Soybean Rust: Historical Significance and U.S. Perspective

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Abstract

Soybean rust, caused by *Phakopsora pachyrhizi*, occurs in all major soybean-growing regions of the world except the North American mainland. Soybean rust is one of the most destructive foliar disease of soybean. Yield losses of over 50% can occur when environmental conditions are conducive for disease development and no fungicides are applied. Heavily infected plants defoliate and mature more rapidly than plants not infected with rust. *P. pachyrhizi* has a broad host range and can infect many other legumes including some native to Australia. A number of physiological races of the fungus have been reported on these native legumes from Australia and on soybean. Four single genes for rust resistance were previously identified in four different soybean plant introductions. These sources of resistance also have been reported to be susceptible in some field locations and when challenged with certain isolates of *P. pachyrhizi*. Partial resistance, expressed as reduced pustule number and increased latent period, has also been reported, but has not been widely used in breeding programs. Yield stability, defined as the percentage of yield compared to fungicide control plots, has also been used in the past. Although soybean rust has not been found in the continental U.S., a proactive project to evaluate the USDA soybean germplasm collection for rust resistance was initiated in 2002 at the Fort Detrick BL-3 containment facility and at six international locations. Part of this project is to discover soybean lines with yield stability in the presence of rust, to find additional single genes for resistance, and define and utilize partial resistance. In addition to research on the host, there is also research on fungicide efficacy and application methods. Along with this, research is being developed on the epidemiology and its potential movement into the U.S. Lastly, there is a great deal of activity on educating growers, and scientists from industry and universities about soybean rust diagnosis and management of rust with the use of fungicides.

Introduction

The Asian soybean rust, *Phakopsora pachyrhizi* has been known to occur in Asia and Australia for over 50 years and was first reported in Japan in 1902 (Hennings, 1903). There are numerous reports and summaries about soybean rust in Asia and Australia. All the literature up to 1992 was summarized in a bibliography published in 1992 (Hartman, 1992). In general, soybean rust is endemic to parts of the tropical and subtropical areas of Asia and Australia, and more recently to parts of Africa and South America. It is introduced irregularly to more temperate and nonconductive environments like areas in northern China, India and Nepal. Although countries in Asia have had soybean rust for years, the endemic regions do not have concentrated areas of soybean production like what is found in North and South America.

On the African continent, the distribution of soybean rust was not well known before 1996, but since then a more expanded view of soybean rust in Africa has been reported indicating that it was found in 1996 in Uganda, Kenya, and Rwanda, in Zambia and Zimbabwe during 1998, Nigeria in 1999, Mozambique in 2000, and South Africa in 2001 (Levy, 2003). There is one earlier report of it occurring in Togo (Mawuena, 1982), and it may well have been in various countries in central and west Africa for years before it hit the major soybean productions areas in southern Africa.

The first detection of *P. pachyrhizi* in South America was in Paraguay in the 2000-2001 growing season (Yorinori et al., 2003). The disease was found on soybeans grown in the Parana River basin on the eastern border with Brazil in a limited number of fields. Argentina confirmed the occurrence of soybean rust in early 2002 (Rossi, 2003). During the 2003 growing season the pathogen was found in most of the soybean growing regions of Brazil and came late in the season for the first report in Bolivia (Yorinori et al., 2003).

Although soybean rust was first found in the U.S. in Hawaii in 1994, it has not been reported in any of the soybean production area in the U.S. The rapid spread of *P. pachyrhizi* and the potential for severe yield losses makes this potentially the most destructive foliar disease of soybean (Sinclair, 1999). Soybean rust, if introduced into the U.S., could have a major impact on both total soybean production and production costs in the U.S. (Livingston et al., 2004).

Host Range

Phakopsora pachyrhizi infects over 95 species of plants from more than 42 genera including soybean and related *Glycine* species (Ono et al., 1992; Rytter et al., 1984). Species that serve as hosts for *P. pachyrhizi* include many of the wild and edible legumes and kudzu, an exotic weed that is widespread in the U.S. These alternative or bridge hosts that *P. pachyrhizi* infects increases the likelihood that this pathogen will survive and over winter in the southern U.S. as well as in Central America or in the Caribbean producing a potential reservoir of spores that can be blown north during the soybean production in the continental U.S.

