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Management of *Sclerotium rolfsii*-caused stem and pod rots of groundnut—a critical review†

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Abstract. *Sclerotium rolfsii*-caused stem and pod rots are major constraints to groundnut production in many groundnut-growing regions, and pose a serious threat to post-rainy and summer season groundnuts in expanding irrigated production systems. Considerable research has been carried out on the management of these diseases. The most relevant literature is reviewed and future research strategies are indicated.

1. Introduction

Sclerotium rolfsii, a necrotrophic soil-borne fungal pathogen, attacks many crop species in the warm temperate and tropical regions of the world. In groundnut, the fungus commonly causes stem and pod rots which can be major constraints to production. Stem rot, also known as Sclerotium blight, Sclerotium rot, southern blight, southern stem rot, Sclerotium wilt, root rot, and white mould, is the most economically damaging disease of groundnut in the USA, annually accounting for 5–10% loss in yields despite the use of disease management practices (Bowen *et al.*, 1992). It also occurs in parts of India, Thailand, Indonesia, Taiwan, and the Philippines where yield losses usually range from 10 to 25% but may reach 80% in severely infested fields (Mayee and Datar, 1988).

Peg and pod rots caused by *S. rolfsii* are also common in parts of many countries, resulting in serious pod loss at harvest. While warm and moist conditions favour stem rot development, pod rots are favoured by rather drier soil conditions. In heavy soils, *S. rolfsii* is most damaging to groundnut plants at or near the soil surface, but in lighter soils it can be active at greater depths, causing severe damage to pegs and pods (Mehan and McDonald, 1990).

The first comprehensive review of *S. rolfsii*-incited diseases of crop plants was given by Aycock (1966). Approximately 20 years later, Punja (1985) critically reviewed the literature on various aspects of the biology and ecology of *S. rolfsii* and briefly outlined strategies for control of the diseases it caused. However, this review did not encompass information on host plant resistance. Numerous papers on specific aspects of epidemiology and control of stem and pod rots of groundnut have appeared since the first review by Aycock (1966). This wealth of information highlights the worldwide importance of *S. rolfsii*-caused diseases in groundnut. In this review, we present a critical assessment of the pertinent literature on various management options for the control of stem and pod rot diseases of groundnut.

2. General background—Pathosystem and disease incidence/severity assessments

2.1. *Pathosystem*

The pathogen survives as a saprophyte on plant debris, even debris from non-host crops. Sclerotia survive well (3–4 years) at or near the soil surface but survive poorly when buried deep because the fungus has a high oxygen demand. Leaves shed from the plants because of foliar diseases/pests and natural senescence, and plant debris from previous crops stimulate germination of the overwintering sclerotia and serve as a food base for proliferation of the fungus and development of inoculum potential. The fungus may adopt a saprophytic or parasitic mode. Any part of the groundnut plant in contact with the soil may be invaded. The onset of stem rot usually coincides with early stages of peg and pod formation, particularly under warm, high moisture conditions.

There are some indications of differences in virulence of isolates from various hosts (Cooper, 1961; Punja, 1985), but host specialization has not yet been clearly demonstrated.

2.2. *Stem rot/pod rot assessment*

In most studies in the USA, stem rot incidence is reflected in terms of 'disease loci', or 'infection sites' (Rodriguez-Kabana *et al.*, 1975). Only loci with dead plants are included in the infection counts recorded 1–2 weeks before harvest. Researchers in other countries have relied on percentage disease incidence for comparisons. Since pod rots can occur in plants without evident stem rot infections, it is important to record pod rot incidence in stem rot-affected and stem rot-free plants in a plot. For pod rot evaluations, early workers used a 0 to 4 scale where 0 = no pod rot symptoms and 4 = 51–100% surface area of pods damaged (Cooper, 1961). In more recent studies (Smith *et al.*, 1989; Grichar and Smith, 1992), a 0 to 10 scale has been used where 0 = no disease symptoms and 10 = pods completely rotted.

