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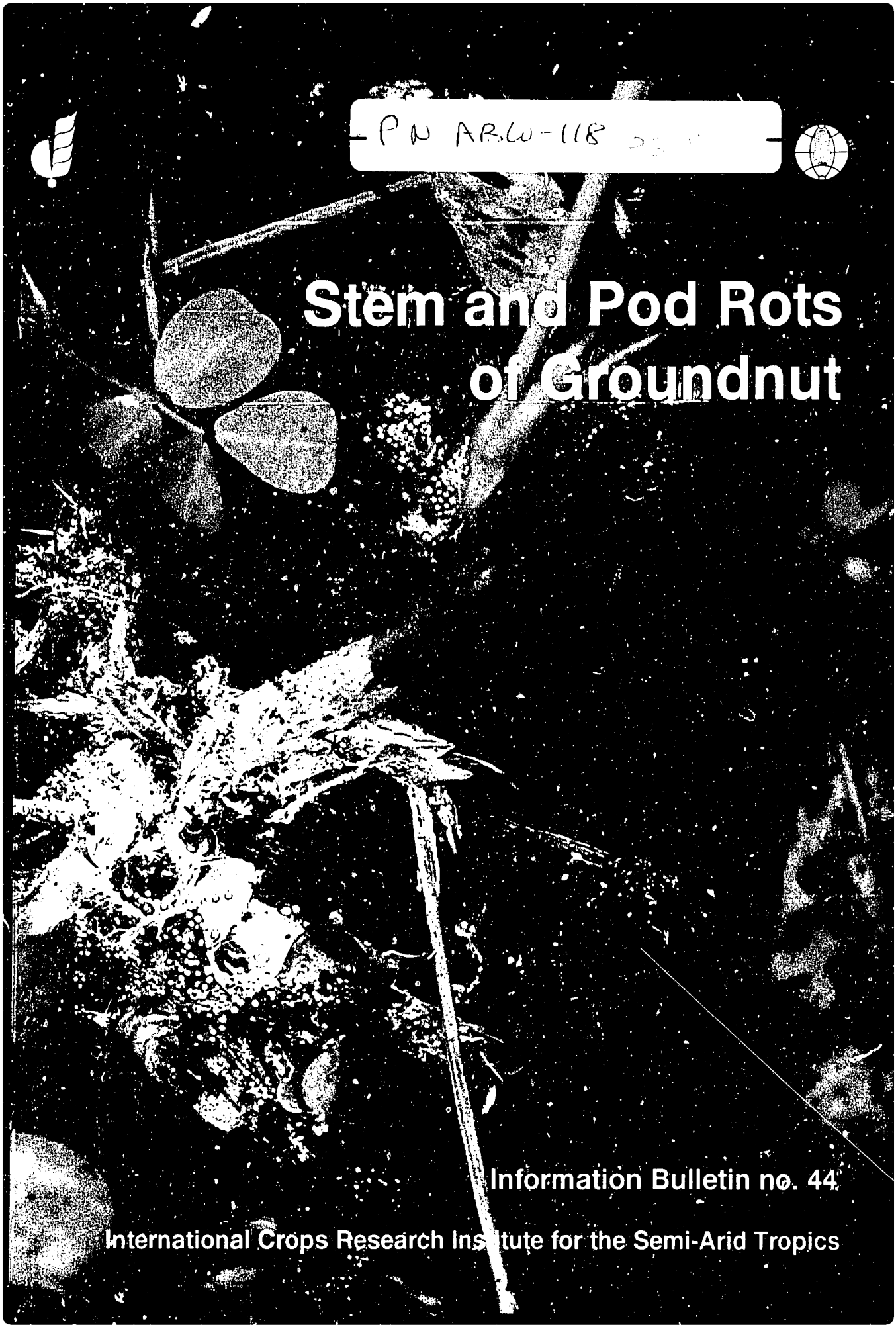
Stem and Pod Rots of Groundnut



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Abstract

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Stem and pod rots caused by *Sclerotium rolfsii* affect groundnut crops in many countries, reducing yields by 10–25%. Pod yield losses can reach over 80% in heavily infested fields. This publication summarizes the considerable progress that has been made in understanding the epidemiology of the diseases. Effective greenhouse- and field-screening techniques have been developed, resistance sources identified, and some resistant cultivars bred. Options for disease management are discussed, and an integrated disease management approach is advocated.

Résumé

Pourriture de la tige et des gousses de l'arachide. La pourriture de la tige et des gousses causée par *Sclerotium rolfsii* affecte les cultures arachidières dans plusieurs pays et abaisse les rendements de 10 à 25%. Les pertes de rendement en gousse peuvent dépasser 80% dans les champs sévèrement infestés. Cette publication fait le point sur les progrès considérables faits dans les connaissances de l'épidémiologie de ces maladies. On a pu mettre au point des techniques de criblage efficaces en serre et aux champs, identifier des sources de résistance et élaborer des cultivars résistants. Des options dans la lutte contre ces maladies sont examinées et la lutte intégrée est recommandée.

Resumen

Descaecimiento de vainas y tallos en maní. El descaecimiento de vainas y tallos causado por *Sclerotium rolfsii* afecta las cosechas de maní en muchos paises de manera que se reduce el rendimiento por un 10 a 25%. Las perdidas de vainas pueden alcanzar un 80% en campos con fuertes infestaciones. Esta publicación resume el progreso alcanzando en el entendimiento de la epidemiología de las enfermedades. Se han desarrollado tecnicas eficaces del invernadero y del campo y tambien se han identificado las fuentes de resistencia y se han producido algunos cultivares resistentes. La publicación examina las distintas opciones del manejo de enfermedades y aboga por un manejo integrado de enfermedades.

Stem and Pod Rots of Groundnut

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Foreword

Stem and pod rots caused by *Sclerotium rolfsii* are groundnut diseases of economic importance in North America; in the USA they have been major diseases for over 40 years. In the state of Georgia alone, the annual yield loss is valued at US$ 43 million. The pathogen is widespread and has been recorded in most groundnut-producing areas of the world, but only rarely has it been reported to cause serious damage outside North America. This situation appears to be changing, and *S. rolfsii* induced stem and pod rots are reported to be causing significant damage to groundnut in several humid tropical environments. Concern has also been expressed about their potential to cause economic damage to groundnut crops grown in soils of high organic matter content in those parts of the semi-arid tropics where assured rainfall or irrigation favor high productivity.

This information bulletin provides a comprehensive description of the pathogen and the groundnut diseases it causes. Up-to-date information is provided on control measures, and this book should be a valuable reference source to those concerned with developing disease management packages and advising farmers. Techniques to isolate the causal fungus and identify resistant germplasm are described, and should be useful to research scientists worldwide.

The authors are to be commended for their interest and dedication in developing this publication. The Peanut Collaborative Research Support Program (Peanut CRSP) is pleased to cosponsor its publication.

David G Cummins
Program Director, Peanut CRSP

Introduction

Stem and pod rots of groundnut (*Arachis hypogaea* L.) caused by *Sclerotium rolfsii* Sacc. are major constraints to production in many countries in Asia, Africa, and the Americas. Stem rot, also known as southern blight, southern stem rot, sclerotium rot, or white mold, is the most important groundnut disease (in economic terms) in the southern USA. Peg and pod rots caused by *S. rolfsii* are common in parts of many countries, and result in pod loss at harvest. Peg and pod rots can be caused by several other fungal pathogens such as *Fusarium*, *Rhizoctonia*, and *Pythium* spp. In some cases it may be difficult to diagnose the specific pathogens involved, but *S. rolfsii* symptoms can be easily distinguished from those caused by other pathogens. *Sclerotium rolfsii* stem and pod rots are a potential threat to groundnut production in many warm, humid areas, especially where irrigated groundnut cultivation is expanding, or where cultural practices are changing.

Geographical Distribution and Importance

Stem and pod rots caused by *S. rolfsii* occur wherever groundnut is grown (Fig. 1). They are widely distributed in India and the USA, and cause serious losses in Bolivia, China, Egypt, India, Taiwan, Thailand, and the USA. The diseases are also important in parts of Argentina, Australia, Bangladesh, Botswana, Brazil, Côte d'Ivoire, Indonesia, Israel, Japan, Lesotho, Mali, Nepal, Nigeria, Papua New Guinea, Paraguay, Peru, the Philippines, Rwanda, Senegal, South Africa, Tanzania, Uruguay, Zambia, and Zimbabwe.

In the USA, stem rot is most severe in the southeastern states (Texas, Georgia, Oklahoma), where it has been a major disease of groundnut for nearly 40 years. Pod yield losses commonly range from 10 to 25%, but can reach over 80% in heavily infested fields (Porter et al. 1982, Bowen et al. 1992, Mehan and McDonald 1990). In Georgia, the largest groundnut-producing state in the USA, annual yield losses caused by stem rot are valued at US$ 43 million (Branch and Brenneman 1993, Georgia Cooperative Extension Service estimates, 1988–93). It is also important in North Carolina, Alabama, Florida, and New Mexico.

In India, stem rot occurs in all groundnut-growing states; it is most severe in Maharashtra, Gujarat, Madhya Pradesh, Karnataka, Andhra Pradesh, Orissa, and Tamil Nadu, where it is estimated that over 500 000 ha of groundnut fields are infested with the pathogen. Yield losses of over 25% have been reported (Mayee and Datar 1988). Pod rot incited by *S. rolfsii* is also economically important in central and southern Maharashtra, and in parts of Uttar Pradesh, Orissa, Bengal, Bihar, Punjab, Gujarat, and Karnataka.

