

RESPONDING TO THE SOYBEAN RUST EPIDEMIC IN SUB-SAHARAN AFRICA: A REVIEW

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ABSTRACT

Soybean rust (*Phakopsora pachyrhizi* Sydow), a major threat to soybean production, is a new pathogen on the African continent, where it is increasingly threatening soybean production. The fungus is highly variable, and this complicates most disease management strategies. Most research on soybean rust, its epidemiology and management has been in the Orient, and only limited work has been done in Africa. However, experiences in the Orient will be important for soybean rust researchers in Africa, who are currently combating the epidemic. This approach will be necessary to design and implement rust management strategies in the African countries already affected, and those as yet unaffected. Because there is little information on distribution, epidemiology, and management of soybean rust from Africa, this paper provides an overview on 1) soybean rust epidemiology, disease assessments and management, as experienced in the endemic areas, 2) the distribution of soybean rust in Africa, 3) on-going research activities in the African countries most affected, and 4) discusses priority research activities. This review is intended to stimulate future research activities, leading to a better understanding of the pathogen, its biology and ecology, and management.

Key Words: Control, epidemiology, *Phakopsora pachyrhizi*, yield losses

RÉSUMÉ

La rouille du soja (*Phakopsora pachyrhizi* Sydow), une menace majeure de production du soja, est un nouveau pathogène sur le continent Africain, où il est entrain de menacer de manière croissante la production du soja. Le champignon est hautement variable, et ceci complique la plupart des stratégies de gestion de la maladie. La plupart des recherches sur la rouille du soja, son épidémiologie et sa gestion ont été faite en orient, et seulement du travail limité a été fait en Afrique. Cependant, les expériences en orient seront importantes pour les recherches de la rouille en Afrique, qui combattent couramment l'épidémie. Cette approche sera nécessaire pour concevoir et implémenter les stratégies de gestion de la rouille dans les pays Africains déjà affectés, et ceux pas encore atteints. Parce que il y a peu d'information sur la distribution de la rouille du soja, l'épidémiologie et la gestion de la rouille venant de l'Afrique, cet article fourni une vue générale sur 1) la rouille du soja, l'épidémiologie, l'évaluation et la gestion de la maladie, telle que expérimentée dans les aires endémiques, 2) la distribution de la rouille du soja en Afrique, 3) les activités de recherche courantes dans les pays Africains les plus affectés, et 4) discute la priorité des activités de recherche. Cette évaluation est proposée pour stimuler les activités futures de recherche, menant à une meilleure compréhension de pathogène, sa biologie et son écologie, et sa gestion.

Mots Clés: Contrôle, épidémiologie, *Phakopsora pachyrhizi*, les pertes de rendement

INTRODUCTION

Soybean *Glycine max* Merrill, is native to China, where it has been cultivated since the 11th century (Probst and Jude, 1973). The crop is a recent introduction to Africa, with earliest records of its cultivation in the early 1800s (Mayo, 1945). Currently, North America is the largest producer of soybean (42% of world production), followed by South America (32.1%), Asia (22.9%), Europe (1.6%); Africa accounts for only 1.22% (FAO, 2002). Nevertheless, there is potential for increased soybean production in Africa, especially when key production constraints are addressed.

The importance of soybean is largely because the crop can be produced more cheaply than other legume crops; it yields the highest amount of oil and protein per unit area, and has a longer post-harvest storage life without weevil infestations. Soybean seed contains 39-42% protein, 18-22% oil, an optimal supply of essential amino acids and nutrients, and a high calorie value (Nakamura, 1980), all of which are required for human consumption and/or as a raw material in industries. Also, when the crop is included in rotations it disrupts the build-up of pests and diseases in cereals (Pandle, 1987), and restores the fertility of marginal soils (Nkhuzenje *et al.*, 2002). These aspects make soybean an ideal crop for the African farmers. Indeed, soybean hectareage in Africa rose from an estimated 928,658 ha in 1995 to 1,062,498 ha in 2002 (FAO, 2002). It is therefore crucial that any constraint to soybean production be adequately addressed to expand and/or sustain the soybean industry on the continent.

Soybean yields in tropical countries average 1000 kg ha⁻¹, as compared to 2000 kg ha⁻¹ in the temperate countries (AVRDC, 1987). Low yields in the tropics, especially in Africa, are attributed to a number of biological and social economic constraints (Singh and Rachie, 1987). Insect pests, diseases, pod shattering, sensitivity to photoperiod and environment, and non-adoption of appropriate management practices are some of the key biological constraints, while lack of awareness of soybean utilisation and markets are the major social-economic limitations to soybean production in Africa.

Among the biological constraints, diseases are by far the most important (Hartman *et al.*, 1999).

Of these, soybean rust, which is incited by the fungus *Phakopsora pachyrhizi* Sydow, causes the greatest yield reduction, and is now considered a world threat to soybean production (AVRDC, 1992). The disease is endemic in the Orient, where it has caused substantial yield losses (Bromfield, 1984; AVRDC, 1992). Currently, the disease is infecting soybean in several sub-Saharan African countries, and has thus raised both regional and national concerns about the future of soybean production on the African continent. For newly introduced pests and pathogens there is need for information on the biology of the pest pathogen in its new environment, and its distribution. Unfortunately, for most of the African countries currently experiencing the epidemic, there is limited information on rust distribution, epidemiology and management. This is a major obstacle to both national and regional scientists, policy makers, extension personnel and other stakeholders, who have the mandate to address alien pests and pathogens. Drawing experiences from the rust-endemic regions where extensive research has been conducted will be of relevance to soybean rust researchers in African countries currently experiencing the epidemic. It is for these reasons that we compiled this review. This paper provides: 1) an overview on soybean rust epidemiology, assessment and management, as experienced in the endemic areas, 2) the distribution of soybean rust in Africa, 3) highlights the on-going research activities in the most affected African countries (Uganda, Zimbabwe, South Africa, Nigeria), and 4) discusses priority research activities and collaboration.