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3. Cultural control measures

3.1. *Crop sanitation*

Removal of crop residues and weeds is important for stem rot management. Cultural practices should be designed (i) to bury the necrotrophic food base deep in the soil, and (ii) to prevent accumulation of such a food base in the crown area of the plant during the crop season. Deep ploughing to bury all undecayed organic matter and plant debris to at least 9 cm can greatly reduce stem rot infection and increase yield (Boyle, 1956; Garren, 1961). Control of foliar pests and diseases will prevent accumulation of leaf litter in the crown area/pegging zone and so reduce the food base. It is also important to avoid the practice of 'dirting' groundnuts where soil is moved against plant limbs and crown for weed suppression, and other cultural practices that cause damage to the plant and smother the base of the plant with soil.

3.2. *Crop rotation*

In view of the wide host range of *S. rolfsii*, and prolonged perennation of sclerotia of the fungus, early researchers (McClintock, 1917) cautioned against placing much hope in rotation as a means of controlling stem rot of groundnut. Interestingly, the encouraging results obtained in trials several decades later have highlighted rotation as a major component of stem rot management.

Rotation of groundnut with non-susceptible crops such as corn, cotton, and wheat can greatly reduce stem rot incidence and severity (Garren, 1961; Rodriguez-Kabana *et al.*, 1987, 1991a; Wokocha, 1988). Rodriguez-Kabana *et al.* (1987) reported that groundnut rotation with cotton not only reduced populations of root knot nematodes, but also decreased the sclerotial counts, thereby reducing the incidence of stem rot. The value of crop rotation with cotton in greatly reducing stem rot has been amply demonstrated in various field trials in disease endemic areas of the USA (Rodriguez-Kabana *et al.*, 1991a). Such crop rotation should be particularly useful in vertisols, and this is now being recommended in several cotton-growing regions of India where stem and pod rots can be serious problems in the post-rainy/summer season groundnut. Rotation of groundnut with wheat and corn is also effective against stem rot (Garren, 1961; Minton *et al.*, 1991); this is a common practice in several parts of northern India and China. Rotating groundnut with crops belonging to the Liliaceae family such as onion and garlic has proved effective against stem rot (Zeiden *et al.*, 1986; Asghari and Mayee, 1991). Several other crops such as castor and bahiagrass (*Paspalum notatum*) are also useful in crop rotation for control of stem rot (Rodriguez-Kabana, 1991b). Although crop breaks for periods of 2–3 years with non-susceptible crops have proved effective in containing the disease, longer breaks (4–5 years) are advised for the most effective control, especially in soils that are heavily infested with the pathogen. Little is known as to how different cropping systems affect soil microflora in general and *S. rolfsii* in particular.

3.3. *Tillage*

Control of *S. rolfsii* can be achieved through tillage operations that are detrimental to survival of the sclerotia at the soil surface. Early studies (Tisdale, 1921; Bottomley, 1940) recommended the 'stirring' of soil before sowing, or immediately after harvesting, to promote drying out of sclerotia. These studies demonstrated differences between tillage and no-tillage for stem rot incidence; tillage operations reduced stem rot. Surprisingly, in several other studies conducted in the late 1980s, stem rot was not highlighted as a severe problem in the no-tillage system (Colvin *et al.*, 1986; Grichar and Boswell, 1987; Grichar and Smith, 1991).

3.4. *Control of moisture*

Practices that reduce moisture retention in the canopy can discourage stem rot infection and development. Planting on raised beds promotes drainage and reduces moisture in the canopy. In several trials carried out in vertisols in Maharashtra State of India, stem rot incidence in groundnut was much lower on raised beds than on flat plantings (Mayee, C. D., personal communication). Similarly, irrigation management has a profound influence on stem rot. Irrigations should be properly scheduled to allow application of adequate but not excessive amounts of water, and to maximize the dry period between irrigations; this is particularly important for the post-rainy/summer season crop.