In Thailand, stem rot is serious in the northeastern region (Lim et al. 1989, Wongkaew et al. 1989). In Indonesia, minor attacks of stem and pod rots are relatively common; severe attacks have been reported, but are sporadic (Moehadi 1978, Mehan, V K, personal communication). In the Philippines, stem rot is particularly severe in the wet season (Valencia and Natural 1988). The disease has recently increased in importance in Australia. *Sclerotium rolfsii* stem and pod rots are widespread in South America, and are economically important in Bolivia, Paraguay, and Uruguay (Godoy and Giandana 1992).

In South Africa, *S. rolfsii* causes stem rot of groundnut, and is considered to be a threat to production (Kolte 1985).

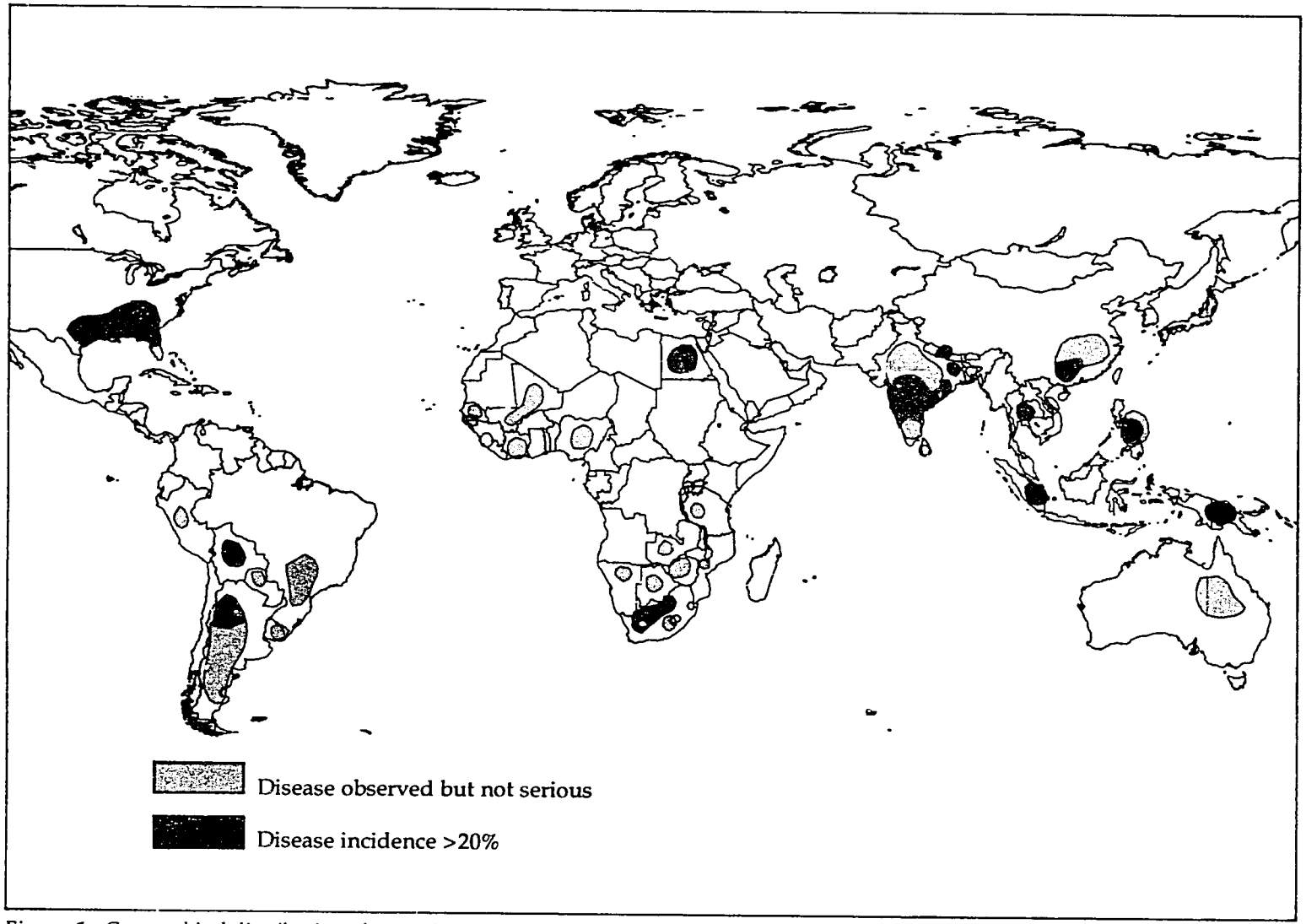

Figure 1. Geographical distribution of groundnut stem and pod rots induced by Sclerotium rolfsii.

Stem rot has also been reported from Bangladesh, the Dominican Republic, Japan, Nepal, South Korea, Sri Lanka, and Vietnam, but information on disease patterns is sparse and the present status of the disease in these countries is unknown.

Symptoms

The first symptoms of stem rot are the yellowing and wilting of a lateral branch or, if the main stem is attacked, of the whole plant. Leaves on affected branches become chlorotic and then turn brown as they rapidly dry out. Sheaths of white mycelium of *S. rolfsii* are seen around affected plants at or near the soil surface, imparting a 'white-washed' appearance to the base of the affected plants (Fig. 2). This mycelial growth may radiate out over the soil surface, and is best observed when the soil surface is moist. Mycelium may not be visible on affected plant parts during periods of drought, but may still be active below ground, causing lesions on underground plant parts.

Lesions on infected stems are at first light brown, then become dark brown. Advanced symptoms develop when lesions coalesce to girdle the lower stem (Fig. 3). The infected areas of the stem become shredded and the sheathing mycelium quickly produces abundant spherical sclerotia on the surface of the affected plant parts or on the soil surface adjacent to affected plants. The sclerotia are initially white but soon turn dark brown as they

Figure 2. Groundnut plant showing white-washed appearance of base of stem.

Figure 3. Advanced symptoms of stem rot (lesions girdling the stem).

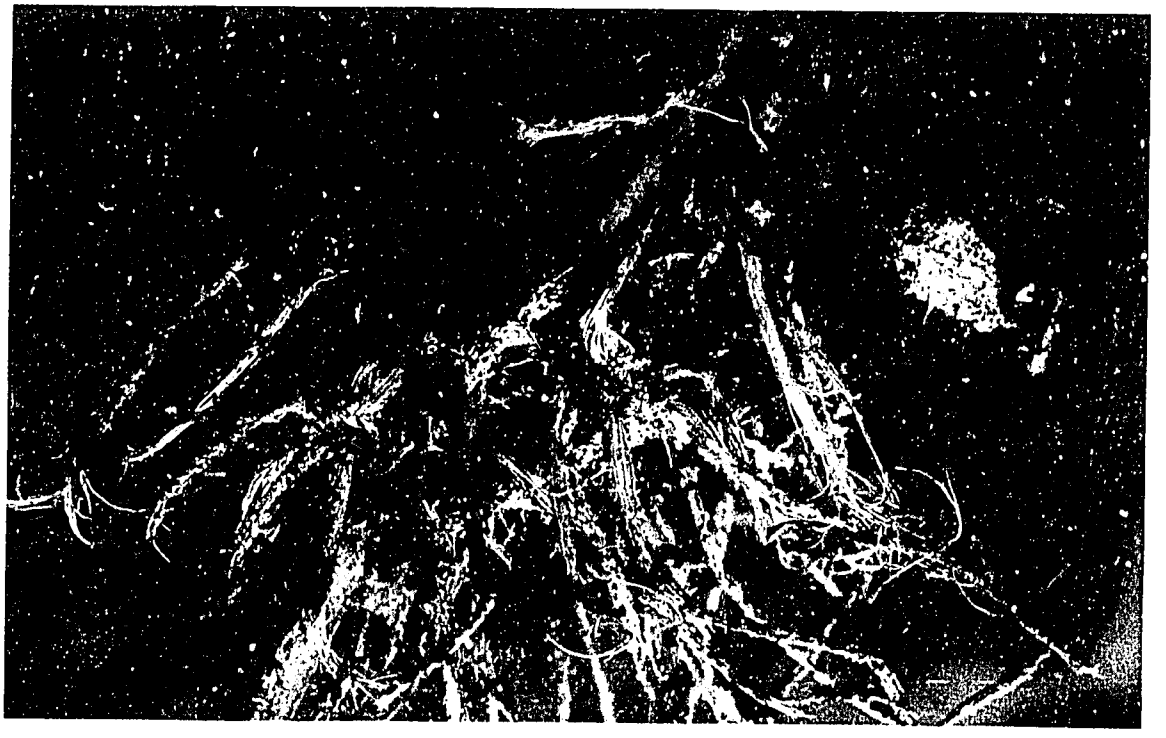

Figure 4. Peg colonization by Sclerotium rolfsii *and consequent loss of pods.*

mature. Shredded stem tissue is a typical symptom of stem rot. Wilt and death of a single branch or of the entire plant may follow. Dead plants tend to remain upright in the row.

Pegs colonized by *S. rolfsii* first show light to dark brown lesions; they later become shredded and pods become detached and are left in the soil at harvest (Fig. 4). Pods are also attacked; affected young pods show light tan colored lesions. Severely infected pods are completely covered with a white mycelial mat (Fig. 5). In some cases, the seeds from diseased pods show a characteristic bluish-gray discoloration of the testa, known as 'blue damage' (Fig. 6). This is caused by oxalic acid produced by the fungus.