GEOGRAPHICAL DISTRIBUTION OF SOYBEAN RUST

Soybean rust is incited by two fungal species *Phakopsora pachyrhizi* Sydow and Sydow, and *Phakopsora meibomia* (Arthur) Arthur (Ono *et al.*, 1992). The species *P. pachyrhizi*, also known as the Asian or Australian soybean rust, is the most aggressive and widespread. On the contrary, *Phakopsora meibomia* the new world type, is a much weaker pathogen and of limited distribution, occurring in Central and South America, and in the Caribbean (Costa Rica, Cuba, Dominican

Republic, Guatemala, Mexico, Venezuela, Bolivia, Barbados, Trinidad, Chile, St. Thomas, Brazil, Colombia, and Puerto Rico).

It is not possible to distinguish between these two species in the field and under the microscope; they have so far only been distinguished by use of polymerase chain reaction (PCR) based primers (Frederik *et al.*, 2002). Herein, we focus on *P. pachyrhizi*, which is more aggressive, and rapidly spreading through soybean producing regions of the world.

Phakopsora pachyrhizi was first reported from Japan in 1902, where it was found infecting soybean on the island of Shikoku (see Kitani and Inoue, 1962). Thereafter, the disease spread to other Asian countries: India, Indonesia, Nepal, Philippines, Peoples Republic of China, Taiwan, Thailand, Vietnam, and on the Australian island (Bromfield, 1984). In the Americas, the disease appeared between 1913 and 1979, and has been reported in Puerto Rico, Mexico, Cuba, Trinidad, St. Thomas, Colombia, Guatemala, Brazil, Venezuela, Chile, Bolivia, Dominican Republic, Barbados and Costa Rica (Bromfield, 1984). More recently, the disease was reported in Paraguay in 2001 (Morel and Yorrinori, 2002) and Argentina in 2003 (Rossi, 2003). In Africa, earlier reports documented that *Phakopsora pachyrhizi* infected several leguminous crops (except soybean) in Ghana, Sierra Leone, Sudan, Tanzania, and Democratic Republic of Congo (CMI Dist. Map No. 504, 1975; cited by Bromfield, 1984). Recent reports have however reported the disease in several sub-Saharan

African countries (Clive Levy, and Frederick, 2001). By 1996, the disease was reported in Kenya, Rwanda and Uganda; the disease spread southwards to Zambia and Zimbabwe in (1998), Mozambique (2000), and by 2001, it had established in South Africa. In the westward direction, the disease has been reported in Nigeria (Akisanmi *et al.*, 2001). Apparently, it's only in the continental USA, a major soybean growing region, where soybean rust has so far not established.

SYMPTOMS AND EPIDEMIOLOGY

Pictures of soybean rust symptoms are presented on plates 1-4. Rust is conspicuous on leaves, though lesions also appear on petioles, pods and stems (Bromfield, 1984; Tschanz and Shanmugsundarum, 1985). Initially, small, water-soaked lesions appear on the underside of leaves. At this stage, the lesions are similar to those of bacterial pustule, *Xanthomonas campestris* pv. *glycines* (Sinclair, 1982), but they have characteristic blister-like uredia with a central pore with extruding urediniospores on the abaxial (lower) side of the leaf (Yorinori, 1994). Lesions gradually increase in size, and they latter turn from gray to tan, reddish-brown or dark brown and assume a polygonal shape restricted by leaf veins (Tschanz and Shanmugsundarum, 1985). The most commonly observed symptom is that of sporulating lesions on the lower surface of the leaf (Sinclair and Backman, 1989). Each lesion may have to five uredia, which are

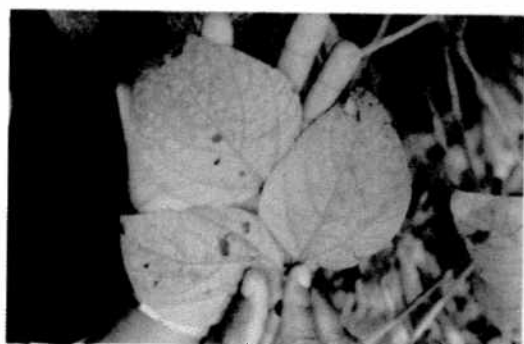


Plate 1. Close-up of rust lesions on the upper leaf surface of trifoliolates.

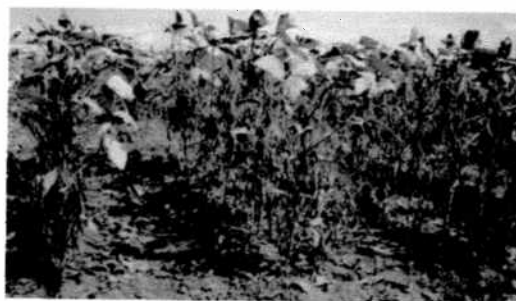


Plate 2. Soybean extensively defoliated by soybean rust infection.

usually more abundant on the abaxial than on the adaxial (upper) leaf surface (Sinclair, 1982; Tschanz and Shanmugasundaram, 1985). Higher lesion density is frequently associated with premature yellowing and defoliation (Bromfield, 1984).

Bromfield *et al.* (1980) reported three infection types of soybean rust: Type 0, denotes absence of macroscopically visible symptoms on infected plants. Type RB (reddish brown, low infection type), have characteristically reddish-brown lesions of about 0.4 mm² with 0-2 uredia per lesion. Type TAN (high infection type), have TAN-coloured lesions of 0.4 mm² with 2-4 uredia per lesion. Bromfield (1984) however, documented that some variations do exist within the RB and TAN infection types, and thus developed a new infection grade: 0= no microscopically visible symptoms; 1=RB lesions small, irregular and lacking uredinia; 2= RB lesions with one or two sparsely sporulating uredinia per lesion; 3=RB lesions with three or more profusely sporulating uredinia per lesion; 4= TAN lesions with two to five uredinia per lesion; and 5= TAN lesions with more than five uredinia per lesion. With this grade, infection type 0 indicates host immunity; types 1, 2, and 3, host specific resistance; and 4 and 5, host susceptibility (Bromfield, 1984).