3.5. *Soil amendments*

Addition of compost, oat or corn straw to soil can reduce disease incidence (Garren, 1959), probably because of the release of toxic ammonia, or increases in populations of resident antagonistic soil microorganisms. This should be an economical approach to disease control in small-scale subsistence agricultural systems, but may not be practical in large-scale production systems unless used in conjunction with crop rotation wherein the straw from a preceding cereal crop is disked into the soil.

Application of nitrogenous fertilizers such as urea, ammonium nitrate, and ammonium bicarbonate can reduce stem rot (Harrison, 1961; Maiti and Sen, 1985). Increased calcium levels in plant tissues following applications of calcium nitrate or calcium sulphate provide some disease control, especially under low inoculum pressure conditions. High levels of calcium in plant tissues partially offset the action of oxalic acid and the cell wall-degrading enzymes of the pathogen. Soil application of gypsum reduces stem rot and increases yield (Grichar and Boswell, 1990).

3.6. *Soil solarization*

Soil solarization should prove useful in reducing stem rot and pod rot of groundnut. Solarization to disinfest soil involves mulching soil with transparent polyethylene sheets for 4 weeks in the hot season before planting. This reduces the survival ability of the pathogen and increases its vulnerability of sclerotia to antagonists. This approach has been found to significantly decrease incidence of stem rot (Grinstein *et al.*, 1979; Mihail and Alcorn, 1984), and can be adopted in areas where temperatures are high (above 43°C) and irrigation facilities are available.

4. Biological control

Several soil fungi (e.g. *Trichoderma harzianum*, *T. viride*, *T. longibrachiatum*, *Gliocladium virens*), bacteria (*Pseudomonas fluorescens*, *P. aeruginosa*, *Bacillus subtilis*), and mycorrhizal fungi have been shown to be highly antagonistic to *S. rolfsii* and several other soil-borne pathogens that attack groundnuts (Wells *et al.*, 1972; Elad *et al.*, 1980; Brathwaite and Cunningham, 1982; Krishna and Bagyaraj, 1983; Henis *et al.*, 1984; Ganesan and Gnanamanickam, 1987; Sreenivasaprasad and Manibhusanrao, 1990). Although some of these microorganisms suppressed stem rot under controlled experimental conditions, few studies have been made to test their efficacy in the field.

Several *Trichoderma* spp. have been shown to control seed, root and stem rots in many crops including groundnut. Weindling (1932) was probably the first to demonstrate that *Trichoderma* spp. parasitized as well as inhibited the development of *S. rolfsii*, indicating the potential of these fungi as biocontrol agents. The efficacy of *T. harzianum* for control of *S. rolfsii* has been well documented in various studies. Some 35–50% reduction in *S. rolfsii*-caused stem rot/pod rot by *T. harzianum* or *T. longibrachiatum* has been reported under field conditions (Backman and Rodriguez-Kabana, 1975; Sreenivasaprasad and Manibhusanrao, 1990; Asghari and Mayee, 1991). Isolates of *Trichoderma* spp. differ in their ability to attack *S. rolfsii* (Elad *et al.*, 1982). Therefore, it is essential to employ the most effective isolates as biocontrol agents. Much progress has been made in the past decade in developing commercial biopesticides based on *Trichoderma* spp., particularly *T. harzianum*, and several such products are now marketed. Treatment of seeds with spore suspensions of these antagonists is a practical way of delivering these products for management of *S. rolfsii*-caused diseases of groundnut (Mukhopadhyay *et al.*, 1992). The utilization of biological seed treatment requires a commercial supply of seed coated with viable antagonist. The feasibility of producing and applying large volumes of antagonists are major factors that limit the use of biocontrol agents (Cook, 1991). Fortunately, *Trichoderma* spp. have advantages as biological seed protectants as they are compatible with most of the chemicals commonly used for seed treatments (Mukhopadhyay *et al.*, 1992). Apart from application on or with seed, it is difficult to apply microbial preparations to all target sites.