Causal Organism

Morphology and taxonomy

Sclerotium rolfsii Saccardo
Corticium rolfsii (Sacc.) Curzi
Pellicularia rolfsii (Sacc.) West
Aethalia rolfsii (Curzi) Tu & Kimbr. (teleomorph)

The name *Sclerotium rolfsii* was given by Saccardo (1911), who characterized the fungus as an imperfect form without asexual spores. The basidial stage was subsequently known from culture only and was assigned the name *Corticium rolfsii* (Sacc.) Curzi, later changed to *Pellicularia rolfsii* (Sacc.) West (West 1947). The basidial stage is rarely found in nature, and it is a common practice to use the name of the sclerotial stage.

Figure 5. Groundnut pods shredded as a result of colonization by Sclerotium rolfsii.

Figure 6. 'Blue damage' of seeds caused by Sclerotium rolfsii.

The pertinent morphological characters of the sclerotial stage are:

Mycelium: is septate and hyaline with conspicuous branching at acute angles. The well-developed mycelium is in cord-like strands. The hyphae have clamps in the form of forks and hooks or H-like connections (Aycock 1966). The young growing mycelial mass, in vivo and in vitro, is snow-white with a silky luster. The developed mycelium growing in strands at its tips initiates sclerotial formation in 6–12 days (Fig. 7).

Sclerotia: are at first white, becoming light brown to dark brown at maturity. They are subspherical, the surface being finely wrinkled or pitted; sometimes flattened, commonly 0.5–1.5 mm in diameter.

The important characters of the basidial stage are:

Hymenium: is at first coarsely areolate, becoming more dense with the addition of basidia, but never forming a continuous or fleshy layer; 30–40 μ thick, white to gray in color (West 1947).

Basidia: are obovoid, 7–9 μ long by 4–5 μ wide, each bearing 2 to 4 parallel or divergent sterigmata that bear basidiospores.

Basidiospores: are hyaline, smooth, elliptical to obovate, rounded above, rounded to pointed at the base, apiculate; 3.5–5.0 μ by 6–7 μ.

Cultural characteristics

Sclerotium rolfsii grows well on a wide range of culture media. The addition of thiamine @ 0.1 ppm to culture media encourages abundant growth of the fungus. Growth occurs over a wide range of pH (1.4–8.8), the optimum being pH 3–5. The temperature range for growth is 8–40°C, the optimum being 27–30°C. The number and size of sclerotia are influenced by the sources of carbon and nitrogen in the medium, and by pH. In general, media that support extensive mycelial growth yield the highest number of sclerotia (Fig. 7).

Although pronounced variability in morphological characteristics of various *S. rolfsii* isolates is well documented (Punja 1985), there are only a few reports of differences in pathogenicity and virulence of isolates from various hosts (Cooper 1961). Recent studies have confirmed that *S. rolfsii* isolates may vary considerably in their ability to colonize groundnut plants (Shokes, F M and Brenneman, T B, un-

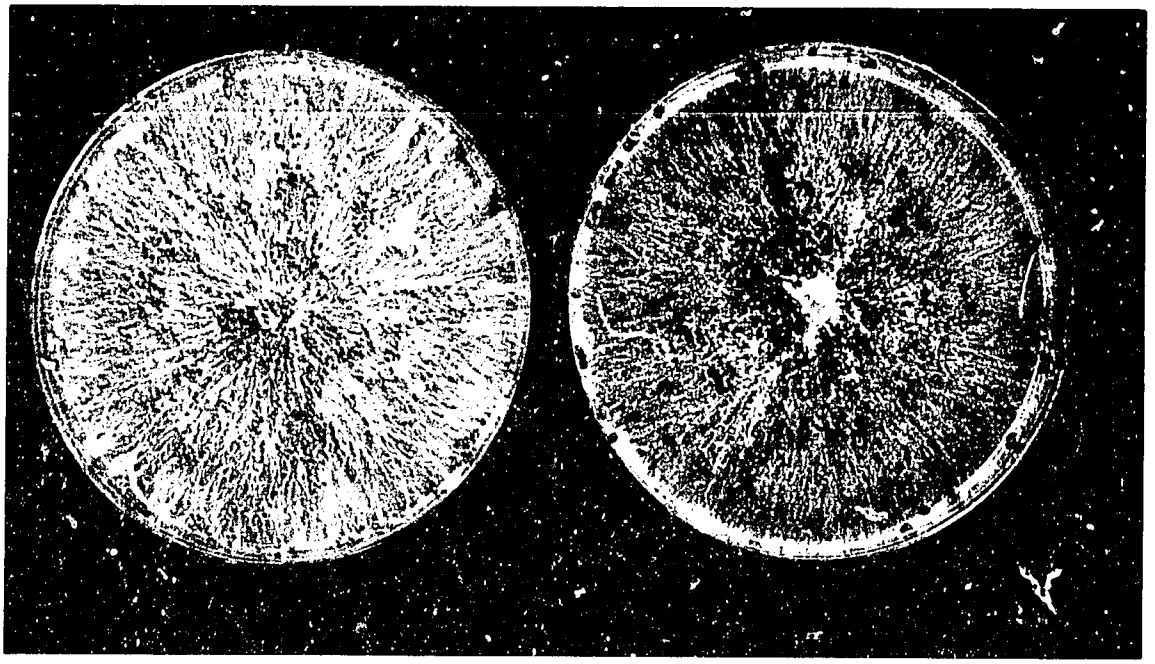

Figure 7. Typical cultures of Sclerotium rolfsii *isolates on potato dextrose agar, showing mycelial and sclerotial production.*

published). Host specialization has not yet been demonstrated.

Selective medium for isolation of *Sclerotium rolfsii*

Sclerotium rolfsii grows rapidly in vitro and is readily isolated from diseased plants on most general-purpose media. The selective medium developed by Backman and Rodriguez-Kabana (1976) is useful for isolation of *S. rolfsii* from soil. The composition and procedure for its preparation are given below.

1. Mix 1 g KH_2PO_4, 0.5 g $MgSO_4.7H_2O$, 2 g KNO_3, 0.001 g thiamine hydrochloride, 10 mL of minor element solution (containing 1 g $FeSO_4.7H_2O$, 0.6 g $MnSO_4.H_2O$, and 1 g $ZnSO_4.7H_2O$ L^{-1}), 0.16 g gallic acid, and 10.0 g potassium oxalate in 250 mL of distilled water. Filter-sterilize this solution and adjust its pH to 4.2 with HCl.
2. Dissolve 20 g agar in 750 mL of distilled water, and steam-sterilize it for 15 min at 121°C. Allow it to cool to 60°C.
3. Mix 1 with 2, and pour the medium into plates immediately.

Soil sampling for sclerotial recovery

Sclerotia of *S. rolfsii* are irregularly distributed in fields, in clusters or aggregates (Punja et al. 1985), and this determines the pattern of disease distribution. The population mean and frequency distribution of sclerotia are influenced by the sample size and sampling pattern. For determining the spatial pattern of inoculum, it is useful to assay large soil samples, and to consider both biological and

statistical parameters. The biological parameters include:

- Depth of soil
- Volume of soil
- Sclerotial extraction procedure.

Soil sampling can be done by taking 10–20 cores at random or at specific locations along diagonal paths within a plot/field. Soil cores are obtained by inserting a 2.5-cm diameter soil auger 15 cm deep (Rodriguez-Kabana et al. 1974, Shew et al. 1987) and bulking the samples. Soil samples are placed in polythene bags and stored in insulated containers for more than 5 days before assay. Subsequently, replicate subsamples are taken for determining inoculum density in the soil.

Techniques for recovering sclerotia from soil

Several techniques are available for recovering *S. rolfsii* from soil. These include wet-sieving (Leach and Davey 1938), flotation sieving (Rodriguez-Kabana et al. 1974), and methanol assay (Rodriguez-Kabana et al. 1980). The flotation-sieving technique is an adaptation of the method used to extract nematodes from soil. It is the most rapid procedure, but is relatively expensive. This is based on the use of an extraction solution containing a flocculating agent and with a density equal to or higher than that of the sclerotia. The wet-sieving technique (repeated washing and sieving of soil) is time consuming but very efficient.

Flotation-sieving technique

1. Sieve air-dried soil through a 4 mm screen.
2. Place a 50 mL (70 g) subsample in a 600 mL flask/beaker, and add extracting solution to a volume of 350 mL.
3. Shake vigorously (1600 rpm) for 30 sec, and allow the solution to settle for 30 sec.
4. Decant the liquid rapidly through a 250 μ (60 mesh) screen 7.5 cm in diameter.
5. Wash the residue into a dish, and count sclerotia under diffused white light.

The extracting solution is prepared by mixing 200 mL of blackstrap molasses (density 1.3 g cm^{-3} at 25°C), 800 mL of tap water, and 12.5 μg mL^{-1} of the flocculating agent Separan® NP 10. This extracting solution should have a density of 1.073 g cm^{-3} at 25°C. Sucrose can be used to adjust the solution to this density.

Wet-sieving technique

1. Sieve a weighed amount of soil through a 0.35 mm screen.
2. Wash the residue remaining on the screen, transfer it to a beaker, and distribute the particles evenly on a set of filter papers in a Buchner apparatus. Six to eight filter papers can be placed in each 9 cm culture plate.
3. Dispense 1% agar into culture plates to 2.5 mm depth, and immediately invert the uppermost filter paper on the agar surface to transfer the inoculum.
4. Agitate the culture plates to dislodge and disperse the particles.
5. After 18–24 h, transfer the colonies that develop onto potato dextrose agar for identification. The colonies are best observed by holding the plates against a black background in fluorescent light.

Methanol assay

1. Sieve air-dried soil through a 4 mm screen.
2. Spread the soil (500 g) evenly in a thin layer (2–3 mm) on a layer of absorbent paper towel at the bottom of a large (34 × 24 × 5 cm) aluminium baking pan. Plastic trays can also be used.

