogens occur. This has not occurred in the case of soybean rust, however. Rust has been known for many years to occur on soybeans grown in the tropics and subtropics of the Eastern Hemisphere but has not spread into the temperate regions.

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