Fluorescent *Pseudomonas* spp. have also been reported to suppress several soil-borne pathogens including *S. rolfsii*. They can be useful biocontrol agents as they can improve plant growth by colonizing the rhizosphere and facilitating rapid uptake of nutrients (Mukhopadhyay *et al.*, 1992). There is very limited information on interactions of *Rhizobium* with *S. rolfsii* in groundnut. In a greenhouse study, Bhattacharyya and Mukherjee (1988) reported some inhibition of *S. rolfsii* infection by *Rhizobium* inoculation. Effective, early colonization of roots by beneficial microorganisms can reduce stem rot, probably by improved plant growth.

There is great potential for use of these microorganisms as biocontrol agents for managing populations of *S. rolfsii* and several other soil-borne pathogens. This could result in reduced use of pesticides, and in promoting soil resources through increased activity of non-target beneficial microorganisms. It is emphasized that biocontrol not only embodies the introduction of antagonists into the cropping systems but also manipulation of the environment to favour resident beneficial microorganisms through crop rotation, organic amendments, and other appropriate cultural practices.

5. Chemical control

Chemical control may be indicated for fields where stem rot is the main factor limiting groundnut production. This is relatively straightforward when dealing with a fully mechanized crop as in North America where pesticides may be applied as sprays or in granular form and their efficiency can be enhanced by sprinkler irrigation. The efficacy of pesticide use is dependent upon the application method, the numbers and timing of sprays in relation to disease development and weather factors, and the dosages of appropriate chemicals used. It is important for control of stem rot 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 and pod rots (Csinos, 1989). However, in the case of foliar sprays, fungicide placement does not appear to have a clear impact on disease control and yield. Although there is some advantage in stem rot control in some studies (Csinos, 1989) by banded over broadcast fungicide applications, broadcast applications are more likely to be adopted by farmers because they can use traditional spray equipment. This is particularly useful for applications of foliar fungicides. The application of these fungicides through irrigation water (fungigation) can be as effective or superior to traditional spray applications.

In the small farmer situation typical of developing countries, direct chemical control is rarely practised. However, some farmers do practise fungicide control of foliar diseases and there is potential for this to incorporate some control of stem and pod rots.

5.1. *Fungicides/insecticides for stem and pod rot control*

Chemicals used prior to the mid-1950s were not effective against stem rot. Significant progress in chemical control became possible only with the advent of pentachloronitrobenzene (PCNB). PCNB (Terraclor®) has been evaluated in numerous trials and its efficacy against stem rot is well documented (Aycock, 1966; Thompson, 1978; Backmann and Hammond, 1981; Csinos, 1984; Hagan *et al.*, 1986, 1988; Jackson and Domicone, 1991); this was the fungicide most commonly used in the USA for the control of stem rot in fields severely infested with *S. rolfsii*. It can provide 45–53% control of stem rot with associated yield increases of 7–23% over controls. Granular applications of PCNB 10G at 11·2 kg a.i. ha^{-1} are normally recommended for stem rot control. Recently, PCNB applied to the soil in a narrow band of 10 cm width at half the recommended dose (5·6 kg a.i. ha^{-1}) at pegging was equally effective (Csinos, 1989).

Carboxin 3F at 3·4 l ha^{-1} (applied, at pegging, as a spray directed at the crown of plants) is also effective against stem rot. However, it has certain drawbacks, such as a narrow spectrum of activity, and a restriction that it cannot be applied later than 60 days before harvest.