3. Moisten the soil with 60–75 mL of 1% aqueous methanol, distributing the solution as evenly as possible.
4. Place the pan in a polythene bag sealed to reduce moisture loss, and incubate at room temperature (27–30°C) for 3–4 days.
5. After incubation, count the white mycelial colonies from the sclerotia on the soil surface.

Methanol stimulates the sclerotia to germinate. With this technique only viable sclerotia are counted.

Viability of sclerotia

The following procedure can be used to assess the viability of sclerotia:

1. Transfer sclerotia to culture plates of the selective medium.
2. Incubate the plates at 27°C overnight and then cover the medium with a layer of 0.01 N iodine solution for 30–40 sec, until the medium surface turns black.
3. Place the plates in a shallow pan containing warm water (35–40°C) and wash off the iodine. Viable sclerotia will be surrounded by a clear halo.

Disease Cycle and Epidemiology

Sclerotium rolfsii survives in the form of sclerotia that can remain viable in the soil for 2–3 years. They serve as the primary source of inoculum and are capable of initiating infection with or without an additional food base (Aycock 1966, Punja 1985).

Survival of sclerotia is generally poorer in moist soil than in dry soil. High temperatures coupled with high soil moisture are more detrimental to survival than are high temperatures alone. Cycles of drying and wetting enhance sclerotial decay by increasing nutrient leakage and subsequent microbial antagonism. In moist soil, sclerotia survive better near the surface than when buried beneath it (Punja and Jenkins 1984); soil aeration affects survival. The fungus can survive as mycelium in the soil only for short periods (1–2 months). The mycelium can be seedborne.

When sclerotia germinate they produce two forms of mycelium—hyphal and eruptive. Hyphal germination is characterized by the growth of individual strands from the sclerotium surface, but growth is not extensive unless an external source of nutrients is available. Eruptive germination is characterized by aggregates of mycelium bursting through the sclerotial rind (Punja 1985). Eruptive germination in soil is greatest at 21–30°C and is less common below 15° or above 36°C. Germination is greatest at the soil surface and decreases with soil depth, probably due to poor soil aeration and microbial antagonism. Volatile compounds from remoistened, undecomposed plant tissue (e.g., senescent or dead groundnut leaves) stimulate germination and growth of *S. rolfsii*.

Organic substrates in the soil are readily colonized by the fungus. Increased inoculum potential and disease severity are positively correlated with the food base. Crop debris that serves as a food base can also serve as an infection bridge. The fungus becomes active primarily at the soil surface, and a mat of hyphae is formed over the basal portions of groundnut plants. It penetrates the plant tissues by forming appressoria, and grows into the host cells killed in advance by the fungus. The fungus kills the host tissue by producing large amounts of oxalic acid and pectolytic and cellulolytic enzymes. Fungal hyphae grow through tissue both inter- and intracellularly.

The production of cell wall degrading enzymes in conjunction with oxalic acid appears to be responsible for the extensive range of plants that are attacked by the pathogen. The fungus affects nearly 500 plant species comprising mainly Compositae and Leguminosae. Graminaceous species are less susceptible.

Moderate to high temperatures (25–35°C) and moist conditions enhance disease development (Aycock 1966, Rodriguez-Kabana et al. 1975), and fluctuations in temperature/moisture levels increase disease incidence and severity. Soil temperatures below 22°C do not favor fungal development. Factors that tend to increase or prolong soil moisture retention (e.g., dense foliage canopy, frequent rains or irrigations) favor stem rot development. During dry periods, *S. rolfsii* does limited damage to above-ground plant parts, but can cause severe pod rot. When plants are killed and the food supply of the fungus becomes limiting, numerous sclerotia develop that are easily dislodged and fall to the soil surface. The beginning of stem rot usually coincides with peg and pod formation, but under particularly favorable conditions, the disease may be initiated earlier.

In the USA, stem rot is most prevalent and severe in sandy or sandy loam soils, whereas in India it is predominant in Vertisols (Mayee and Datar 1988) and relatively less severe in sandy loam soils. *Sclerotium rolfsii* appears to have a high oxygen requirement; in heavier soils, this limits sclerotial germination and disease development to near the soil surface. In lighter soils, where oxygen concentrations are greater, the fungus can be active in the pod zone, causing severe peg and pod rot. Alkaline soils (e.g., in the Sudan) do not favor disease development.

Some cultural practices such as dirting (pushing soil around the base of plants to smother weeds), sowing on the flat, continuous cropping of groundnut in the same field year after year, and addition of phosphatic fertilizers, promote disease development. In general, the diseases are severe in soils with a high organic matter content and more prevalent in soils of high fertility. Mechanical or biological damage to stems or pods may increase disease severity.

Disease Management

Various options are available for the management of stem and pod rots. These include:

- Cultural control measures (crop sanitation, crop rotation, control of moisture, soil amendments, soil solarization)
- Biological control
- Chemical control
- Genetic resistance.

Crop sanitation

Crop sanitation (e.g., burning of crop residues, deep plowing before sowing) is important for stem rot management. Such practices deprive the causal fungus of its food base, which is critical for pathogen proliferation and disease development. Burying crop debris deep in the soil to reduce food availability in the crown area of the plant during crop growth should prove useful in reducing the primary inoculum. Burying undecayed organic matter and plant debris to a depth of at least 9 cm reduces stem rot infection and increases groundnut yields (Garren 1961). The accumulation of leaf litter in the crown area of the plant (as a consequence of damage by foliar insects and/or leaf

spot diseases) should be avoided. The practice of dirting groundnut (where soil is moved against plant limbs and crown) during cultivation, and other cultural practices that cause bruising and smothering of the base of the plant with soil, should be avoided.

As a result of improved weed management and soil conservation methods, efforts are now being made to grow groundnut in reduced-tillage systems. Although results have been somewhat variable, the incidence of stem rot in groundnut sown in small-grain stubble has been similar to or less than disease incidence in plots where the soil was deep turned.

Crop rotation

As *S. rolfsii* is soilborne, rotation of groundnut with nonsusceptible crops is obviously very important. Rotation with such crops as cotton (*Gossypium* spp), maize (*Zea mays*), wheat (*Triticum* spp), onion (*Allium cepa*), and garlic (*A. sativum*) is an effective means of control. It is well established that rotation of groundnut with cotton for 3–4 years can greatly reduce stem rot incidence and severity (Rodriguez-Kabana et al. 1991b). Groundnut-cotton rotation systems are successfully used in Vertisols in central and western India, where stem and pod rots can be severe in the postrainy season. Rotation of groundnut with wheat and maize is also effective against stem rot (Garren 1961, Minton et al. 1991); this is a common practice in parts of northern India and China. Rotation with members of the Liliaceae family (onion and garlic) has proved effective against stem rot in Israel (Zeiden et al. 1986) and India (Asghari and Mayee 1991). In drylands, rotation of groundnut with castor (*Ricinus communis*) and bahiagrass (*Paspalum notatum*) is useful in containing the disease (Rodriguez-Kabana et al. 1991a). In the USA, the introduction of improved bahiagrass varieties such as Tifton 9 has resulted in increased rotation of bahiagrass with groundnut, and the suppression of *S. rolfsii* has been excellent.

Although crop breaks for shorter periods with nonsusceptible crops have proved effective in containing the disease, a gap of at least 4–5 years between groundnut crops is advised for most effective control, especially in soils that are heavily infested with the pathogen. Rotations of 1, 2, or 3 years of bahiagrass resulted in a cumulative decrease in stem rot, although the mycoflora from groundnut pods was similar to that where groundnut had been grown continuously (Brenneman et al. 1994a). Little is known as to how different cropping systems affect soil microorganisms in general and the perpetuation/survival of *S. rolfsii* in particular.

Control of moisture

Practices that reduce moisture retention in the canopy discourage stem rot infection and development. Sowing on raised beds improves drainage and reduces moisture in the canopy. It also reduces the accumulation of leaf litter in the pegging zone (since litter is washed into the row furrows). In several demonstration trials on Vertisols in Maharashtra, India, stem rot incidence was much lower on raised beds than on flat-sown groundnut (Mayee, C D, personal communication). Irrigations should be properly scheduled, with adequate but not excessive amounts of water, and the length of dry periods between irrigations should be maximized. In areas where groundnut is grown under irrigation in the dry season, it should be possible to reduce disease levels by maximizing the dry periods between irriga-

tions, since the mycelium (pathogenic phase) is vulnerable to desiccation.

Soil amendments

Soil application of urea, ammonium nitrate, and ammonium bicarbonate reduces stem rot incidence (Harrison 1961, Maiti and Sen 1985). These fertilizers are likely to inhibit sclerotial germination and retard mycelial growth, especially if ammonia is released. Nitrogenous fertilizers also help the host recover from lesions initiated by the pathogen during early growth. Nitrites inhibit fungal growth. Increased calcium levels in plant tissues following applications of calcium nitrate or calcium sulphate provide some disease control, especially under low inoculum pressure. High levels of calcium in plant tissue partially offset the action of oxalic acid and cell wall degrading enzymes produced by the pathogen. Soil application of gypsum reduces stem rot and increases yield (Grichar and Boswell 1990). However, severe outbreaks of stem rot still occur in the southeastern USA in fields where gypsum is routinely applied to groundnut as a calcium source. Calcium deficiency can predispose groundnut pods to rot induced by a number of pathogens including *S. rolfsii*. Phosphatic fertilizers promote stem rot but potassium fertilizers reduce the incidence of the disease.