Several studies have been conducted to establish the physiological races of *P. pachyrhizi* (See Bromfield, 1984; AVRDC, 1992).

In Taiwan, six pathotypes were distinguished when nine single uredospore isolates of *P. pachyrhizi* were inoculated on five legumes (Lin, 1966). Related studies a set of five differentials identified three races from fifty isolates collected at five locations in Taiwan (Yeh, 1983a, 1985). Other studies (A VRDC, 1992), have however identified nine races, when 42 purified isolates were inoculated on a set of differentials. In most of these studies, the TAN infection type was predominant. A standard set of 11 differentials containing genes conferring race-specific resistance: PI 462312, PI 200492, PI 230970, PI 230971, PI 239871A, 239871B, PI 459024, PI 459025, Tainung 4, Taita Kaohsiung No. 5, and Wayne, have been recommended by the Asian Vegetable Research Development Centre (AVRDC) for identification of rust races (Tschanz and Shanmugasundaram, 1985).

Soybean plants are susceptible to the fungus at all growth stages (Hsu and Wu, 1968; Bromfield, 1976). However, attack towards flowering (Ogle *et al.*, 1979) and at pod filling stage (Shin, 1986), which is commonly evidenced in soybean fields is most yield reducing.

The primary inoculum (uredospores) comes from infected soybean plants and or other leguminous plants that are affected (Hsu and Wu, 1968). Teliospores, the sexually produced spores of *Phakopsora pachyrhizi* have only been reported



Plate 3. Soybean germplasm evaluation in Uganda. Note the effect of growth stage on rust severity; A early maturing and B late maturing soybean lines.

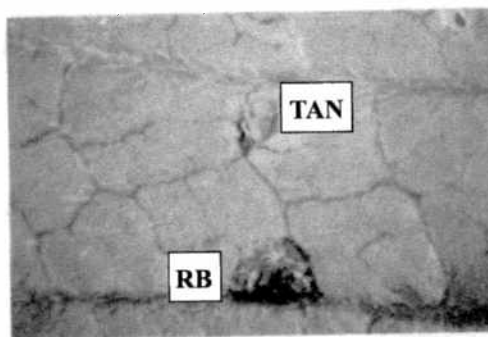


Plate 4. Characteristic TAN lesions and RB lesions of soybean

in nature (under uniquely cool conditions) from several locations and on a number of different hosts (Bromfield, 1984). Although their germination was reported their role in rust epidemics is still unknown (Koch and Hoppe, 1987). Moreover, the fungus has a wide host range, covering over 95 species among more than 42 genera in the family *Fabaceae* (Keogh, 1976; Vakili, 1978; Sinclair, 1982). Included in the list are several wild and edible legumes that are widely grown and or prevalent throughout sub-Saharan Africa. These could potentially serve as pathogen reservoirs, and thus, sustain the pathogen within the environment.

Successful infection of the host is achieved under a series of events in sequence: spore germination, appressorium formation, penetration and colonization, uredinal development, and sporulation (Bonde *et al.*, 1976; Bromfield, 1984). Infection begins when urediniospores germinate to produce a single germ tube, which in turn develops into an appressorium; penetration of the epidermal cells is by direct penetration through the cuticle with help of a penetration peg (Koch and Hoppe, 1988). This aspect makes *P. pachyrhizi* exceptionally unique as compared to other rust pathogens, which enter leaves through stomatal openings, and only penetrate cells once inside the leaf. This could perhaps explain the wide host range of *P. pachyrhizi* as compared to other rust pathogens, which have a fairly limited host range. Upon infection, uredinia develop within 5 to 8 days, with the first urediniospores production occurring 9 days post-infection; uredospore production can continue for up to 21 days (Marchetti *et al.*, 1975). Thus, within a single growing season several *P. pachyrhizi* cycles are completed and thus, a high inoculum build up is inevitable even if the primary inoculum level is low.

The infection process is highly influenced by the biotic factors of the host plant and the pathogen, and by the abiotic factors of the environment. Severe epidemics are unavoidable when prolonged conditions of leaf surface wetness of approximately 10 hours per day, and moderate temperatures of 18–26°C prevail (Kochman, 1979). On the contrary, rust epidemics are retarded under dry conditions, and when temperatures are below 15°C and or greater than 30°C (Kochman, 1979).

Tschanz (1982) further pointed out that rust development is more rapid in areas with more even rainfall distribution through out the season than in areas with uneven rainfall distribution. Other studies have indicated that precipitation is necessary for development of severe rust epidemics, especially when it occurs during the middle period of soybean growth (AVRDC, 1988b). Rust lowers soybean yields through premature defoliation, and by decreasing the number of normal pods per plant, weight of seeds per plant, and 100-seed weight (Bromfield, 1984; Kawuki *et al.*, 2003b). The extent of yield loss depends on the crop growth stage at which disease sets in and its intensity then (Ogle *et al.*, 1979), and with location and growing season (Bromfield, 1984; Kawuki *et al.*, 2003b).