Table 1. Fungicides/pesticides effective against stem rot of groundnut caused by Sclerotium rolfsii

Fungicide/ pesticide	Formulation	Rate (kg a.i. ha^{-1})	% stem rot control	% yield increase	Reference
PCNB	10 G	11·2	47–52	7–13	Hagan *et al.*, 1986; Bowen *et al.*, 1992
PCNB	10 G	5·6	46–48	9–23	Hagan *et al.*, 1991a
PCNB + fensulfothion	10 + 3 G	11·2 + 3·4	19	19	Csinos, 1985
PCNB + Chlorpyrifos	10–15 G	11·2 + 2·24	49–74	16–19	Hagan *et al.*, 1986; Bowen *et al.*, 1992
PCNB + Chlorpyrifos	10 G + 4 EC	11·2 + 2·24	21	27	Csinos, 1989
PCNB + Ethoprop	10 G + 15 G	11·2 + 3·3	35–75	2–52	Hagan *et al.* 1988; Bowen *et al.*, 1992
Chlorpyrifos	15 G	2·24	21–43	7–9	Csinos, 1984; Hagan *et al.*,1986; Bowen *et al.*, 1992
Chlorpyrifos	4 EC	1·12	33	14	Csinos, 1984
Chlorpyrifos	4 EC	2·24	6	6	Csinos, 1984
Tolclofos-methyl	5 G	5·6	73–86	13–23	Csinos, 1985
Flutolanil	50 WP	2·24	62–75	215–237	Csinos, 1989
Flutolanil	50 WP	1·12	25–73	161–191	Csinos, 1989
Diniconazole	25 WP	0·28	64–75	180–213	Csinos, 1989
Tebuconazole	1·2 EC	0·12	52–67	150–171	Brenneman *et al.*, 1991
Tebuconazole	1·2 EC	0·28	61–82	172–194	Brenneman *et al.*, 1991

Several soil fumigants, such as methyl bromide and chloropicrin, have been reported to be effective against stem rot (Cheng *et al.*, 1989). These chemicals have been tested in only a few trials, and are not likely to be economical for use on a large scale.

Tolclofos-methyl (Rizolex®), an organophosphate fungicide with curative and slight systemic action, has been reported to have high fungitoxic action against *S. rolfsii* and *Rhizoctonia solani* (Csinos, 1985; Hari *et al.*, 1989). Under field conditions, tolclofos-methyl applied (at pegging in a 40 cm band over the row) at 5·6 kg a.i. ha^{-1} is as effective or even superior to PCNB in reducing stem rot and increasing pod yield (Csinos, 1985).

Several organophosphate insecticides (chlorpyrifos) and nematicides [ethoprop (Mocap® 10G) and fensulfothion] commonly used for control of soil insect pests and nematodes also exhibit antifungal activity against *S. rolfsii* (Rodriguez-Kabana *et al.*, 1976; Backman and Hammond, 1981; Csinos, 1985). 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; Minton *et al.*, 1990). However, some studies have given inconsistent results in respect of stem rot control with chlorpyrifos (Csinos, 1984; Shew *et al.*, 1985; Hagan *et al.*, 1986). Also, yield increases as a result of application of chlorpyrifos are not substantial. This insecticide is widely used in the USA for the control of both lesser cornstalk borer and stem rot, mainly because it is cheaper than PCNB. It could be an attractive alternative to PCNB in the semi-arid tropics where soil pests can also be damaging to groundnuts. In these situations, combinations of fungicides and insecticides could be useful for management of stem and pod rots. Combinations of PCNB with chlorpyrifos, ethoprop, or fonofos (Dyfonate® 10G) give better stem rot control and yield response than the insecticide or fungicide alone (Hagan *et al.*, 1988). PCNB combined with metalaxyl (Ridomil® PC) is effective against pod rots caused by *S. rolfsii*, *R. solani*, and *Pythium* spp. (Grichar and Boswell, 1990). However, recent increases in the cost of PCNB, and its limited availability in several countries, have greatly reduced its use for control of stem rot.