Soil solarization

Soil solarization has proved useful in reducing stem and pod rots of groundnut (Grinstein et al. 1979, Mihail and Alcorn 1984). Soil is mulched with transparent polythene sheets for 6 weeks during the hot season, raising the soil temperature to >40°C. This affects the survival ability of the pathogen for a very long period and also increases its vulnerability to antagonists. Solarization can be adopted in areas where air temperatures are high (above 42°C) and irrigation facilities are available.

Biological control

Several soil fungi (e.g., *Trichoderma harzianum*, *T. aureoviride*, *T. longibrachiatum*, *Gliocladium virens*), bacteria (*Pseudomonas fluorescens*, *P. aeruginosa*, *Bacillus subtilis*), and mycorrhizal fungi are highly antagonistic to *S. rolfsii* (Elad et al. 1982, Ganesan and Gnanamanickam 1987, Henis et al. 1984, Sreenivasaprasad and Manibhusanrao 1990). Although these microorganisms suppressed stem rot under controlled experimental conditions, efficacy in the field has been inconsistent. Numerous antagonists have been evaluated in the USA, but none has been effective enough to warrant commercial development.

A diatomaceous earth with granules impregnated with 10% molasses solution has been found suitable for growth and delivery of *T. harzianum* to groundnut fields. Granules coated with the growth of *T. harzianum* and applied 70 and 100 days after sowing to infested soil significantly reduced stem and pod rots (Backman and Rodriguez-Kabana 1975). The efficacy of *Trichoderma* spp in controlling *S. rolfsii* has been well documented. Asghari and Mayee (1991) have reported a 30–75% reduction in stem and/or pod rot in the field with *T. harzianum* or *T. longibrachiatum*. Treatment of seeds with spore suspensions of these antagonists is a practical way of delivering these products (Mukhopadhyay et al. 1992). Other studies with *Trichoderma* spp have not been successful, possibly due to the sensitivity of *Trichoderma* to foliar fungicides used on

groundnut or to the short period of activity of this fungus (Csinos et al. 1983).

Fluorescent pseudomonads have been reported to suppress several soilborne pathogens including *S. rolfsii*. They can be useful biocontrol agents as they are known to improve plant growth by colonizing the rhizosphere and facilitating the uptake of nutrients (Mukhopadhyay et al. 1992).

There is great scope for using these microorganisms as biocontrol agents to manage *S. rolfsii* populations. This can be efficiently linked to other management practices to achieve control of stem and pod rots. Practices that improve the resident antagonistic microflora are also extremely useful in biological control.

Table 1. Fungicides/insecticides effective against stem rot.

Fungicide/ pesticide	Formulation	Rate (kg a.i. ha^{-1})	Number of applications
PCNB	10 G	11.2	1
PCNB + chlorpyrifos	10-15 G	11.2+2.24	1
Chlorpyrifos	4 EC or 15 G	1.12	1
Tolclofos-methyl	5 G	5.6	1
Flutolanil	50 WP	1.12-2.24	1-2
Diniconazole	25 WP	0.28	2
Tebuconazole[1]	3.6 F	0.23	4
Propiconazole[1]	3.6 EC	0.12	4
Cyproconazole[1]	320 SC	0.055	7
Fenbuconazole[1]	2 F	0.14	7
Thifluzamide	50 WPG	0.42	1
Fluazinam	500 F	0.85	2

1. Multipurpose fungicide for control of stem rot and foliar fungal diseases.

Chemical control

Before 1978, pentachloronitrobenzene (PCNB) and carboxin (Vitavax®) were the only fungicides recommended for control of stem rot. The situation has changed considerably over the past 15 years, and several new insecticides and fungicides are now available that are more effective against stem rot than PCNB, carboxin, or chlorpyrifos (Table 1). Among fungicides, PCNB (Terraclor®) has been evaluated in numerous trials, and its efficacy against stem rot is well documented (Hagan et al. 1988). Until the registration of two triazoles in 1994, this was the fungicide most commonly used in the USA for control of stem rot in fields severely infested with *S. rolfsii*. Although its efficacy is often erratic it can provide up to 50% control of stem rot, with associated yield increases of 7–23% over the controls. However, recent increases in the cost of PCNB, and its limited availability in several countries, have greatly reduced its use.

Carboxin 3F @ 3.4 L ha^{-1} has good activity against *S. rolfsii*; however, it has a narrow spectrum of control and cannot be applied later than 60 days before harvest.

Several organophosphate insecticides (chlorpyrifos) and nematicides (fensulfothion and ethoprop 10G) that are commonly used to control soil insect pests and nematodes also exhibit antifungal activity against *S. rolfsii* (Csinos 1984, Rodriguez-Kabana et al. 1976). The efficacy of chlorpyrifos (Lorsban® 15G) against stem rot has been demonstrated in a number of field trials (Csinos 1984, Hagan et al. 1986, 1988), but some studies have given inconsistent results (Shew et al. 1985). This insecticide is widely used in the USA to control both stem rot and the lesser cornstalk borer (*Elasmopalpus lignosellus*), mainly because it is cheaper than PCNB. It could be an attractive alternative to PCNB in the semi-arid tropics,

where soil pests can cause considerable damage to groundnut.

In such situations, combinations of fungicides and insecticides/nematicides could be useful. Combinations of PCNB and chlorpyrifos, ethoprop, or fonofos (Dyfonate® 10G) give better stem rot control and yield response than insecticide or PCNB alone (Hagan et al. 1988, 1991b). PCNB combined with metalaxyl (Ridomil®) is effective against pod rots caused by *S. rolfsii*, *R. solani*, and *Pythium* spp (Grichar and Boswell 1990).

Several recently introduced fungicides offer much better control of stem rot than was possible using PCNB or chlorpyrifos. The most widely tested are the sterol biosynthesis inhibitors, particularly the triazoles. Several triazoles are active against late leaf spot (*Phaeoisariopsis personata* = *Cercosporidium personatum* (Berk. & Curt.), early leaf spot (*Cercospora arachidicola* Hori), and groundnut rust (*Puccinia arachidis* Speg.), as well as stem rot and rhizoctonia limb rot (*Rhizoctonia solani* Kuhn). This wide spectrum of activity, combined with the relatively low application rates (62–280 g a.i. ha^{-1}), offer the potential for significant reductions in fungicide inputs (Shokes 1991). Propiconazole is active against *S. rolfsii* (Waterfield and Sisler 1989), but control in the field has been erratic. Application of propiconazole via irrigation water provides the best stem rot control, although this method of delivery reduces its activity against leaf spot (Brenneman et al. 1994b). Tebuconazole has given excellent control of stem rot and large increases in pod yield. Plots treated with tebuconazole have often yielded 1–2 t ha^{-1} more than those treated only with chlorothalonil for leaf spot control (Brenneman et al. 1991). Other triazoles that are active against *S. rolfsii* include diniconazole, ectaconazole, cyproconazole, fenbuconazole, and hexaconazole (Csinos et al. 1987).

Although not currently registered for use on groundnut, other new fungicides look promising for control of stem rot. Thifluzamide (MON-24000), a thiazolecarboxanilide, is one of the most active compounds evaluated thus far (Fig. 8). When used at 0.28 kg ha^{-1} over 4 years, yields increased to 1.77 t ha^{-1}, as against 0.52 t ha^{-1} with PCNB (Brenneman et al. 1993). Flutolanil, a succinate dehydrogenase complex inhibitor, is nearing registration in the USA and provides good control of stem rot in the field (Csinos 1987, 1989, Hagan et al. 1991a). It is also active against rhizoctonia limb rot (Csinos 1989), but will not control leaf spots.

Effective control of foliar diseases of groundnut by preventing leaf drop and subsequent accumulation of dead leaves at the base of plants may lessen the severity of stem and pod rot diseases. However, in some studies, plants treated with benomyl and chlorothalonil had greater stem rot problems than did plants treated with other fungicides. This may happen when sclerotial populations are high. Secondly, these chemicals may suppress soil populations of micro-organisms antagonistic to *S. rolfsii*. Spray applications of chlorothalonil may provide effective foliar disease control, but may simultaneously increase the levels of stem rot, because the high moisture levels in a healthy groundnut canopy favor stem rot development. However, the benefits of maintaining healthy, vigorous foliage far outweigh the relatively minor increase in stem rot.