RUST ASSESSMENT

Accurate disease assessments are necessary for epidemiological studies, as data collected help in guiding scientists in developing disease management strategies. In the case of soybean rust, before 1977, three assessment keys were developed for rust assessment; these based on leaf area affected by rust (see Bromfield, 1984). However, after the international soybean rust meeting in Thailand in 1977, a three-digit rust scoring system was adopted by the International Working Group of Soybean Rust (IWGSR) (plate 5). The first digit denotes the position of the sampled leaf from a single plant; the second digit denotes lesion density (severity) of the sample leaf in comparison to the standard diagram; and the third digit, denotes the reaction type present on the sampled leaf (Yang, 1977). The third digit requires a hand lens (x 20) to distinguish between sporulating and non-sporulating pustules. Bromfield (1984) suggested that this scale is of value in aiding selection in breeding programmes; it is however, of limited use for epidemiological studies that require computation of percentage leaf area affected. This is because, the data collected cannot be adequately subjected to appropriate statistical analysis. Thus, for computation of percentage leaf area affected, other scales can be utilised; the Horsfall and Barrat (1945) scale can be adopted. In fact, it has been used in some soybean rust studies (see

Tschanz and Wang, 1980; AVRDC, 1992). A percentage severity scale of 0-9, where 0 = no disease and 9 = 90% disease plus defoliation has been developed, and used to assess soybean foliar diseases (Walla, 1979; cited by Sinclair, 1982). This scale too can be used to assess rust severity.

In most soybean rust epidemiological studies, assessments are done on a weekly basis (see Yang *et al.*, 1990; Hartman *et al.*, 1991). Soybean rust epidemiological studies have also illustrated the effect of development and maturity of soybean on rust development (Tschanz and Tsai, 1982; Tschanz and Wang, 1987; Tschanz *et al.*, 1985). For instance, on the same day after planting, late maturing are less affected by rust as compared to the early maturing cultivars (Tschanz *et al.*, 1985). Thus, rust assessments without consideration of soybean development will obviously result into inaccurate conclusions on the status of resistance in soybean cultivars (Tschanz *et al.*, 1985).

Tschanz and Wang (1982) suggested that over-rating of susceptibility of early maturing varieties can be avoided by first grouping test materials into maturity groups before evaluation. Clearly, it is important to record the growth stage of the crop during rust assessment. Fehr and Caviness (1977) have provided a description of soybean growth stages. Since rust resistance decreases with crop

age it is necessary that final rust evaluations be done late in the season (Tschanz *et al.*, 1985; Kawuki *et al.*, 2004). Assessments done towards the end of the R6 growth stage are appropriate. This growth stage corresponds to the time when soybean leaves are severely affected by rust (AVRDC, 1988a), and when significant differences in rust severity are observed between susceptible and partially resistant soybean cultivars (Hartman *et al.*, 1991; Kawuki *et al.*, 2004). However, for assessments to be done over a period of time, an evaluation method was developed at the AVRDC, which corrects for the effect of soybean development and maturity on rust severity (Tschanz and Tsai, 1982; AVRDC, 1992). This method uses the relative lifetime (RLT) as the time element instead of the commonly used days after planting; RLT indicates the percentage of soybean cycle that has been completed on a particular date. It is computed from the formula:

$$\text{RLT} = \frac{\text{Days after planting of disease assessment}}{\text{Days to maturity}} \times 100$$

The computed RLT is then regressed on the logit transformation of rust severity; the rate of rust development, which determines the level of rate-

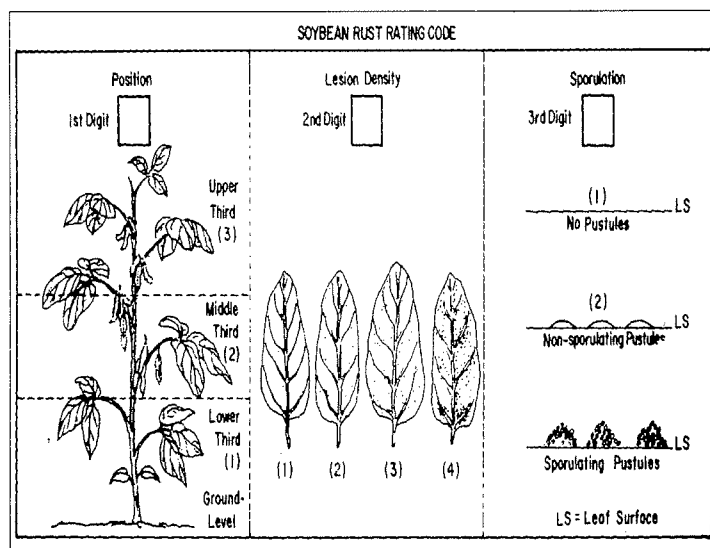


Plate 5.. The three digit 1 WGRS scale (Yang, 1977).

reducing resistance, is the slope (regression coefficient) of the linear regression (Tschanz *et al.*, 1985).

MANAGEMENT OF SOYBEAN RUST

The reportedly high yield losses associated with soybean rust require that effective control strategies be developed to mitigate its effect on the crop. Chemical control, cultural practices and deployment of resistant/tolerant varieties have been widely used in areas where rust is prevalent. This section briefly examines these control options.

Chemical control. Several systemic and protectant fungicides have, since the 1960's, been used in the management of soybean rust (Table 1). We therefore encourage soybean rust researchers in Africa to consider screening some of these fungicides to verify their efficacy under their local conditions. It is evident from literature that universal recommendation of chemical control is somewhat difficult to formulate due to inconsistencies in research findings. For instance, Chan (1965) recommended spraying to begin at early bloom (R1) on a 10-day interval. Shortly after, Tsai (1966) recommended spraying to begin 30 days after planting, and to continue at 7-10 day interval. Yeh *et al.* (1975) however, suggests beginning spraying as soon as disease symptoms appear, while Nakamura *et al.* (1981b) recommends spraying to begin from young pod to full seed formation, which corresponded to 2 or 3 sprays a season. Bromfield (1984) noted that differences in soybean growing environmental factors (weather patterns, cropping system), and economic factors (availability of fungicides, labour, equipment, capital, and cost of materials) all have a bearing on the use of fungicides in the control of soybean rust. Besides, the environmental and social factors, the method of application too, can severely limit the fungicide efficacy. For instance, during the early stages of rust progression, the pathogen is restricted to lower leaves. However, as the plant canopy develops, the inoculum increases and moves up the plant (this coincides with growth stages R1 to R5). During this period, the plant canopy is dense, and as such, limits uniform delivery of the top-applied fungicide down the plant; this is

particularly important with protectant fungicides. It is therefore, crucial that fungicide application be delivered uniformly particularly to the lower plant canopies, which support high inoculum levels. Equally important is to ensure that the abaxial leaf surface, which is most affected, receives adequate amounts of the applied fungicide.