Several new fungicides and insecticides that are more effective against stem rot than PCNB, carboxin, fensulfothion, or chlorpyrifos are now available (Table 1).

Flutolanil 50 WP applied as a banded foliar spray at the rates of 1·12–5·6 kg a.i. ha^{-1} at pegging has been reported to be more effective against stem rot than PCNB granular application (Csinos, 1987; Hagan *et al.*, 1991a; Jackson and Domicone, 1991). Flutolanil is also effective against blight caused by *R. solani* (Csinos, 1989).

Several recently introduced triazole fungicides offer a much greater level of control of stem rot than was possible using PCNB or chlorpyrifos (Brenneman *et al.*, 1991). Of triazole fungicides, efficacy of diniconazole (Spotless® 25W) and tebuconazole (Folicur®) has been confirmed in various field trials (Csinos *et al.*, 1987; Csinos, 1989; Rudolph *et al.*, 1989; Sumner and Littrell, 1989; Hagan *et al.*, 1991a; Sumner *et al.*, 1991). Diniconazole and tebuconazole applied as banded foliar sprays or broadcast at 0·28 and 0·25 kg a.i. ha^{-1} respectively, have proved to be more effective against stem rot than PCNB. Large increases (150–237%) in yield have been reported following application of flutolanil, diniconazole, and tebuconazole (Csinos, 1989; Brenneman *et al.*, 1991). This was probably because of their efficient control of leaf spots, although significant reductions in stem rot were achieved. In areas where leaf spots are not severe, stem rot control achieved by the applications of diniconazole and tebuconazole may not result in substantial increase in yield (Bowen *et al.*, 1992). Propiconazole (Tilt® 2·5G) and hexaconazole have also been reported to reduce stem rot (Brown *et al.*, 1988), but they are not as effective as the other triazoles.

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. But, in some studies, plants treated with benomyl and chlorothalonil had greater stem rot problems than plants treated with other fungicides. These chemicals may suppress soil populations of microorganisms antagonistic to *S. rolfsii.*

Tebuconazole and diniconazole provide excellent control of both foliar fungal diseases and some soil-borne diseases including stem rot (Brenneman *et al.*, 1991; Hagan *et al.*, 1991a). Number and timing of fungicide sprays to achieve effective and economical control of foliar diseases and stem and pod rots should be determined for particular situations.

6. Resistance

As *S. rolfsii* has an unusually wide host range, and is capable of producing a non-specific metabolite, oxalic acid, and several cell wall-degrading enzymes, it is logical to predict a low probability for success in finding useful levels of host resistance. This may be one of the reasons for the relatively low emphasis placed on breeding groundnuts for resistance to *S. rolfsii.* There have been few concerted efforts to identify resistance in groundnut to *S. rolfsii.* However, McClintock (1917, 1918) reported that Virginia runner groundnuts were more resistant than other types. These findings were substantiated by other researchers (Reyes, 1937; Cooper, 1961), but some workers remained sceptical about the existence of marked differences in susceptibility among groundnut genotypes (Garren and Bailey, 1963; Garren, 1964). Data from most studies suggested that differences in susceptibility to stem rot were actually related to growth habit; the semi-decumbent or bunch types being more susceptible than the runner types. Some recent studies have supported these observations (Grichar and Smith, 1992). However, Branch and Csinos (1987) observed that as a group, Spanish types were less susceptible than other types. Only a limited number of genotypes have been evaluated, and a much wider range of germplasm should be examined before drawing any conclusions.

6.1. *Sources of resistance*

Most of the sources of resistance to *S. rolfsii* belong to Virginia runner and Virginia bunch types (*Arachis hypogaea* subsp. *hypogaea*). Interestingly, stable resistance to stem rot has been reported in a few Spanish genotypes (Toalson and Tx855138). It appears that Valencia (var. *fastigiata*) type groundnuts are highly susceptible to *S. rolfsii*, and Spanish (var. *vulgaris*) are more susceptible than Virginia (var. *hypogaea*) types (Mehan *et al.*, 1995).