Triazoles such as tebuconazole and diniconazole provide excellent control of foliar fungal diseases and some soilborne diseases including stem rot (Brenneman et al. 1991,

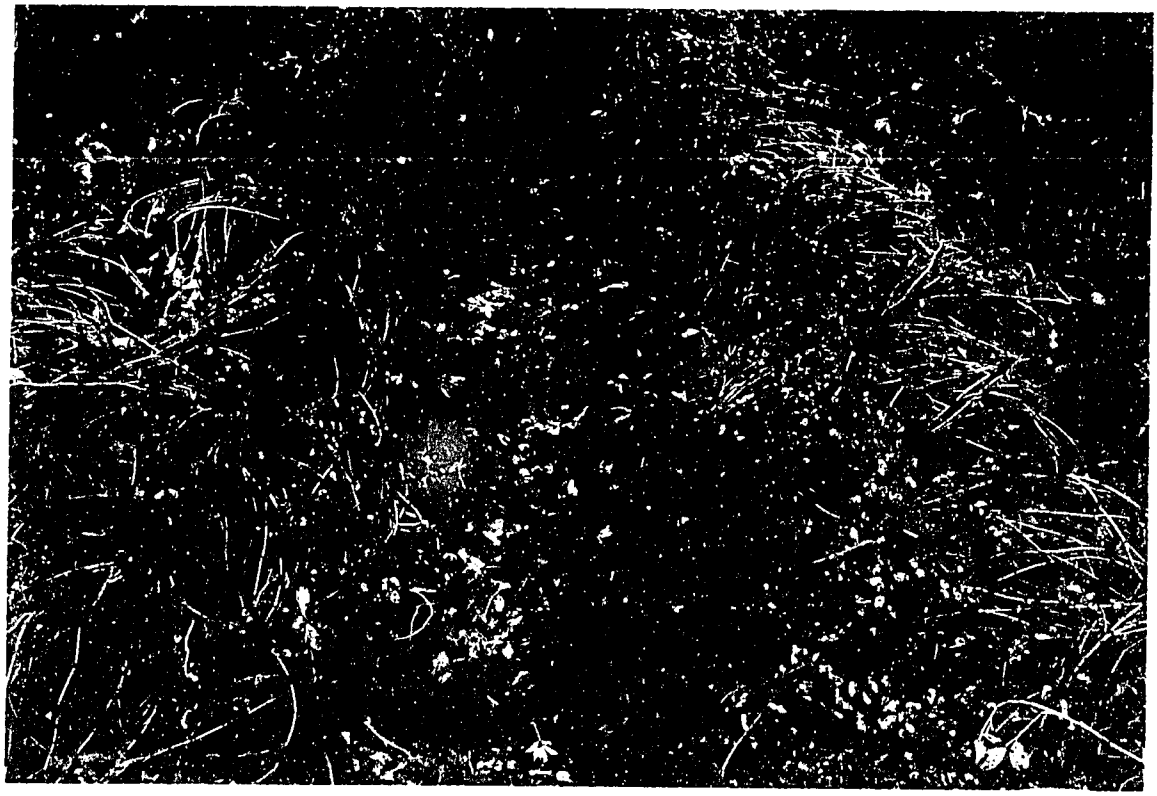

Figure 8. Chemical control of stem rot by thifluzamide sprays. Left: plants from control (untreated) plot. Right: plants from fungicide-treated plot.

Hagan et al. 1991a). It would be useful to determine the timing and number of fungicide sprays needed to achieve optimum control of these diseases.

The efficacy of pesticide use in disease management depends on the application method, the number and timing of sprays in relation to disease development and weather factors, and the dosages used. It is important to apply the chemical around the crown of the plant, which is highly prone to infection by *S. rolfsii*. Soil applications of fungicides as narrow bands along the plant rows should give improved control of stem rot. However, in the case of foliar sprays, fungicide placement does not appear to have a clear impact on disease control and yield. In some studies (Csinos 1989), banded application of fungicide gave better stem rot control than broadcasting. However, farmers are more likely to adopt the latter method because they can use traditional equipment. The application of these fungicides through irrigation water can be as effective as or superior to traditional spray applications.

Genetic resistance

The use of resistant cultivars is considered a practical method for the control of stem and pod rots. In view of the wide host range of the pathogen, only limited efforts were made to locate possible sources of resistance in groundnut until the mid 1980s. In recent years

some progress has been made in developing screening techniques, identifying sources of resistance, and breeding resistant cultivars.

Evaluation of resistance to stem and pod rots has been based largely on field experiments. Greenhouse screening techniques are required for more precise studies (controlled temperature and moisture, inoculum concentration, placement, etc.), but progress in developing such techniques has been limited.

Greenhouse screening. A simple, commonly used screening technique (Shew et al. 1987) is described below:

1. Isolate *S. rolfsii* by hyphal-tip culture on potato dextrose agar.
2. Prepare mycelial and sclerotial inoculum from young cultures of highly virulent isolates grown on rehydrated autoclaved groundnut shells, sorghum (*Sorghum bicolor*) grains, or oat (*Avena sativa*) meal.
3. Grow groundnut seedlings in 15-cm diameter pots containing a 1:2 mixture of sand and greenhouse potting mix.
4. Add 10 mature, well-dried sclerotia along with mycelial growth to the pots 8 weeks after sowing or just at pegging.
5. Cover the surface of soil in the pots with two layers of cheesecloth and keep the cloth wet (by contact with water in temperature tanks) to ensure that the soil surface and plant crowns are kept humid. Water the pots every 1–2 days to maintain adequate soil moisture.
6. Incubate the inoculated plants in a greenhouse at 28–30°C and relative humidity >85%, with 12-h light and dark periods.
7. Harvest the plants 30 days after inoculation and count the lesions on stems. Calculate average length of the three longest lesions on each stem.

Field screening. Field screening under uniform, high disease pressure is a useful way to identify sources of resistance. It is desirable to use the same field each year to encourage the build-up of *S. rolfsii* inoculum in the soil. Genotypes to be screened are sown in replicated plots. Rows of highly susceptible cultivars (Gangapuri and Kadiri 3 have been used in trials at ICRISAT Asia Center) are grown after every 5 or 10 plots of test genotypes (Mehan et al. in press). The plots are irrigated using a perfo irrigation system to promote stem rot development. Water is applied to field capacity at 10-day intervals till pegging, after which the intervals between irrigations can be reduced to 7 days. To facilitate pod rot development, it is important to increase the interval between irrigations to 15 days during the pod development stage.

Mass production of inoculum. It is important to use *S. rolfsii* isolates of known virulence, since differences have been found in degree of pathogenicity.

1. Use virulent cultures of *S. rolfsii* grown on potato dextrose agar in petri plates.
2. After extensive mycelial growth, subculture the fungus onto sterile, rehydrated, autoclaved groundnut shells in autoclavable polythene bags and incubate at 28 ± 2°C for 15–17 days. The fungus produces profuse mycelium and sclerotia on the groundnut shells. The inoculum can also be multiplied in a similar way on sorghum-sand, wheat-sand, or grain-sand mixtures (Mehan et al. in press, Asghari and Mayee 1991).

Soil application of inoculum

1. Raise the inoculum on groundnut shells or grain-sand medium, as described above.
2. Apply the inoculum (mycelium and sclerotia) to the soil surface around the base of

the plants at approximately 200 g per 4-m row, 50–60 days after sowing or at pegging.

3. Scatter sorghum stubble (3–4 cm pieces) along the rows to enhance fungal growth on soil.
4. Irrigate the field using the perfo system for 30 min to moisten the soil and increase humidity.
5. Repeat the inoculation after 2 weeks.
6. Irrigate the field at 7-day intervals until pod formation to promote stem rot development, and then increase the interval between irrigations to 15 days to promote pod infection.

Assessment of stem and pod rots

Visual estimation of the percentage of rotted plants and pods is an efficient evaluation method when large numbers of genotypes are to be tested. Stem rot incidence is assessed twice—15 days before harvest and at harvest—by counting dead or wilted plants showing *S. rolfsii* sclerotia and/or mycelial growth. Percentage incidence is computed from the total number of stem rot affected plants in a plot over the two assessments.

The test genotypes are harvested at maturity and pods from all plants in each plot (if the plot size is small) are scored for incidence and severity of pod rot. Incidence is measured as proportion of rotted to healthy pods and expressed as a percentage. Disease severity is scored as slight (<25% surface area of pods damaged), moderate (25–50% surface area damaged), or severe (>50% damaged). Field screening techniques used in the USA have been refined recently into a three-tiered system as outlined by Shokes et al. (1994), but in most studies in the USA, stem rot incidence was reflected in terms of 'disease loci', 'nits', or 'infection sites'. An infection locus is defined as an infected area ≤30 cm in length in a standard row (Rodriguez-Kabana et al. 1975). (When the infected area is larger due to the confluence of two or more infection sites, the number of loci is determined in terms of 30-cm multiples and fractions thereof.) Only loci with dead plants are included. Infection counts are recorded 1–2 weeks before harvest.

This method is useful in estimating yield losses, but cumbersome when large numbers of test entries are involved. It is appropriate to determine disease incidence as a proportion of infected to healthy plants in a plot, highlighting plant mortality. This is especially important where observations on pod rot caused by *S. rolfsii* are also to be recorded. Since pod rot can occur in plants without stem rot infection, it is useful to record pod rot incidence in stem rot affected and stem rot free plants in a plot. For pod rot evaluations, early workers (Cooper 1961) used a 0–4 scale where 0 = no pod rot and 4 = 51–100% pod rot. In recent studies (Smith et al. 1989, Grichar and Smith 1992), a 0–10 scale has been used where 0 = no disease symptoms and 10 = pods completely diseased.

Identification of resistance

Only limited resistance screening of germplasm has been attempted. There are a few reports of clear varietal differences in resistance to stem and pod rots. Although no genotypes are known to be immune or even highly resistant to *S. rolfsii*, several genotypes and breeding lines have shown field resistance (Smith et al. 1989, Grichar and Smith 1992, Branch and Brenneman 1993, Mehan et al. in press, Smith et al. 1994, Shokes et al. 1993).

Groundnut genotypes found resistant or partially resistant to stem and/or pod rots are

listed in Table 2. Partial resistance in Toalson and Southern Runner has been reported by several workers (Simpson et al. 1979, Smith et al. 1989, Brenneman et al. 1990, Branch and Brenneman 1993, Wells et al. 1994). Some breeding lines (e.g., T × Ag-3) developed at the Texas A&M University, USA, are more resistant than Toalson (Smith et al. 1989). T × Ag-3 is a selection from PI 365553, an introduction from the Honduras, and possesses multiple resistance to *Pythium myriotylum*, *Rhizoctonia solani*, and the lesion nematode, *Pratylenchus brachyurus*. Shokes et al. (1993) found two genotypes (a virginia bunch and a runner type) that were more resistant to stem rot than Southern Runner. Recently, Branch and Brenneman (1993) reported a high level of resistance to *S. rolfsii* in a Georgian groundnut breeding line, GAT 2741. This genotype has recently been released as Georgia Browne.