Host plant resistance. This is the most recommended and long-term solution against many plant diseases. For soybean rust, host plant resistance as a management tool was first used in Taiwan in the 1960s; both race-reducing (or partial resistance) and race-specific resistances have been identified, but with no immune cultivars developed so far (Bromfield, 1984; Tschanz *et al.*, 1985). Soybean lines with partial resistance are rated as moderately resistant in field evaluations owing to fewer lesion developments during the growing season (Wang and Hartman, 1992). Specific resistance to soybean rust is under control of one or 2 major genes, and its expressed as a hypersensitive reaction characterized by limited pathogen development and sporulation (Singh and Thapliyal, 1977). Burdon (1986) however, established that race-specific resistance to soybean rust is associated with three infection types: 1) dark brown or purple necrotic flecks with no sporulation, 2) light brown flecks with occasional sporulation, and 3) small pustules surrounded by chlorotic or necrotic regions. Indeed, soybean accessions with specific resistance have been identified and utilised in various soybean rust breeding programmes in Asia (Bromfield, 1984). Unfortunately, the identified sources of specific resistance are known to be challenged by at least one known isolate of *Phakopsora pachyrhizi* (Hartwig and Bromfield, 1983; Bromfield, 1984; AVRDC, 1992), thus making race-specific resistance unsustainable. Tschanz *et al.* (1985) further points out that the presence of multiple virulence genes in the rust pathogen population, and the absence of multiple specific resistance genes in the host plant, make race-specific resistance ineffective and unsustainable. In fact, some soybean accessions have been found to be resistant in some locations, but highly susceptible in other parts of the world (Table 2).

General resistance has also been observed; it is

TABLE 1. A checklist of some fungicides that have been reported to be effective against soybean rust

Country reported	Fungicide	Active principle	Fungicide properties	Reference
Taiwan	Dithane Z-78	Zineb	Protectant	Wang, 1961
	Dithane M-45	Mancozeb	Protectant	Jan and Wu, 1971; Yeh, 1983
	Dithane M-22	Maneb	Protectant	Hung and Liu, 1977
	Bayleton 25 WP	Triadimefon	Systemic with preventative and curative properties	Hu and Yang, 1977; Yeh, 1983
	Bavistin 65 WP	Carbendazim	Systemic with a protective and curative action	Hu and Yang, 1977
	Benlate	Benomyl	Systemic with a protective and curative action	Hu and Yang, 1977
	Saprol	Triforine	Systemic with protectant and curative characteristics	Yeh, 1983b
	Plantvax	Oxycarboxin	Systemic	Yeh, 1983b
	Bayleton 25 WP	Triadimefon	Systemic with preventative and curative properties	Osathaphant 1981
	Manzate D	Maneb	Protectant	Pupipat and Choochawong, 1981
Thailand	Plantvax	Oxycarboxin	Systemic	Sangawongse, 1973
Philippines	Dithane M-45	Mancozeb	Protectant	Quebral, 1977
	Zineb	Zineb	Protectant	Nakamura <i>et al.</i> , 1981b
Japan	Bayleton	Triadimefon	Systemic with preventative and curative properties	Nakamura <i>et al.</i> , 1981b
India	Saprol	Triforine	Systemic with protectant and curative	Maiti <i>et al.</i> , 1982
	Delan	Dithianon	Protective characteristics	Maiti <i>et al.</i> , 1982
	Dithane M-45	Mancozeb	Non-systemic/protectant	Maiti <i>et al.</i> , 1982
	Saprol	Triforine	Systemic with protectant and curative characteristics	Kawuki <i>et al.</i> , 2002
Uganda	Folicur	Tebuconazole	Systemic with protectant and curative characteristics	Kawuki <i>et al.</i> , 2002
	Dithane M-45	Mancozeb	Protectant	Kawuki <i>et al.</i> , 2002
	Punch C	carbendazim + flusilazole	Systemic with protectant, curative and eradication activity	Tukamuhabwa <i>et al.</i> , 2001
	Alto 100	Cyproconazole	Systemic with protectant, curative and eradication activity	Tukamuhabwa <i>et al.</i> , 2001
	Bayco	Difenoconazole	Systemic with curative and preventative characteristics	Tukamuhabwa <i>et al.</i> , 2001
	Score			

reported to reduce the amount of rust and the rate of rust development even if the infection type produced is similar to that of a highly susceptible cultivar (Bromfield, 1984). Thus, it appears that general resistance could be effective against most if not all rust pathogen populations, and thus making it more useful than race-specific resistance.

Its quantification however, requires periodic assessment of rust severity throughout the cropping season across a number of years (Bromfield, 1984). Though general resistance appears to be more efficient and sustainable than the race-specific resistance in rust control, its identification and utilization lags far behind that of race-specific resistance. Difficulties associated with both race-specific and rate-reducing resistances have led to search for new methods, such as rust tolerance, which can be used to minimise yield losses (AVRDC, 1992). Tolerance to rust is defined as relative yielding ability of soybean under rust stress; it has been used to minimize yield losses associated with soybean rust (Tschanz and Tsai, 1983; Kawuki *et al.*, 2004). Tolerance is a strategy to select for genotypes that have a higher yield potential and with less yield loss due to soybean rust. Tolerance screening began at AVRDC

(Hartman, 1995), where yields of paired plots (with and without fungicide application) are compared to determine losses due to rust infection; higher yielding cultivars with lower yield loss were considered tolerant, while cultivars with higher yield loss were considered intolerant. Variation in rust tolerance can also be identified by comparing the yields of soybean cultivars under severe rust stress (Kawuki *et al.*, 2004). It has now been established that there is greater variation in tolerance among soybean cultivars than variation in rate-reducing resistance (Tschanz *et al.*, 1985; Kawuki *et al.*, 2004).

Cultural control. Adjusting sowing dates, utilization of early maturing varieties, growing varieties with a short pod-filling stage, control of wild weeds hosts, and strategic selection of planting sites have been the major components of this control option (Bromfield, 1984). Clearly, most of these strategies attain to avoid conditions that promote disease and or implementing practices that optimise overall yields. Indeed, several studies (eg. Nakamura *et al.*, 1981a; Desborough, 1984; do Vale *et al.*, 1985) have indicated that late-planted soybean tends to avoid rust, and thus

TABLE 2. A selection of rust reaction of soybean accession at different location

Soybean accession	Location		
	Resistant	Susceptible	Both resistant and susceptible
PI 200492	China, Nepal, India, Japan	Brazil	Australia, Taiwan
PI 230970	China, Nepal, Thailand, Brazil		Taiwan,
PI 230971	Brazil, Nepal, Thailand		Taiwan,
PI 459024	Nepal, China		
PI 459025	Nepal, China, Taiwan, India		
PI 339871	Korea, Taiwan		
Kaoshung 3		Taiwan, Philippines,	Australia
Tainung 3	Nepal	Indonesia, Philippines,	Australia
Tainung 4	Nepal, Australia, Vietnam	Philippines, Taiwan	
Bragg		Nepal, Brazil, India	
Cobb		Nepal	
Harde	Brazil	Nepal, India	
P-28		Nepal	
P-32		Nepal	
Clarke 63		India, Thailand,	
Wayne		Philippines, Indonesia, Thailand, Brazil	
PI 462312 (Ankur)	India, Brazil	Taiwan,	
PI 200490	India, Nepal, Japan,	Brazil	Taiwan
TGx 1835-10E	Uganda ¹		
TGx 1838-5E	Uganda ¹		
Nam 2		Uganda ¹	

Source: (AVRDC, 1992) ¹ Kawuki *et al.* (2004)

suffers less from the disease. Selection for early maturing cultivars, which have a short pod filling stage, has been utilized by the AVRDC to minimize yield losses attributable to soybean rust (AVRDC, 1985). Recent studies have established that late maturing cultivars are more severely affected by rust, and consequently experience more yield losses as compared to early or medium maturing soybean cultivars (Kawuki *et al.*, 2004).

As noted earlier, *Phakopsora pachyrhizi* has a wide host range, suggesting that appropriate management and or control of these alternative hosts can help in controlling the disease. This will be particularly useful in sub-Saharan Africa, where a diversity of legumes, which are known hosts of *Phakopsora pachyrhizi* are cultivated. A case in point is from Australia, where it is strongly recommended not to grow soybean near the tropical forage legume *Neonotonia wightii*, which hosts the fungus (Anon., 1974). In other studies, fields with poor drainage have been reported to have more rust than fields with good drainage (AVRDC, 1992).

SOYBEAN RUST RESEARCH IN AFRICA

There is scanty information on soybean rust in Africa; only a few yield loss and rust screening trials have been conducted (Tables 3 and 4). Therefore, information gathered from the soybean rust endemic areas as evidenced in the foregoing sections, is relevant to African countries, which are currently experiencing the rust epidemic. Gathering and exchange of information between soybean rust scientists within Africa, will also contribute to a better understanding of the disease epidemiology, and hence its management. This section briefly examines soybean rust research activities in the most severely affected countries

in Africa namely, Uganda, Zimbabwe, South Africa and Nigeria.

Uganda. Soybean was introduced to Uganda in the early 1900's (Hittle, 1987). To date, it is produced on 151,000 ha (FAO, 2002). Soybean rust was first observed in the country in 1996 at Namulonge Agricultural Research Institute, in central Uganda; thereafter the disease was observed on farmers' fields throughout the country. Between 1996 and 1998, a total of 196 soybean materials, 57 from IITA, 93 from Zimbabwe (SEEDCO), 9 from South Africa (PANNAR) and 3 local, were screened for rust resistance at Namulonge Agricultural Research Institute. None of these accessions was immune to rust infection, eight were resistant, 45 moderately susceptible, 31 susceptible and 112 very susceptible (Tukamuhabwa, pers. Comm.). However, of the 8 genotypes rated as resistant, only one, UG-5 exhibited resistance traits under advanced field testing. Most of the genotypes reacting as moderate susceptible, later deteriorated to susceptible and very susceptible category with maturity, indicating that rust gets more intensified as the crop advances from R5 to R7 stage. Line UG-5 was clearly tolerant; it developed rust spores, but they could not sporulate and it was the only one, which reacted to rust in such a manner. Soybean rust research only began in 2000 through collaborative efforts between the National Agricultural Research Organisation (NARO) and Makerere University. The objectives were to: 1) establish the incidence, severity and race pattern of soybean rust in Uganda, 2) quantify yield loss associated with soybean rust, 3) develop a fungicide spray regime, and 4) screen soybean introduction for resistance. Soybean rust was found prevalent in all the major soybean growing areas in the country, with severities of over 90 percent (Lamo, 2004).

All commercial varieties (Nam 1, Nam 2 and Namsoy 3) are highly susceptible, registering yield losses as high as 40 percent (Kawuki *et al.*, 2003b). Yield losses vary with season and location; the central region experiences higher yield losses as compared to the northern region. Soybean introductions from the International Institute of Tropical Agriculture (IITA) have been screened; only 2 lines (TGx 1835-10E and TGx 1838-5E) were graded as moderately resistant (Kawuki *et*

TABLE 3. Yield losses associated with soybean rust in some African countries

Country	Yield loss	Source
Uganda	23-36	Kawuki <i>et al.</i> , 2003
Zimbabwe	60-80	Levy, <i>pers. comm.</i>
Nigeria	23-42	Akinsanmi <i>et al</i> 2001
Togo	30-50	Mawuena, 1982
South Africa	4-23	Pretorius <i>et al.</i> , 2001

al., 2004). The early maturing lines registered higher levels of rust tolerance (yields $>1.2\text{ t ha}^{-1}$). High rates of rust development or low rates were not consistently associated with higher rust susceptibility and/or lower rust susceptibility (Table 4). Racial identification studies using a set of 19 differentials have confirmed presence of at least two races of rust in Uganda (Lamo, 2004).

Fungicide evaluation trials have also been conducted (Kawuki *et al.*, 2002). Three fungicides: dithane-M45 (contact wettable powder), saprol and folicur (both systemic), were evaluated under three spray regimes (weekly, 2-weekly, and 3-weekly sprays), from disease onset to full seed formation. These corresponded to 5, 3, and 2 sprays, respectively. The highest yield increase with dithane-M45 (26.9%), saprol (33.3%), and folicur (38.9%), respectively were obtained under the weekly, 2-weekly, and 3-weekly spray schedules. The implications are that the spray schedule will vary depending on the type of fungicide, and that systemic fungicides are more effective than protectant fungicides, as they require less number of sprays. Current research activities include: 1) molecular characterisation of rust the pathogen in Uganda, 2) screening more fungicides and manipulation of spray schedules to come up with the most economically profitable package, 3) screening introduced soybean germplasm from

AVDRC and IITA for possible sources of resistance/tolerance, and 4) hybridisation programmes aimed at improving the locally adapted cultivars using the identified resistant/tolerant lines.

Zimbabwe. Soybean have since the 1940's been produced on commercial farms, it is just of recent that the crop has been adopted on the smallholder sectors (Mpepereki *et al.*, 2000). Available statistics indicate that soybean is currently being produced on 77,150 ha (FAO, 2002). Soybean rust was first identified in Zimbabwe in January 1998, but it now occurs in all soybean-growing regions (Levy and Frederick, 2001; cited by Zakheleni *et al.*, 2002); seasonal appearances of soybean have also been observed. All commercial varieties (Storm, Solitaire, Magonye, and Hurungwe) are susceptible to rust (Zakheleni *et al.*, 2002). On commercial farms yield losses ranging between 60-80 % have been reported (C. Levy, *pers. comm.*), while on communal farms yield losses of 50-100% have been registered (S. Mpepereki, *pers. comm.*). The University of Zimbabwe with support from the Rockefeller Foundations' Forum on Agricultural Husbandry is implementing research on soybean rust (Koomen, *et al.*, 2002; Zakheleni *et al.*, 2002). The research is examining the effect of planting

TABLE 4. Reaction of selected soybean lines to rust in Uganda (Kawuki *et al.*, 2004)

Entry	Rust reaction at R6 ¹	Rate of rust development ³	Yield kg ha ⁻¹
a) Early maturing (85-99 days)			
TGx 1835-10E	MR ²	0.184	1535
TGx 1740-2E	MS	0.131	1486
TGx 1876-4E	MS	0.127	1325
TGx 1805-8F	MS	0.108	1251
B) Medium maturing (100-110 days)			
TGx 1895-50F	MS	0.114	1179
TGx 1895-33F	MS	0.153	1079
TGx 1893-10F	MS	0.153	1063
TGx 1895-49F	MS	0.118	1015
c) Late maturing (111-120 days)			
TGx 1838-5E	MR	0.146	938
TGx 1848-10E	MS	0.134	647
TGx 1869-13E	HS	0.149	516
TGx 1844-4E	HS	0.143	350

¹See Fehr and Carviness (1977); ² MR= moderately resistant, MS = moderately susceptible, HS =highly susceptible; ³ Slope of the linear regression of the relative life time (RLT) on the logit transformation of rust severity

date on rust severity; results so far obtained indicate that the earlier planted crop registered higher severity as compared to the latter planted crop (Zakheleni *et al.*, 2002). These findings are consistent with earlier findings (Desborough, 1984; do Vale *et al.*, 1985).

On commercial farms, soybean rust is being controlled by fungicide application; three triazole fungicides, Tilt (propiconazole), Punch extra (flusilazole), and Score (difenoconazole) are being used (C. Levy, *pers. comm.*). Farmers are advised to be vigilant and spray against the disease 2 or 3 times a season depending on the severity; the first application being made at approximately 50 days after planting, and thereafter on 20-day intervals.

Collaborative research activities with institutions in USA, Australia, and Taiwan have been initiated; the research on soybean rust is being implemented at Rattray Arnold Research Station, Harare. Efforts are being directed towards: 1) screening soybean introductions against rust, 2) evaluating fungicides and spray regimes against rust, and 3) breeding for rust resistance.

Nigeria. Soybean is produced on 624,000 ha (FAO, 2002), making Nigeria the largest producer of soybean in Africa. Soybean rust was first observed in Nigeria in 1999 on soybean farms in Oniyo and in the neighbouring villages of Ogbomoso (Akinsanmi *et al.*, 2001). Thereafter, the disease was observed in Benue State, the major soybean producing region in Nigeria. Yield loss due to rust infestation on three commercial TGx varieties (TGx 1485-1D, TGx 1448-2E, and TGx 1440-1E) were 28, 52, and 49%, respectively (Akinsanmi *et al.*, 2001); it was also established that soybean planted late was most affected by rust. This finding is however, in sharp contrast with earlier studies (Desborough, 1984; do Vale *et al.*, 1985), which established that late planted soybean tends to escape rust infection, and thus experiences lower yield losses as compared to the early planted crop.

Currently, the International Institute of Tropical Agriculture (IITA) is pursuing most research on soybean rust in Nigeria. On-going research activities include: 1) studies on the effect of variety and planting date on rust progress, 2) screening available fungicides against rust, 3) screening of soybean germplasm against rust, and

4) developing soybean populations through hybridization, and 5) studying mechanism of resistance to the Nigeria strain(s) of soybean rust. The Soybean Programme, Oilseeds Division is also conducting studies on soybean rust in the northern Guinea savannah of Nigeria.

South Africa. Soybean is produced on 124,150 ha (FAO, 2002), with most production being concentrated in KwaZulu-Natal (KZN), an area associated with medium to high rainfall amounts. The first report of soybean rust in the country was in February 2001, when it was found near Vryheid in northern KZN (Pretorius *et al.*, 2001). Subsequently, the disease was observed in other parts of the country, Karkloof, Cedara, Howick, Greytown, Piet Relief, Bergville, Amsterdam and Ermelo, with more severe epidemics in the humid eastern production areas. All the commercial varieties (Pan 589, Pan 780, Pan 854, Octa, and Prima) are highly susceptible. For the moment, fungicides are the mainstay against soybean rust; triazole fungicides have received emergency registration, and are being used for control of soybean rust (Pretorius *et al.*, 2001).

Soybean rust research is being conducted by both academic and national research institutes. Neal (2001) outlined priority research areas; the epidemiological significance of disease foci, identification of sources of resistance and races, prediction models, and optimization of spray regimes. Additionally, the University of Natal is also conducting soybean rust research (<http://www.ppath.unp.ac.za>). The research is investigating: 1) the role of environmental factors (temperature, relative humidity), and overwintering uredospores on the development of soybean rust; 2) screening fungicides (particularly triazoles), and manipulation of spray schedules and rates against rust; and 3) establishment of the rust races using differential set from the AVRDC. The United States Development Agency (USDA) has initiated collaborative work with South Africa to screen US soybean varieties for rust resistance under field conditions.

Other African countries. For the other rust-affected countries: Kenya, Mozambique, Rwanda, Burundi, Zambia, Botswana, Ghana, Sierra Leone,

Sudan, Tanzania, Democratic Republic of Congo and Malawi, information is very scanty, and not conclusive. In fact, some have just reported the presence of the disease, without any quantification. Nevertheless, even where research is well underway, information is scanty and there is very limited inter-African collaboration.

CONCLUDING REMARKS AND FUTURE RESEARCH DIRECTION

It is apparent that soybean rust has now established in Africa. For other soybean growing countries, which currently are unaffected by the disease, it is just a matter of time before the disease occurs. The pathogen is well adapted for long-distance dispersal, because the spores can be readily carried by the wind, making it an ideal means for introduction to new, rust-free regions. Since environmental conditions appear to favour the rust pathogen (as observed from the rapid and widespread rust epidemics in the affected countries), complete eradication of the disease is practically not possible. The disease is here to stay, but we must minimise its disastrous effects on the crop.

In terms of control, management experiences from Asia can in the mean time be replicated in Africa, as the disease is studied under our local conditions. However, a few issues need to be considered before implementation of these control strategies. First, fungicides are currently the main control measure in the rust affected countries; this is mainly because resistant and/or tolerant soybean cultivars are virtually absent. It suffices to note that fungicides should be used with utmost caution; the fungicide resistance that occurred with the late blight fungus *Phytophthora infestans* management (Dowley and O'Sullivan, 1981) should be avoided. This can be achieved by use of an array of fungicides of different active principals (Table 1). Secondly, for cultural practices, some of the rust control practices are readily applicable (i.e., sowing early maturing varieties, varieties with a short pod-filling stage, and strategic selection of planting sites). Others are however, difficult to apply (e.g. control of alternative hosts and adjusting sowing dates). For host plant resistance, virtually no resistant and/or tolerant cultivars are available in most rust affected

countries. This should be a priority focus, which justifies collaborative undertaking both within and outside the continent. To maintain the soybean crop on the continent, it is necessary that soybean rust epidemic be contained; both basic and applied research activities are necessary. Hereafter, we examine priority research areas.

Early and accurate detection of disease causative agents is an important aspect of understanding disease epidemiology and reducing their impact. Equally important is an update of the distribution and spread of alien pests, in this case soybean rust in Africa. It is therefore, important that protocols be developed that can both accurately and quickly distinguish the soybean rust biotypes. As reported earlier, primers have been developed for polymerase chain reaction (PCR) for identification of the two *Phakopsora* species. The primer base should however, be broadened by carrying out further research. Key sequences of DNA to distinguish the soybean rust fungus from other related species should also be established.

Phakopsora pachyrhizi is highly variable; it is therefore crucial that its race pattern be established at both regional and national level, as this will help in strategic deployment of resistant cultivars across the continent. This can best be achieved using molecular based techniques. At the local level, information on disease forecasting and early detection (initial symptoms) will be needed. This would help in the timely management of the disease; development of education manuals for soybean rust identification and management will be useful in this aspect.

Detailed studies on the epidemiology of soybean rust, in particular the influence of climatic factors (rainfall patterns, temperature, humidity); alternative hosts; altitude; and cropping systems (crop rotation and intercropping), on soybean rust severity need to be explored. The cropping system in Africa is very complex and variable, and thus needs to be incorporated in soybean rust studies. Equally important is the quantification of regional and national yield losses associated with soybean rust infection. This will help in assessing the economic impact of the disease, and consequently help in the formulation of appropriate rust management strategies. Other management interventions (cultural practices, fungicide use, host plant resistance, and perhaps biological

control) need to be addressed at both regional and national levels. Clearly, a regional network to coordinate soybean rust research will be necessary to implement this research. The network should also monitor and initiate collaborative efforts with the necessary stakeholders, specifically, with the soybean rust researchers in the endemic regions.

Capacity building is a key component of agricultural development. It is necessary therefore that a critical mass of scientist be trained on soybean rust. Agricultural based universities within and outside Africa can provide appropriate training at masters and PhD level. This endeavour will considerably boost regional and national capacity for research. Also, opportunities for exchanging information should be forged through which soybean rust scientists in Africa can have a forum to exchange information and network. In this respect, annual workshops or conferences can be extremely useful in this aspect.

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