Although no genotypes are known to be immune or even highly resistant to *S. rolfsii*, several genotypes and breeding lines have been found to show lower than average susceptibility to stem rot/pod rot under field conditions (Wynne and Beute, 1983; Beute *et al.*, 1986; Arnold *et al.*, 1988; Smith *et al.*, 1989; Brenneman *et al.*, 1990; Grichar and Smith, 1992). Of several genotypes reported as partially resistant (NC 2, NC Ac 18016, NC8C, Toalson and Southern Runner), resistance of Toalson has been confirmed by several researchers (Simpson *et al.*, 1979, Branch and Csinos, 1987; Smith *et al.*, 1989). Southern Runner, a commercial cultivar in the USA, has also consistently shown partial resistance to stem rot in field trials (Arnold *et al.*, 1988; Jaboci and Backman, 1989; Brenneman *et al.*, 1990). Groundnut genotypes with resistance to stem and pod rots are listed in Table 2.

Some breeding lines (e.g. T × Ag-3) recently developed at the Texas A.&M. University, USA, are more resistant than Toalson (Smith *et al.*, 1989). T × Ag-3 has consistently shown low stem rot incidence, and has resistance to *Pythium myriotylum*-caused pod rot (Grichar and Smith, 1992). This line is a selection from PI 365553 (introduced from Honduras) which has multiple resistance to *P. myriotylum*, *R. solani*, and the lesion nematode *Pratylenchus brachyurus*. Recently, Branch and Brenneman (1993) reported a high level of resistance to *S. rolfsii* and Rhizoctonia limb rot in a Georgian groundnut breeding line, GAT-2741.

Recently, researchers in India (Mehan *et al.*, 1995) found several lines with field resistance to stem and pod rots. Most of these lines are interspecific hybrid derivatives, viz. 326, 1019, 1267, and 1364. They have consistently shown low incidences of stem and pod rots ($< 10\%$) in trials at ICRISAT Center and in Parbhani, Maharashtra State. Some breeding lines (ICGV 86590 and ICGV 87359) with useful resistance to rust and late leaf spot have shown lower incidence of stem rot (10–15%) than the susceptible cultivars Kadiri 3 and Gangapuri.

Evaluation of resistance has been mainly on the basis of field tests under high natural disease pressure or with addition of inoculum to the soil surface. A few studies have utilized greenhouse screening techniques for identifying resistance to stem rot (Shew *et al.*, 1987). Comparative reactions of certain genotypes have varied between greenhouse and field evaluations; for example NC 2 and NC Ac 18016 which showed resistance to *S. rolfsii* in the field were less resistant in inoculation tests in the greenhouse, while for other genotypes

Table 2. Groundnut genotypes reported to be resistant and partially resistant to Sclerotium rolfsii-caused stem rot/pod rot

Genotype(s)	Reference
NC2	Garren, 1964, Beute *et al.*, 1986; Shew *et al*, 1987
Toalson[a]	Simpson *et al*, 1979; Branch and Csinos, 1987
NC Ac 18016	Wynne and Beute, 1983; Beute *et al*, 1986; Shew *et al*, 1987
NC8C[b]	Wynne and Beute, 1983
NC Ac 18416	Shew *et al.*, 1987
Southern Runner	Arnold *et al*, 1988; Jacobi and Backman, 1989
NC Ac 17941A × Florigiant	Beute *et al.*, 1986
NC 9	Brenneman *et al.*, 1990
TxAG-3[c]	Smith *et al*, 1989; Grichar and Smith, 1992
Tx855138	Grichar and Smith, 1992
GAT-2741[d]	Branch and Brenneman, 1993

[a] Also resistant to pod rot caused by *Pythium myriotylum* and *Rhizoctonia solani.*

[b] Also resistant to Cylindrocladium black rot

[c] Also resistant to Pythium pod rot.

[d] Also resistant to Rhizoctonia limb rot

the reverse was the case (Shew *et al.*, 1987). Some genotypes (e.g. NC Ac 18416) have shown resistance in both field and greenhouse tests.

No obvious linkage has been demonstrated between resistance to stem rot and pod rot diseases.

Several other lines/cultivars with moderate resistance to *S. rolfsii* have been reported from India, Bangladesh, Thailand, and the Philippines (Mathur and Kureel, 1965; Khan and Mian, 1974; Muheet *et al.*, 1975; Valencia and Natural, 1988; Kitisin *et al.*, 1989), but further evaluations in multilocational trials are required.

6.2. Breeding for resistance

Breeding for resistance to *S. rolfsii* has been largely limited to the USA. Exploitation of resistances of Toalson and T × Ag-3 has been actively pursued in the Texas groundnut breeding programme (Smith *et al.*, 1989). No high-yielding cultivar with a high degree of resistance to *S. rolfsii* has yet been released to any part of the world.

6.3. Resistance mechanisms

Resistance has been attributed mainly to a thick, impervious cuticle, thick-walled cortical cells, and cork cambium activity (Higgins, 1927; Cooper, 1961). Resistance may also be associated with phenology (plant canopy) and active responses of the plant (metabolic resistance) to infection (Shew *et al.*, 1987). However, components of metabolic resistance are not known.

7. Integrated management

Cultural practices such as crop rotation, deep ploughing, and good seedbed preparation are the foundation of effective management of *S. rolfsii*-caused diseases of groundnut, but when used alone are often inadequate to prevent crop losses. Certain fungicides are effective against the disease, but they provide only partial control, and sometimes give erratic results. Commonly grown groundnut cultivars exhibit little resistance to *S. rolfsii* infection. Improved control of stem rot is possible by combining partial resistance with limited use of pesticides (Shew *et al.*, 1985). However, cultivars with moderate or partial resistance are available in the Virginia runner types, and such long duration cultivars are commonly grown in the USA where the disease is severe. In many groundnut-growing areas, early-maturing Spanish types are preferred by farmers. Emphasis should be placed on an integrated management approach to control of stem and pod rots, involving appropriate components of cultural measures, host resistance and limited use of pesticides (particularly in heavily disease-infested areas). Biological control is likely to be an integral part of the disease management strategy in the near future. In this context, it would be useful to develop commercial products of effective biocontrol agents for seed treatment.

8. Concluding remarks

Sclerotium rolfsii-incited stem and pod rots continue to be major constraints to groundnut production in many groundnut-growing regions, and pose a serious threat to post-rainy and summer season groundnuts in expanding irrigated production systems, particularly in light sandy soils and vertisols. Although some fungicides are vey effective against stem rot and pod rot diseases, their use is largely confined to high-input conditions. They may not be compatible with lower-input sustainable production systems. Certain cultural practices (e.g. deep p [illegible] reducing *S. rolfsii* populations in the soil. These practices need to be adopted more rigorously for containing the disease, and farmers should be persuaded to adopt the technology of raised bed planting for ensuring better crop growth and soil moisture management. There is a strong need to conduct on-farm demonstrations of the value of these cultural practices. Agricultural extension workers can play an important role in educating the farmers regarding the importance of cultural measures for management of stem and pod rots. Biological control of *S. rolfsii* has attracted much attention in recent years, and holds promise for incorporation into integrated management systems, particularly through seed treatments with biocontrol agents. There has been some progress in identifying usable levels of host resistance to *S. rolfsii*. Concerted efforts are now needed to enhance levels of resistance for use in breeding programmes. Attention needs to be paid to developing effective field and greenhouse resistance screening techniques. It is important to understand the mechanisms of resistance to *S. rolfsii*. Efforts should be made to utilize all feasible components of disease management into an integrated approach to the problem.

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