Table 2. Groundnut genotypes reported resistant and partially resistant to stem and pod rots caused by *Sclerotium rolfsii*.

Genotype	Botanical type	Origin
NC 2	Virginia runner	USA
Toalson[1]	Spanish bunch	USA
NC Ac 18016	Virginia bunch	USA
NC 8C[2]	Virginia bunch	USA
NC Ac 18416	Virginia runner	USA
Southern Runner	Virginia runner	USA
NC Ac 17941A × Florigiant	Virginia bunch	USA
NC 9	Virginia bunch	USA
T × AG-3[3]	Virginia runner	USA
T × 855138	Spanisn bunch	USA
GAT-2741[4]	Virginia runner	USA
UF 81206-2-216-62-B		USA
UF 79 × 4-6-2-1-1-63-B-21-62-B		USA
ICGV 87359	Spanish bunch	India
ICGV 86022	Spanish bunch	India
ICGV 86590	Spanish bunch	India
ICGV 87160	Spanish bunch	India
1364	Virginia runner	India

1. Also resistant to pod rot caused by *Pythium myriotylum* and *Rhizoctonia solani*.
2. Also resistant to *Cylindrocladium* black rot.
3. Also resistant to *Pythium* pod rot.
4. Also resistant to *Rhizoctonia* limb rot.

The stem rot resistant lines show 80–95% survival without any lesion formation or mortality, compared to <40% survival in susceptible cultivars in infested fields. Lines showing stem rot incidence below 10% are considered highly resistant, while those with 10–20% incidence are termed resistant. Recently, Mehan et al. (in press) reported several lines resistant to stem and pod rots. Most of these are interspecific hybrid derivatives (326, 1019, 1267, and 1367) that have consistently shown low incidence (<10%) in multilocational trials in India. Some other genotypes (ICGV 86590, ICGV 87359) with some resistance to rust and late leaf spot have shown lower incidence of stem and pod rots (10–20%) than susceptible commercial cultivars.

Resistance has been evaluated mainly on the basis of field tests under high natural disease pressure or with addition of inoculum to the soil. A few studies have used greenhouse screening to identify stem rot resistance (Shew et al. 1987). Certain genotypes (e.g., NC 2 and NC Ac 18016) have shown resistance in the field but are less resistant in greenhouse tests. Multilocational field evaluation for several seasons, particularly under high disease pressure, is the most useful method for determining host-plant resistance.

Breeding for resistance

Most breeding for resistance to *S. rolfsii* has been done in the USA. Exploitation of the resistances of Toalson and T × Ag-3 has been actively pursued in the Texas Groundnut

Breeding Program (Smith et al. 1989), and programs are currently ongoing in Georgia and Florida. A program on breeding for stem rot resistance has recently been initiated in Thailand. However, no high-yielding cultivar with a high degree of resistance to stem and pod rots has so far been released in any country; and neither have the genetics of resistance to stem and pod rots been studied.

Mechanisms of resistance

Resistance to stem and pod rots has been attributed mainly to a thick, impervious cuticle, thick-walled cortical cells, and cork cambium activity (Higgins 1927, Cooper 1961). Resistance has also been associated with plant canopy/phenology and active responses by the plant (metabolic resistance) to infection. Differences in susceptibility to stem rot have been related to growth habit, semidecumbent or bunch types being more susceptible than runners (Grichar and Smith 1992). However, a few spanish types have been reported to be resistant (Branch and Csinos 1987, Mehan et al. in press). Many resistant lines have nonsucculent stems and smooth, hard shells, indicating that resistance may be related to morphological characters of stem and pod. It would be useful to study the components of biochemical and structural resistance to stem and pod rots.

Integrated disease management

An integrated management approach is advocated for stem and pod rot control. Partially resistant cultivars could be grown in rotation with crops highly resistant to *S. rolfsii*, and with such cultural measures as deep plowing, raised-bed sowing, and proper water management. Certain fungicides (Table 1) are effective against *S. rolfsii*, and depending on their availability, they can be integrated with this approach on the basis of minimum use. Biological control can become an integral part of disease management once effective biocontrol agents are developed and made commercially available.

References

Asghari, M.A., and **Mayee, C.D.** 1991. Comparative efficiency of management practices on stem and pod rots of groundnut. Indian Phytopathology 44:328–332.

Aycock, R. 1966. Stem rot and other diseases caused by *Sclerotium rolfsii*. North Carolina Agricultural Experimental Station Technical Bulletin no. 174. 202 pp.

Backman, P.A., and **Rodriguez-Kabana, R.** 1975. A system for growth and delivery of biological control agents to the soil. Phytopathology 65:819–821.

Backman, P.A., and **Rodriguez-Kabana, R.** 1976. Development of a medium for the selective isolation of *Sclerotium rolfsii*. Phytopathology 66:234–236.

Bowen, K.L., Hagan, A.K., and **Weeks, R.** 1992. Seven years of *Sclerotium rolfsii* in peanut fields: yield losses and means of minimization. Plant Disease 76:982–985.

Branch, W.D., and **Brenneman, T.B.** 1993. White mold and Rhizoctonia limb rot resistance among advanced Georgia peanut breeding lines. Peanut Science 20:124–126.

Branch, W.D., and **Csinos, A.S.** 1987. Evaluation of peanut cultivars for resistance to field infection by *Sclerotium rolfsii*. Plant Disease 71:268–270.

Brenneman, T.B., Branch, W.D., and **Csinos, A.S.** 1990. Partial resistance of Southern Runner, *Arachis hypogaea*, to stem rot caused by *Sclerotium rolfsii*. Peanut Science 18:65–67.

Brenneman, T.B., Csinos, A.S., and **Hawf, L.R.** 1993. Management of soilborne peanut pathogens with thifluzamide (abstract). Page 54 *in* Proceedings of the 6th International Congress of Plant Pathology, 28 Jul–6 Aug 1993, Montreal, Canada. Ottawa, Canada: National Research Council.

Brenneman, T.B., Murphy, A.P., and **Csinos, A.S.** 1991. Activity of tebuconazole on *Sclerotium rolfsii* and *Rhizoctonia solani*, two soilborne pathogens of peanut. Plant Disease 75:744–747.

Brenneman, T.B., Sumner, D.R., Baird, R.E., Burton, G.W., and **Minton, N.A.** 1994a. Effects of rotation with Tifton 9 bahiagrass on peanut diseases, soil and shell mycoflora, and pod yield. Proceedings of the American Peanut Research and Education Society 26:56.

Brenneman, T.B., Sumner, D.R., Chandler, L.R., Hammond, J. M., and **Culbreath, A.K.** 1994b. Effect of application techniques on performance of propiconazole for peanut disease control. Peanut Science 21:134–138.

Cooper, W.E. 1961. Strains of, resistance to, and antagonists of, *Sclerotium rolfsii*. Phytopathology 51:113–116.

Csinos, A.S. 1984. Evaluation of the insecticide chlorpyrifos for activity against southern stem rot of peanut. Peanut Science 11:98–102.

Csinos, A.S. 1987. Control of southern stem rot and Rhizoctonia limb rot of peanut with flutolanil. Peanut Science 14:55–58.

Csinos, A.S. 1989. Targeting fungicides for control of southern stem rot of peanut. Plant Disease 73:723–726.

Csinos, A.S., Bell, D.K., Minton, N.A., and **Wells, H.D.** 1983. Evaluation of *Trichoderma* spp, fungicides, and chemical combinations for control of southern stem rot on peanuts. Peanut Science 10:75–79.

Csinos, A.S., Kvien, C.S., and **Littrell, R.H.** 1987. Activity of diniconazole on foliar and soil-borne diseases of peanut. Applied Agricultural Research 2:113–116.

Elad, Y., Chet, I., and **Henis, Y.** 1982. Degradation of plant pathogenic fungi by *Trichoderma harzianum*. Canadian Journal of Microbiology 28:719–725.

Ganesan, P., and **Gnanamanickam, S.S.** 1987. Biological control of *Sclerotium rolfsii* Sacc. in peanut by inoculation with *Pseudomonas fluorescens*. Soil Biology & Biochemistry 19:35–38.

Garren, K.H. 1961. Control of *Sclerotium rolfsii* through cultural practices. Phytopathology 51:120–124.

Godoy, I.J., and **Giandana, E.H.** 1992. Groundnut production and research in South America. Pages 77–85 *in* Groundnut: a global perspective. Proceedings of an International Workshop, 25–29 Nov 1991, ICRISAT Center (Nigam, S.N., ed.). Patancheru 502 324,

Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Grichar, W.J., and **Boswell, T.E.** 1990. Comparison of metalaxyl/PCNB with PCNB, gypsum, and metalaxyl for the control of peanut pod rot. Oléagineux 45:183–187.

Grichar, W.J., and **Smith, O.D.** 1992. Variation in yield and resistance to southern stem rot among peanut (*Arachis hypogaea* L.) lines selected for pythium pod rot resistance. Peanut Science 19:55–58.

Grinstein, A., Katan, Z., Razik, A.A., Zeydan, O., and **Elad, Y.** 1979. Control of *Sclerotium rolfsii* and weeds in peanuts by solar heating of the soil. Plant Disease Reporter 63:1056–1059.

Hagan, A.K., Weeks, J.R., and **Bowen, K.** 1991a. Effects of application timing and method on control of southern stem rot of peanut with foliar-applied fungicides. Peanut Science 18:47–50.

Hagan, A.K., Weeks, J.R., and **Bowen, K.** 1991b. Effect of placement and rate of PCNB and PCNB + ethoprop on the control of southern stem rot of peanut. Peanut Science 18:94–97.