Resistance

Specific resistance and physiological specialization. Specific resistance to *P. pachyrhizi* is known and four single dominant genes have been identified as *Rpp_1* (McLean and Byth, 1980), *Rpp_2* (Bromfield et al., 1980), *Rpp_3* (Bromfield and Hartwig, 1980; Bromfield et al., 1980; Hartwig and Bromfield, 1983), and *Rpp_4* (Hartwig, 1986). These four genes condition resistance to a limited set of rust isolates (Table 1). The *Rpp_1* was described as having an immune reaction when inoculated with a few isolates, while other rust isolates on *Rpp_1* or the other genes produces a resistant red-brown (RB) lesion with no or sparsely sporulating uredinia. The RB lesion type is considered to be a resistant lesion type when compared to a fully susceptible TAN lesion (Fig. 1). Single gene resistance has not been durable and the usefulness of the sources of single genes was ineffective soon after the sources were identified (Kochman, 1977). For example, the accession PI230970 was identified as resistant in field evaluations in 1971-1973, but by 1976 a few susceptible lesions were observed on plants in the field. In 1978, most of the lesions found on plants in the field were of the susceptible TAN type (Bromfield, 1984). Similarly, the cultivar Komata was identified as resistant in germplasm evaluations done during 1961-1963 (Bromfield, 1984). By 1966, susceptible lesions were found on plants of Komata in field trails, and by the mid 1970's the line was not considered to be a useful source of resistance (Kochman, 1977). The resistance in Ankur, identified in the early 1970s (Singh et al., 1975) was ineffective in the late 1970s (Bromfield, 1984), providing another example of the ability of *P.*

pachyrhizi to overcome single gene resistance. Only Bing Nan, the source of the *Rpp$_4$* gene, has not been reported to be defeated in the field, although observations both in the field in Paraguay and greenhouse inoculation tests indicate that it is susceptible to at least some *P. pachyrhizi* isolates.

Soybean rust was of great concern in some countries in Asia. For example, in Taiwan, from the 1960s until the early 1990s, research on soybean rust focused on epidemiology and resistance (Hartman, 1995; Hartman et al., 1991). In Taiwan, there was a very active field program on soybean rust and many soybean accessions were screened for resistance. Physiological races of *P. pachyrhizi* were first described in 1966 when a set of nine single urediniospore isolates were inoculated onto six soybean and five legume accessions (Lin, 1966). The reactions of the nine isolates were similar on all six of the soybean genotypes, but six pathotypes were identified based upon their reactions on the legume accessions. The first example of virulence diversity on soybean cultivars was described in Queensland, Australia (McLean and Byth, 1976) where one rust isolate was found to be virulent on the cultivar 'Willis' but avirulent on the accession PI 200492, while another isolate was virulent on both soybean genotypes. Several other studies have also shown considerable variation in virulence among isolates from the same field as well as isolates collected from wide geographical areas (Poonpolgul and Surin, 1985; Shin and Tschanz, 1986). Use of single genes to control rust may have some utility, but other options like using partial resistance may be needed to develop "slow-rusting" cultivars.

Partial resistance. Partial resistance, or rate reducing resistance, is also known in soybean (Wang and Hartman, 1992). Lines with partial resistance in field evaluations are rated as moderately resistant, since fewer lesions develop on plants throughout the season. In greenhouse studies, host-pathogen combinations that resulted in RB reaction types tended to have longer latent periods, lower rates of increase in pustule number over time, and smaller lesions compared with susceptible interactions that resulted in a TAN reaction type (Bromfield and Hartwig, 1980; Marchetti et al., 1975). Identification and utilization of partial resistance in breeding programs has been limited. The evaluation methods may be time consuming and difficult to incorporate into breeding programs and therefore limited to use with advanced generations. These difficulties, at least in part, led to the development of a strategy to select genotypes with what was defined as yield stability or tolerance despite being heavily infected with *P. pachyrhizi* (Hartman, 1995; Wang and Hartman, 1992)

Yield stability. Yield stability, or tolerance, refers to the strategy of selecting genotypes with high yield potential and less yield loss from soybean rust. Screening for yield stability to soybean rust was started at the Asian Vegetable Research and Development Center (Hartman, 1995), where yields from paired plots, with and without the fungicide Dithane M-45 applied every 2 weeks, were compared for losses due to rust. High yielding genotypes with lower yield loss under severe rust conditions were considered to be tolerant. Rust development rates and estimates of rust severity on foliage were not correlated with yield loss in tolerant materials. Using fungicide protected plots as yield checks, tolerant lines from breeding populations were identified without having to take notes on rust severity (Hartman, 1995). Cultivars with yield stability may have some partial resistance that was not characterized or selected for in the breeding program.

Current Research in the U.S.

Since the report of soybean rust in Hawaii in 1994, the USDA-ARS has renewed its support for soybean rust research. The FDWSRU at Ft. Detrick is the focal point of this research, with additional collaborators in several states including Illinois and Iowa and additional support coming from the United Soybean Board. Part of the research focus has been to identify resistant germplasm. There are over 16,000 soybean accessions in the USDA Germplasm Collection located at the University of Illinois. These soybean accessions, along with commercial and public cultivars grown in the U.S., are being evaluated for resistance to *P. pachyrhizi* in the USDA-ARS FDWSRU Biosafety Level 3 Containment Greenhouses at Fort Detrick, MD. The germplasm evaluations are done on seedlings using a mixture of isolates from Africa, Asia and South America. Over 16,000 soybean accessions have been screened to date, fewer than 100 have been identified as having resistance that needs to be further characterized. None of the U.S. commercial cultivars evaluated were found to be resistant to the mixture of isolates. The soybean accessions showing some level of resistance are being further evaluated using individual isolates to characterize race specific and/or partial resistance. These accessions also have been planted in field trials in Brazil, Paraguay, China, Thailand, South Africa and Zimbabwe for evaluation of adult plant resistance. Additional research is being conducted to determine the best way to evaluate partial resistance and yield stability. Besides soybean, about 1,000 *G. soja* accessions have or will be screened along with some of the perennial *Glycine* spp. previously reported as having resistance (Hartman et al., 1992). As sources of resistance are identified, crosses will be made to incorporate these resistance traits into adapted backgrounds for commercial use.

Management of Soybean Rust

Control of soybean rust can be accomplished through utilization of fungicides (Miles et al., 2003). Fungicides will be used to control soybean rust when it arrives onto the continental US. There are two fungicide compounds (chlorothalonil sold as Bravo® and Echo®, and azoxystrobin sold as Quadris®) that are registered for use on soybean and labeled for soybean rust. Additionally, there are seven compounds or mixtures of compounds that have been submitted to the EPA under a Section 18 Emergency Exemption request including several triazoles and two additional strobalurins. When used correctly fungicides have been effective in controlling soybean rust and knowing how to use them in a curative or preventive way will be an important management decision. Preventative fungicides, like the strobalurins, should be applied before the disease is present, while the curative compounds (triazoles) should be used after the rust is present. However, once the disease reaches 10% severity even the curative fungicides may not provide full yield protection. Application timing of the fungicides also will be important and a general recommendation may be to apply the first fungicide at or soon after flowering; a second application should be made 14 to 20 days later. A third application may be needed only in a severe epidemic. Fungicides will need to be used in rotation; strobalurins should be used only once each season with no more than one of two applications in mixes.

Summary

To be prepared for soybean rust, producers will need to be familiar with the available fungicides, their mode of action, and how and when to apply them. Once commercial U.S. cultivars are fully evaluated in the field, there will be a recommended list of highly susceptible cultivars that growers should not plant. Single gene resistance may or may not be part of the overall picture for control, although single genes are easy to work with in a backcrossing program and are can be moved into elite breeding stock in a relatively short time period, their durable is in question. Partial resistance may also contribute to the control of soybean rust in that it will slow down the epidemic, thereby decreasing the build up of rust spores. Fewer spores produced over time could effectively reduce the need for multiple fungicide applications. Yield stability, with or without single, stacked or partial resistance also may be effective in reducing potential yield losses. Cultivars that show some level of yield stability will be identified. Dealing with yield stability in a breeding program may not be an easy task since this will require that later generation material be evaluated by comparing yields of plants in plots with rust to plants in plots sprayed with a fungicide to control rust so that percentages of yield among lines based on the control plots can be compared.

Each season in the U.S. without rust provides additional time to evaluate and register fungicides, and test and incorporate resistance and/or yield stability into more adaptable soybean breeding lines. Right now there are many educational activities occurring in the U.S. in terms of grower meetings, state emergency action plans, and general awareness through popular press and web sites. The heightened awareness of the potential devastation of soybean rust will help to moderate its effects once it becomes epidemic in the U.S. soybean belt.

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Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

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Table 1. Named single genes, original sources and *Phakopsora pachyrhizi* isolates used in studies of the inheritance of resistance to soybean rust

Named single gene	Accession number and cultivar name of original source	*Phakopsora pachyrhizi* isolates[a]	
		Resistant reaction	Susceptible reaction
Rpp$_1$	PI200492	IN 73-1[bc]	TW 72-1, TW 80-2
	Komata		(Hartwig and Bromfield, 1983; McLean and Byth, 1980)[d]
Rpp$_2$	PI230970	AU 72-1[c], IN 73-1[c],	TW 80-2
		PH 77-1[c], TW 72-1[c]	(Bromfield and Hartwig, 1980; Hartwig and Bromfield, 1983[McLean, 1980 #671)[d]
Rpp$_3$	PI462312	IN 73-1[c]	TW 72-1, TW 80-2
	Ankur		(Hartwig and Bromfield, 1983)[d]
Rpp$_4$	PI459025	IN 73-1[c,] TW 72-1[c],	
	Bing Nan	TW 80-2[c]	(Hartwig, 1986)[d]

[a]AU = Australia, IN = India, PH = Philippines, TW = Taiwan.
[b]Immune reaction type.
[c]Isolates used in original inheritance studies to examine segregation patterns.
[d]Reference citation.

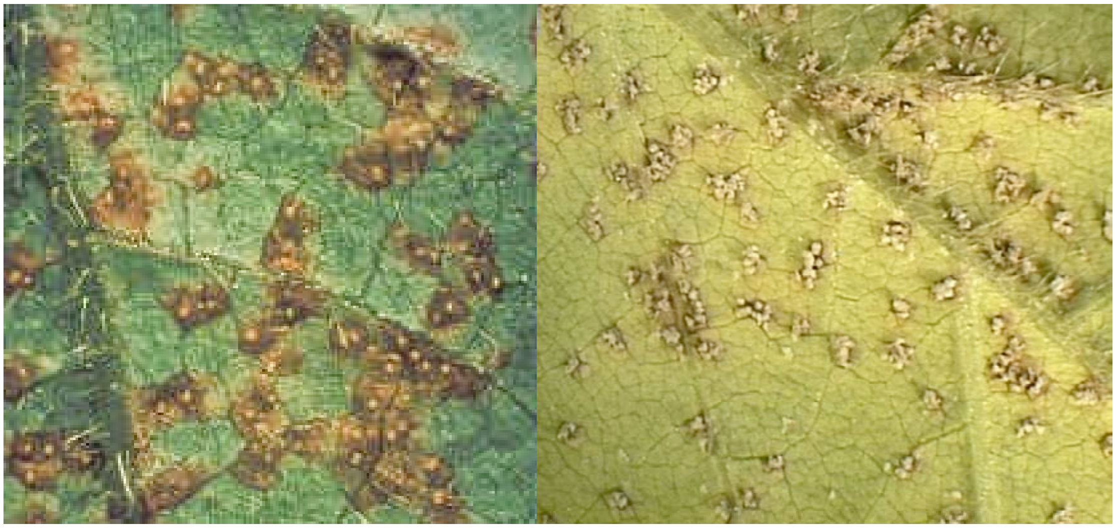

Fig. 1. Lesions on soybean leaves infected by *Phakopsora pachyrhizi*. A red brown (RB type) resistant reaction type (left) and a susceptible (TAN) reaction type (right).