Hagan, A.K., Weeks, J.R., and **McGuire, J.A.** 1988. Comparison of soil insecticides alone and in combination with PCNB for suppression of southern stem rot of peanut. Peanut Science 15:35–38.

Hagan, A.K., Weeks, J.R., and **Reed, R.B.** 1986. Southern stem rot suppression on peanut with the insecticide chlorpyrifos. Peanut Science 13:36–37.

Harrison, A.L. 1961. Control of *Sclerotium rolfsii* with chemicals. Phytopathology 51:124–128.

Henis, Y., Lewis, J.A., and **Papavizas, G.C.** 1984. Interactions between *Sclerotium rolfsii* and *Trichoderma* spp: relationship between antagonism and disease control. Soil Biology & Biochemistry 16:391–395.

Higgins, B.B. 1927. Physiology and parasitism of *Sclerotium rolfsii* Sacc. Phytopathology 17:417–448.

Kolte, S.J. 1985. Diseases of annual edible oilseed crops. Vol. 1: Peanut diseases. Boca Raton, Florida, USA: CRC Press, Inc. 182 pp.

Leach, L.D., and **Davey, A.E.** 1938. Determining the sclerotial population of *Sclerotium rolfsii* by soil analysis and predicting losses of sugarbeets on the basis of these analyses. Journal of Agricultural Research 56:619–631.

Lim, S., Kritsanecpaiboon, W., Chuenechit, S., Agampongsai, A., and **Chouysatis, D.** 1989. Survey of groundnut diseases in farmers' fields. Pages 162–163 *in* Proceedings of the Seventh Thailand National Groundnut Meeting for 1987, 16–18 Mar 1988, Pattaya, Chonburi, Thailand. Khon Kaen, Thailand: Faculty of Agriculture, Khon Kaen University.

Maiti, D., and **Sen, C.** 1985. Integrated biological control of *Sclerotium rolfsii* with nitrogenous fertilizers and *Trichoderma harzianum*. Indian Journal of Agricultural Sciences 55:464–468.

Mayee, C.D., and **Datar, V.V.** 1988. Diseases of groundnut in the Tropics. Review of Tropical Plant Pathology 5:85–118.

Mehan, V.K., Mayee, C.D., McDonald, D., Ramakrishna, N., and **Jayanthi, S.** In press. Resistance in groundnut to *Sclerotium rolfsii*-caused stem and pod rots. International Journal of Pest Management.

Mehan, V.K., and **McDonald, D.** 1990. Some important diseases of groundnut – sources of resistance and their utilization in crop improvement. Paper presented at the In-Country Training Course on Legumes Production, 9–17 July, 1990, Sri Lanka. (Limited distribution.)

Mihail, J.D., and **Alcorn, S.M.** 1984. Effects of soil solarization on *Macrophomina phaseolina* and *Sclerotium rolfsii*. Plant Disease 68:156–159.

Minton, N.A., Csinos, A.S., Lynch, R.F., and **Brenneman, T.B.** 1991. Effects of two cropping and two tillage systems and pesticides on peanut pest management. Peanut Science 18:41–46.

Moehadi, S.D. 1978. Penyakit belang dan becak daun pada kacang tanah perlu diperhatikan [Attention should be paid on Sclerotium and wilt diseases in peanut]. Majalah-Pertanian (Indonesia) 25:58–60.

Mukhopadhyay, A.N., Shrestha, S.M., and **Mukherjee, P.K.** 1992. Biological seed treatment for control of soil-borne plant pathogens. FAO Plant Protection Bulletin 40/1–2:21–30.

Porter, D.M., Smith, D.H., and **Rodriguez-Kabana, R.** 1982. Peanut plant diseases. Pages 362–410 *in* Peanut Science and Technology (Pattee, H.E., and Young, C.T., eds.). Yoakum, Texas, USA: American Peanut Research and Education Society.

Punja, Z.K. 1985. The biology, ecology, and control of *Sclerotium rolfsii*. Annual Review of Phytopathology 23:97–127.

Punja, Z.K., and **Jenkins, S.F.** 1984. Influence of temperature, moisture, modified gaseous atmosphere, and depth in soil on eruptive sclerotial germination of *Sclerotium rolfsii*. Phytopathology 74:749–754.

Punja, Z.K., Smith, V.L., Campbell, C.L., and **Jenkins, S.F.** 1985. Sampling and extraction procedures to estimate numbers, spatial pattern, and temporal distribution of sclerotia of *Sclerotium rolfsii* in soil. Plant Disease 69:469–474.

Rodriguez-Kabana, R., Backman, P.A., Karr, G.W., and **King, P.S.** 1976. Effects of nematicide fensulfothion on soil-borne pathogens. Plant Disease Reporter 60:521–524.

Rodriguez-Kabana, R., Backman, P.A., and **Wiggins, E.A.** 1974. Determination of sclerotial populations of *Sclerotium rolfsii* in soil by a rapid flotation-sieving technique. Phytopathology 64:610–615.

Rodriguez-Kabana, R., Backman, P.A., and **Williams, J.C.** 1975. Determination of yield losses to *Sclerotium rolfsii* in peanut fields. Plant Disease Reporter 59:855–858.

Rodriguez-Kabana, R., Beute, M.K., and **Backman, P.A.** 1980. A method for estimating numbers of viable sclerotia of *Sclerotium rolfsii* in soil. Phytopathology 70:917–919.

Rodriguez-Kabana, R., Robertson, D.G., Weaver, C.F., and **Wells, L.** 1991a. Rotation of bahiagrass and castorbean for management of *Meloidogyne arenaria*. Journal of Nematology 23:658–661.

Rodriguez-Kabana, R., Robertson, D.G., Wells, L., Weaver, C.F., and **King, P.S.** 1991b. Cotton as a rotation crop for management of

Meloidogyne arenaria and *Sclerotium rolfsii* in peanut. Journal of Nematology 23:652–657.

Saccardo, P. A. 1911. Notae Mycological. Annals of Mycology 9:247.

Shew, B.B., Beute, M.K., and **Bailey, J.E.** 1985. Potential for improved control of southern stem rot of peanut with fungicides. Peanut Science 12:4–7.

Shew, B.B., Wynne, J.C., and **Beute, M.K.** 1987. Field, microplot and greenhouse evaluations for resistance to *Sclerotium rolfsii* in peanut. Plant Disease 71:188–191.

Shokes, F.M. 1991. New indications for azoles: peanuts as a special example. Pages 288–304 *in* Sterol biosynthesis inhibitors: pharmaceutical and agrochemical aspects (Berg, D., and Plempel, M., eds.). Weinheim, Germany: VCH.

Shokes, F.M., Gorbet, D.W., and **Brenneman, T.B.** 1994. Effective methods for in-field evaluation of resistance to southern stem rot in peanut. Proceedings of the American Peanut Research and Education Society 26:55.

Shokes, F.M., Gorbet, D.W., and **Knauft, D.A.** 1993. Resistance to southern stem rot in selected peanut genotypes and yield effects. Proceedings of the American Peanut Research and Education Society 25:59.

Simpson, C.E., Smith, O.D., and **Boswell, T.E.** 1979. Registration of Toalson peanut. Crop Science 19:742–743.

Smith, O.D., Brenneman, T.B., Mullinix, B.G., Shokes, F.M., and **Gorbet, D.W.** 1994. Interaction of five peanut genotypes with 10 isolates of *Sclerotium rolfsii*. Phytopathology (Abstract) 84:1101.

Smith, O.D., Boswell, T.E., Grichar, W.J., and **Simpson, C.E.** 1989. Reaction of select peanut (*Arachis hypogaea* L.) lines to southern stem rot and pythium pod rot under varied disease pressure. Peanut Science 16:9–14.

Sreenivasaprasad, S., and **Manibhusanrao, K.** 1990. Biocontrol potential of the fungus antagonist *Gliocladium virens* and *Trichoderma longibrachiatum*. Zeitschrift fur Pflanzenkrankheiten und Pflanzenschutz 97:570–579.

Valencia, L.D., and **Natural, M.P.** 1988. Sclerotium wilt of peanut. Philippines Phytopathology 24:66–67.

Waterfield, W.F., and **Sisler, H.D.** 1989. Effect of propiconazole on growth and sterol biosynthesis by *Sclerotium rolfsii*. Netherlands Journal of Plant Pathology 95 (Supplement 1):187–195.

Wells, M.A., Grichar, W.J., Smith, O.D., and **Smith, D.H.** 1994. Response of selected peanut germplasm lines to leaf spot and southern stem rot. Oléagineux 49:21–25.

West, E. 1947. *Sclerotium rolfsii* Sacc. and its perfect stage on climbing fig. Phytopathology 37:67–69.

Wongkaew, S., Kantrong, S., and **Boonjarern, P.** 1989. Groundnut diseases survey in the dry season. Pages 157–158 *in* Proceedings of the Seventh Thailand National Groundnut Meeting for 1987, 16–18 Mar 1988, Pattaya, Chonburi, Thailand. Khon Kaen, Thailand: Faculty of Agriculture, Khon Kaen University.

Zeiden, O., Elad, Y., Hadar, Y., and **Chet, I.** 1986. Integrating onion in crop rotation to control *Sclerotium rolfsii*. Plant Disease 70:426–428.

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The semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, finger millet, chickpea, pigeonpea, and groundnut; these six crops are vital to life for the ever-increasing populations of the semi-arid tropics. ICRISAT's mission is to conduct research which can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

ICRISAT was established in 1972. It is one of 16 nonprofit, research and training centers funded through the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an informal association of approximately 50 public and private sector donors; it is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank.