AN OVERVIEW OF STEM ROT DISEASE OF RICE (Sclerotium oryzae Catt.) AND IT’S COMPREHENSIVE MANAGEMENT

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ABSTRACT: Rice (Oryza sativa L.) is one of the important staple food crops for more than 60 per cent of the world’s population. Over 90 per cent of the rice produced in the world is consumed in the Asian countries only. India is the number one country in the world in cultivating rice in an area of 43.5 million hectares with an annual production of 893.1 million tones and it ranks second to china in the production (Centre for Monitoring Indian Economy Report, 2010).

Stem rot disease caused by Sclerotium oryzae which was earlier considered as a minor disease has now become one of the major limiting factors in rice cultivation especially in delayed transplanted conditions. Although the disease manifests from panicle initiation stage but the conspicuous diagnostic symptoms are usually seen at later growth stages of crop i.e., from milky to grain hardening stage. In severe cases, lodging of the crop may occur and sclerotia of the pathogen are found within the host tissues.

The yield losses up to a maximum of 80 per cent in different rice cultivars has been reported by several workers from varied agro climatic regions in India and aboard. (Hernandez, 1923; Srivastava et al., 1971; Kang et al., 1970; Webster et al., 1972; and Krause and Webster 1972; Al Heeti and El–Bahadli, 1982; Li et al., 1984; Ou, 1985; Cother and Nicol, 1999).

In this chapter we have critically reviewed disease occurrence and yield losses, symptomatology, pathogen, isolation of the pathogen, maintenance and mass multiplication of the pathogen under laboratory conditions, pathogenicity test, host range, viability and source of survival, pathogenic variability and management aspects of stem rot of rice.

DISEASE OCCURRENCE AND YIELD LOSSES

Stem rot of rice, Sclerotium oryzae Catt., has been reported practically from every rice growing country of the world. Shaw made first Indian collection of disease in Noakhali (now in Pakistan) in 1913. Since then the disease has been reported from Madras (Shaw 1913), Bihar (Shaw 1913; Butler 1918), Punjab (Luthra and Sattar, 1936); Assam (Nandi, 1941), Paracer and Luthra, 1944 and Madhya Pradesh (Nikam, 1954).

In Philippines, losses ranging 30 to 80% have been estimated in Tarlac Province (Hernandez, 1923) and in Arkansas, USA (Anon., 1930), and as high as 75% in certain fields, with an annual average of 10% in severely infected areas.
Stem rot of rice caused by *Sclerotium oryzae* Catt. was present in all rice growing regions worldwide (Ou, 1972 and 1985), including in California (Krause and Webster, 1972, 1973; Webster et al., 1971, 1972). Yield losses of up to 18% have been recorded under field conditions in California (Krause and Webster, 1972 and Webster et al., 1972). The pathogen has been reported to cause 5–80 per cent losses in grain yield in different parts of the world (Al Heeti and El–Bahadli, 1982; Li et al., 1984; Ou, 1985; Cother and Nicol, 1999).

Stem rot disease of rice incited by *Sclerotium oryzae* (Perfect state - *Magnaporthe salvinii* Krause and Webster, conidial state – *Nakataea sigmoidea* Cav.) has been one of the major limiting factors in rice cultivation (Bedi, 1953; Ghose et al., 1960).

Singh and Pavgi (1966) reported up to 70% loss in grain yield due to stem rot disease in Uttar Pradesh. During 1962 and 1963, the fungus was widespread on paddy in the months of October – November in the Shahabad district of Bihar, especially in the areas under Intensive Agricultural Development Programme at Bikramgunj and Buxar, where the variety 2206-B (BR 34) was mostly grown (Misra and Mohammad, 1964).

The disease was known to cause losses in yield up to 60% (Chauhan et al., 1968). It was also reported to be most destructive in Punjab (Kang et al., 1970; Srivastava, 1971).

Stem rot of rice incited by sclerotial fungi such as *Sclerotium oryzae* Catt., *S. hydrophilum* Sacc. and *Sclerotium oryzae* var. *irregulare* Roger was a common disease in rice growing areas of India. It was more destructive in Punjab, Haryana and Tamil Nadu (Padmanabhan 1974, Ahuja et al., 1981), particularly on high yielding varieties.

The disease was much prevalent in Haryana and adjoining areas (Ahuja et al., 1981; Yadav and Mehratra, 1982; Sharma et al., 1984). Konthoujam (1998) reported the endemic nature of stem rot infecting due to monoculturing of rice in Manipur.

Stem rot of rice was rapidly spread throughout the Manipur valley during past 9 years (1997-2005). Production oriented survey for the occurrence of stem rot rice conducted by Directorate of Rice Research, Rajendranagar, Hyderabad in different states of India. andhra pradesh. (DRR Production Oriented Survey Reports 2004, 2006, 2007 and 2008) varied from 0 – 15%.

### Table-1: Stem rot incidence in India

<table>
<thead>
<tr>
<th>Year</th>
<th>Andhra Pradesh</th>
<th>Bihar</th>
<th>Chhattisgarh</th>
<th>Haryana</th>
<th>Uttaranchal</th>
<th>West Bengal</th>
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<tr>
<td>2004</td>
<td>L – M</td>
<td>L – M</td>
<td>T</td>
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<td>2006</td>
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<td>L – M</td>
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<td>2007</td>
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<td>L – M</td>
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<td>2008</td>
<td>L</td>
<td>-</td>
<td>M – S</td>
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</tr>
</tbody>
</table>

L – low, M – medium, S - severe, T - traces
Low –0-5%, Medium –5.1-10.00%, Severe – 10.10 – 15%, Traces – 0

### Table-2: Stem rot incidence in Andhra Pradesh

<table>
<thead>
<tr>
<th>Year</th>
<th>West Godavari</th>
<th>East Godavari</th>
<th>Krishna</th>
<th>Kadappa</th>
<th>Nalgonda</th>
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<td>2006</td>
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<td>2007</td>
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<td>2008</td>
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</tbody>
</table>

L – low, M – medium, S - severe, T - traces
Low –0-5%, Medium –5.1-10.00%, Severe – 10.10 – 15%, Traces – 0

### SYMPTOMATOLOGY

Only a few workers have studied and described symptoms of stem rot of rice.

Ferreria and Webster (1976) observed the stem rot of rice symptoms caused by *Sclerotium oryzae* in the field first appeared as small dark lesions on the leaf sheath at the water level. Disease progression was characterized by the death and sloughing of the infected sheath followed by penetration of the entire culm. When the culm was infected both grain quality and panicle size were reduced. When infection occurs early in the season, tillers were killed or fail to produce panicles. Further, they observed that additional reduction in yield resulted from increased lodging of infected plants.
In spite of several published reports, stem rot by and large had remained difficult to diagnose because the symptoms were not pronounced till flowering and were often confused with symptoms caused by other diseases and pests. Severe lodging due to the stem rot was ascribed to weak stem and was ignored (Amin, 1976).

Ou (1985) reported that symptoms are usually seen at the later growth stages. Necrotic lesions begin on the outer leaf sheath near the water line, these spread gradually to the inner sheaths and the stem base. At maturity lodging may occur and sclerotia found within the tissues.

Similarly Kumar et al., (2003 a) reported that this disease mainly affects the stem resulting in rotting and subsequent lodging of the crop.

Pathogen

Sclerotium oryzae was first described from Italy by Cattaneo, (1876) in the sclerotial state and was named Sclerotium oryzae Catt. Cavara (1889) later reported Helminthosporium sigmoideum Cav. on rice.

Mundkur (1935) found Sclerotium oryzae to be pathogenic on rice seedlings but under field conditions it was considered to be a weak parasite. Luthra and Sattar (1936) and Paracer and Luthra (1944) however found it to be pathogenic under field conditions.

Ferreira and Webster (1975) reported that stem rot of rice was caused by Magnoprole sa lvii Catteneo. This fungus has best known for its sclerotial state Sclerotium oryzae Catt. The conidial state had been referred as Nakates sigmoidea (Cav.) Hara, Vakrabeeja sigmoidea (Cav.) or Helminthosporium sigmoideum (Cav.). Further, they described the fungus as heterothallic; two alleles at one locus which determine the compatible mating reaction for the ascomycetous state.

Stem rot an important disease of rice in the states of Tamil Nandu, Punjab, Haryana and Uttar Pradesh was known to be incited by Sclerotium oryzae Catt., Sclerotium oryzae Catt. var irregularare Roger and S. hydrophilum Sacc. Among these, Sclerotium oryzae and Sclerotium oryzae irregularare were common while S. hydrophilum had been reported from Bengal, Haryana, Punjab and Andhra Pradesh. The later was regarded as a weak parasite which may cause lodging (Ahuja et al., 1988).

Isolation of the pathogen

In order to test the pathogenicity of Sclerotium oryzae, Misra and Mohammad (1964) isolated the pathogen from diseased culms of cv. 2206-B (BR 34) and brought into pure culture by plating a single sclerotium on PDA.

Singh (1982) isolated and maintained eight isolates of Sclerotium oryzae isolated from the specimens collected from different parts of India. Gangopadhyay and Das (1983) isolated Sclerotium oryzae on to the artificial medium containing rice hills (10g), CaCO3 (4g), CaNO3 (1g), KC1 (0.25g), MgSO4 (0.25g), Sucrose (2g) and Agar (10g per liter of sterile water).

Inagaki et al. (1987) isolated S. hydrophilum from the infected plant residue at 90 days and more frequently from the sclerotia exposed on the soil surface.

Ali and Singh (1994 (a)) isolated Sclerotium oryzae from the infected rice samples showing stem rot symptoms. The fungus was successfully grown on PDA medium at a temperature ranging between 20 – 35 °C.

Kadowaki et al. (1995) isolated S. hydrophilum from different parts of rice plants such as roots, non elongated internodes and leaf sheaths and the isolation rate was high in lower leaf sheaths compared to the upper parts of the plants.

Lanoiselet et al. (2001) isolated S. hydrophilum on to PDA medium from the infected leaf sheaths prior to which the samples were surface sterilized in 2% sodium hypochlorite for 2 min followed by thorough rinsing in sterile distilled water.

Maintenance and Mass Multiplication of the pathogen under Laboratory Conditions

Misra and Mohammad (1964) recorded good growth and sclerotial production of the fungus when multiplied on sterilized soil–oats or sand-maize medium (soil 95g, crushed oats or maize 5g) and potato dextrose agar.

Amin (1976) recorded good growth of Sclerotium oryzae on peptone-sucrose-agar medium which was incubated at 25 - 300 C for 10 to 15 days. The inoculum was also mass multiplied on mass scale on sucrose–coated stem pieces.

Ferreira and Webster (1976) used rice hull and unmilled rice by mixing in 2:1 ratio and wetted a solution consisting of 4 g CaCO3; 1g CaNo3; 0.25g MgSO4; 0.25g KCl; 0.25g KH2PO4; 1g Sucrose and 2 liters distilled water for production of Sclerotia.
Sclerotium oryzae was mass multiplied on a 2:1 mixture of rice and rice husk, typha (Typha angustata) pieces, rice stem pieces of susceptible cultivar PR 106 and rice grain husk + sand medium (2:1) in 250 ml Erlenmeyer flasks at 28 ± 2°C for 20 days (Kumar et al., 2003a).

Sclerotium oryzae inoculum multiplied on rice grain husk + sand medium produced maximum disease (62%) under pot conditions followed by inoculum raised on rice stem and typha pieces (Kumar et al., 2003b).

Pathogenicity Test
Shaw (1913), Butler (1918) and Mundkur (1935) observed heavy infection during pathogenicity test conducted on rice seedlings grown in test tubes, but under natural conditions the fungus was as weak parasite. On the other hand Luthra and Sattar (1936) and Paracer and Luthra (1944) showed the pathogenicity of Sclerotium oryzae and carried tests for varietal resistance under natural conditions.

Misra and Mohammad (1964) reported the occurrence of stem rot disease by using cv. 2206-B, when the inoculum of Sclerotium oryzae was mixed in the upper layers of steam sterilized soil at seven days before sowing of the seed or transplanting the seedlings.

Kang et al., (1970) infected the soil with infected stubbles and produced the sclerotia in the laboratory and they stated that it was possible to induce stem rot by soil infestation but, the progress of the disease was slow.

Krause (1971) did not find the effect of the pathogen on disease development when plants were inoculated at mid tillering or booting stage. In all India coordinated rice improvement project, it was proposed to inoculate the main tiller 20 days after transplantation (40-50 days after sowing). This gives enough time for pathogen to infect, penetrate and develop the disease, as Sclerotium oryzae was a weak and refined parasite. Further, the incidence of disease had increased when sheaths were slightly scraped with finger nails before placing inoculum over it by stem tape method.

The cut stem technique followed by Ou (1972), in which roots and top parts were cut off and the inoculum was placed at the bottom cut end, could not give the plants opportunity to express their potential for resistance.

Various pathogenicity tests viz., soil infestations and inoculations of plants by spraying inoculum on plants and by stem tape inoculation were carried out by Amin (1976) in the green house. The stem tape inoculation method was found suitable for screening a large number of rice varieties.

While undertaking pathogenicity studies Kumar et al. (2003a) noted that inoculation of injured plants with air-dried sclerotia produced more disease vis-a-vis uninjured plants.

Host Range
Cralley and Tullis (1934) isolated S. hydrophilum from Echinochloa crusgalli (L), E. colonum (L) and Typha latifolia (L).

Nakata and Kawamura (1939) from Japan reported the occurrence of stem rot on several plants other than rice in nature and the fungus when artificially inoculated resulting in invading several graminaceous and cyperaceous plants.

Chen (1971, 1973) reported 10 species of graminiae, three of cyperaceae and one of liliaceae, as hosts of Sclerotium oryzae var. 'sigoidea' and 13 of graminea, two of cyperaceae and one of juncaceae as host for Sclerotium oryzae var. 'irregulare'.

Ou (1972) also mentioned that Zizania latifolia (T) and Juncellus serotines (R.) and Digitaria sanguninalus (L.) are the hosts of this fungus.

Johnson et al., 1976 successfully inoculated S. hydrophilum on to healthy Nymphaea odoranta leaves, which being first report on the occurrence of the fungus on these hosts.

Punter et al. (1984) isolated a S. hydrophilum, a sclerotium forming fungus from a wild rice species occurring over a wide range of temperature and tropical aquatic macrophyte.

Li and Wang (1985) reported the occurrence of S. hydrophilum, Fusarium spp. and Rhizoctina spp. on 11 aquatic plants.

Viability and source of Survival
Park and Bertus (1932) recovered viable sclerotia after 190 days from air-dry soil and after 132 days from moist rice field soils.
Studies on longevity of *L. salvinii* showed that the sclerotia can remain viable for at least six years in cultivated rice soil (Tullis and Cralley, 1941). After two years viable sclerotia were recovered from stubbles in the field and from stubbles stored in laboratory under less variable conditions after about two and half years. Thus rotation period of 4-6 years apparently did not eliminate disease.

Tullis and Cralley (1941) buried infested rice straw and sclerotia 10-15cms deep in field soil and reported that 3.7% of the sclerotia were viable after 6 years.

Krause and Webster (1972) studied the effect of varying inoculum levels and changes in variability of sclerotia of *Sclerotium oryzae* on the occurrence and severity of stem rot and enabled the desirable methods for quantitative recovery and determination of the viability of sclerotia from infested soil.

Studies on the effect of soil moisture and temperature on viability of *Sclerotium oryzae* showed that alternate wetting and drying resulted in substantial loss of sclerotal weight accompanied by reduction in viability. Viabilities of sclerotia recovered form wet soils after incubation at 240°C were significantly lower than the viabilities of those incubated at 10°C and those incubated at 24°C after they were recovered from soils that had been allowed to dry. They were also lower than viabilities of sclerotia subjected to alternate wetting and drying. It would appear that a soil fungistatic factor was imbibed by sclerotia and retained after their recovery from soil. (Keim and Webster, 1974 a).

Bockus *et al.* (1978) studied the saprophytic ability of *Sclerotium oryzae* derived from sclerotia. The saprophytic ability of *Sclerotium oryzae* was too low to enable it to use residual organic material in either non-autoclaved or autoclaved soil. In autoclaved soil amended with rice sheaths, the sclerotia germinated, the fungus colonized the sheaths, and the number of sclerotia increased within the non-autoclaved soil amended with rice sheaths, a few sclerotia were produced as a result of colonization of the sheaths but they did not contribute significantly to the population of sclerotia in the soil.

Ali and Singh (1994 b) reported that the fungus survives for several years through sclerotia over the infected stubbles left over in the field which serve as primary source of inoculum.

Inagaki *et al.* (2004) obtained *S. hydrophilum* and *Rhizoctonia oryzae-sativae* more frequently from stubble than from surface soil, while there was no significant difference in the isolation frequency of *Rhizoctonia fumigata* between surface soil and stubble, indicating that the survival of *S. hydrophilum* and *R. oryzae-sativae* was highly related to the availability of stubble, where as *R. fumigata* relates to both isolation sources. *R. fumigata*, which had caused sclerotal disease over a wide area (25-30%) of rice fields, over wintered at higher rate in the fields, as compared with fungi such as *R. oryzae-sativae*, *R. oryzae*, *R. solani* which had caused disease only within a limited area (0-15%) of those same fields.

Konthoujam and Chhetry (2005) studied the viability and survival of *Sclerotium oryzae* under natural conditions, compared to those preserved aseptically in the laboratory over the period of 12 months. Their studies revealed that the sclerotia in these free state was less viable than those over wintering naturally inside left over stubbles or in degenerated plant tissue debris in the top soil in the fields. Viability decreased with age in all the isolates collected from different sources. Age and over wintering medium of sclerotia did not have any significant effect on their vigor in germination and formation of fresh sclerotia *in-vitro* conditions.

**Pathogenic variability**

Culture filtrate of different fungi are known to produce either stimulatory or inhibitory effect to the young seedlings (Das and Srivastava, 1971; Anahosur, 1976; Prasad and Hirenath 1983).

Quantitative differences in the rate and amount of conidia and sclerotia produced were determined for isolates of *Sclerotium oryzae* differing in rating type and virulence to determine differences in fitness of *Sclerotium oryzae* in nature (Ferreira and Webster, 1975).

Ferreira and Webster (1976) developed a test to measure the disease reaction of individual *Sclerotium oryzae* isolate-host combinations by estimating the ability of isolates to incite lesions. Since the ability of isolates to incite lesions was correlated with the ability to kill seedlings, virulence of individual isolates can be determined by measuring the ability to cause lesions. They concluded that seedling test can be used to evaluate rice cultivars for stem rot resistance as well as virulence in *Sclerotium oryzae*.

Ali and Singh (1992) investigated to find out the pathogenic variability and the effect of culture filtrate of *Sclerotium oryzae* on inhibition of radical and pumule length in rice. The results indicated that variation in virulence exists in the different isolates of the pathogen and indicating different degree of resistance in rice cultivars against the disease. Culture filtrate of all the isolates inhibited the radicle and plumule elongation which was directly correlated with the concentration of culture filtrate to untreated control. The maximum inhibition of radicle and plumule occurred in undiluted culture filtrate followed by 50 and 25% filtrate.
MANAGEMENT OF STEM ROT
Identification of sources of resistance

The sources of resistance to stem rot under natural and artificial conditions were reported by only a few workers (Cralley, 1936; Kang et al., 1970; Goto and Fukatsu, 1954) from different parts of the country. The details of which are furnished here under.

Misra and Mohammed (1964) carried out varietal reactions at three stages in sterilized and infected soil. Out of ten varieties 115BK, 141Bk, 16BK, 88BK, 36BK, 498-2A, 818-3, 2206-B, CH-10 and CH1007 tested for infection at seedling and after transplantation, none of the varieties proved resistant, though there were differences in the percentage of infection. Among the ten varieties tested for infection at tillering stage, varieties 115BK, 141BK, 16BK, 88BK, 36BK and 818-3 developed stem rot symptoms with sclerotia inside the culms.

Variatel resistance carried out by Srivastava et al., 1971 revealed that out of 44 varieties tested for their resistance to stem rot, 7 were highly resistant, 12 resistant, 5 moderately resistant, 2 moderately susceptible, 4 susceptible and 14 highly susceptible. Among the resistant varieties TN-1, Taichung 65 and Jaya were high yielding whereas Basmati 217 and Basmati 370 were of good quality. Tainan 3’, TN-1, Taichung 65 and Jaya were good for hybridization because there were not only resistant to stem rot but also for blast and Helminthosporium to some extent.

Sixty-nine rice varieties including Pankaj, Jaya, Sabarmati Improved, TKM-6, Sigadis, RP 5-32 and Tadukan were found tolerant to stem rot and other major diseases (Amin, 1976).

Ahuja et al. (1988) studied relative preponderance of sclerotial species on rice and varietal resistance. Their observations on 16 varieties showed occurrence of Sclerotium oryzae, Sclerotium oryzae irregularare and S. hydrophilum on the same hill. Sclerotium oryzae was predominant over S. irregularare and S. hydrophilum in prevalence and severity except in entries CR188-10, Pusa 2-21, HKR 102 and Pusa169 where S. hydrophilum and S. irregularare were predominant.

Ali and Singh (1994 a) screened 52 cultivars against Sclerotium oryzae by artificial inoculation during kharif, 1989 at Pantnagar. Improved Sona, IR 22, Rasi and VL 8 were identified as resistant varieties against stem rot.

Screening of rice genotypes was carried out by Kumar et al. (2003 a) under field conditions and high disease pressure with location severity indices of 7.38 and 7.39 on 0-9 scale during kharif 1998 and 1999. Of 234 rice genotypes screened against stem rot, none of the genotypes were consistently resistant. However, 38 genotypes showed moderately resistant reaction.

Konthoujam et al. (2007 a) noted symptomatological significance characterization of susceptibility resistance group low land rice cultivars towards stem rot of rice in Manipur valley. None of the 33 cultivars studied were resistant or highly resistant against the disease. The degree of susceptibility among cultivars differed with marked symptomatological difference in size, number and position of lesions on infected stems above the field water level. Highly susceptible cultivars exhibited more number of lesions (3.0 to 8.5), larger coalesced lesion size (72.6 sq mm – 406.2 sq mm) at crop maturity and extended to higher portions on the stems up to 6.6” above soil, in fields with 2’ water level during cropping period. The size, number and portions of lesions decreased with increasing resistance of individual cultivars.

Cultural Practices

Paracer and Luthra (1944) recommended the burning of stubbles soon after harvest, drawing the stagnant water and the allowing of fresh water. Similar measures have been recommended by Tullis and Cralley (1941), and Park and Bertus (1932). Cralley and Adair (1943), however found only a slight reduction in severity of infection and no increase in crop yield as a result of either alternate drawing or flooding of field or from with holding water for some time prior to harvest.

Cintas and Webster (2001) reported that fall incorporation of the straw residue, rolling of the straw to enhance soil contact, baling and removal of residue, and fall burning the straw followed by winter flooding appears to be the best alternative to rice straw burning for disposal of residue and management of stem rot.

Konthoujam et al. (2007) by using cv. Sana phou (susceptible to stem rot of rice) as the test plant during kharif. 2004-2005 reported that maximizing soil amendment with N-P-K from 0-0-0 to 80-60-30 kg ha\(^{-1}\) increased the yield by 76.8%. However, further increase of N-P to 120-80 kg ha\(^{-1}\) increased the stem rot incidence by 57.8%, disease severity by 54.3% and resulted to an abrupt decline in yield by 13.6%.

Efficacy of fungicides and herbicides against Sclerotium oryzae

Misra and Das (1967) tested 11 fungicides pertaining to copper, mercury and the dithiocarbamates against Sclerotium oryzae. Out of which Blue copper – 50 (ED 50 in ppm 138) in copper group, mercuric chloride (ED 50 in ppm 10.5) in mercury group and ferbam (ED 50 in ppm 240) in dithiocarbamates were highly toxic for mycelial growth.
The amount of fungicides required for the inhibition of the fungus in the soil was higher than that required on agar medium. The most effective fungicide was mercuric chloride. Its ED 50 value was the lowest as compared to other fungicides.

Jain (1973) reported that the application of Hinosan, Benlate resulted in significant reduction in stem rot incidence on Ratna rice variety

Jackson et al. (1977) conducted a field test to control stem rot disease of rice with triphenyltin hydroxide (TPTH) for three years. A single application of TPTH at the rate of 1.12 kg ha⁻¹ at the mid tillering stage resulted in significant reductions in disease severity which were accompanied by increasing in yield ranging from 6-25 per cent. Further, the results indicated that the fungicide reduced the number of early infections, delayed disease progress, and decreased final disease severity.

Gangopadhyay and Padhi (1984) reported that hinosan and lihocin proved to be the best fungicidal combination for control of stem rot of rice.

Reddy (1984) reported that among 16 fungicides, carbendazim (Bavistin 50 WP), tridemorph, tolfos – methyl, thiophanate methyl, carboxin (Vitavax 75 WP), ziram, cuman L-27 and TCM TB were highly effective even at lower concentration in checking the growth the sclerotial germination of the pathogen. The weedicide bentiocarb (Saturn 50 EC) showed the inhibitory effect on the growth and sclerotial formation of *Sclerotium oryzae*.

Stem rot caused by *Sclerotium oryzae* was one of the major limiting factors in rice cultivation. All the cultivated varieties suffer from this disease. Since resistance to stem rot in rice genotypes is rare (Raina et al., 1980, Chand et al., 1985), management of the disease through chemicals becomes imperative.

Sharma and Verma (1985) reported that out of 17 fungicides, namely, Bavistin, Blitox, Brassicol, Calaxin, Cuprasol, Demosan, Dithane M-45, Dithane Z-78, Difolaton, Hexathir, Hinosan, Kitazin, Thiovit, Topsin M and Vitavax tested by the poisoned food technique, Bavistin, Topsin M, Dithane Z-78, Brassicol and Hinosan were effective against *Sclerotium oryzae* Catt.

Ram Singh et al. (1988) reported that out of six fungitoxicants tested, carbendazim and thiophanate-methyl were effective in inhibiting sclerotial germination and mycelial growth of *Sclerotium oryzae*.

Reddy et al. (1988) reported that Edifenphos, Vitavax, Bromidiol, Panoctine, Dithane M-45, Bavistin, MBC, Busan, Hinosan, Calaxin and Topsin were highly effective against stem rot while Brassicol was least effective

Studies conducted by Singh et al. (1987) indicated that carbendazim and thiophanate methyl effectively inhibited the sclerotial germination and mycelial growth of *Sclerotium oryzae*.

Sunder et al. (1991) reported that the stem rot incidence was reduced by the application of carbendazim at disease initiation and boot stage (two sprays) proved more effective than corresponding sprays of isoprothiolane in reducing the disease during wet season.

The superiority of mancozeb compound against *Sclerotium rolfsii* can be attributed due to inhibition of pentose phosphate pathway and chelation of required heavy metals followed by lethal catalysis in pathogen cell (Nene and Thapliyal, 1993).

Kumar et al. (2003 b) reported that of six resistance inducing chemicals tested, benzoic acid was found to be most effective over other chemicals followed by naphthalene acetic acid in reducing the disease incidence and severity. Benzoic acid reduced stem rot incidence to 61 per cent as against 74 per cent in the check but had no significant effect on disease severity.

Propiconazole was found to be the most promising fungicide and provided 47.5 and 26.5 per cent reduction in disease incidence and severity respectively followed by isoprothiolane (Kumar et al., 2003 b).

Herbicide application has often been cited as an example of a management practice that affects plant pathogens and disease development in various cropping systems. The activity of herbicides can extend beyond their target organisms and inhibit spore germination or mycelial growth, alter the level of phytoalexins, or interfere with other physiological processes in plants (Debanjan Sanyal et al., 2008).

*Trichoderma viride* was found significantly superior over other antagonists in inhibiting the growth of *Sclerotium rolfsii*. Among five pesticides tested for their efficacy, hexaconazole (1000, 1500 and 2000 ppm) and propiconazole (500, 750 and 1000 ppm) completely inhibited the growth of *S. rolfsii*, whereas chlorpyriphos completely inhibited the pathogen at one step lower (1500 ppm) and at recommended concentration (2000 ppm), while quinalphos inhibited the growth at 2000 ppm. Of the four herbicides, pendimethalin completely inhibited the growth of *S. rolfsii* at recommended concentration (1000 ppm). Sensitivity of *T. viride* against three agrochemicals showed complete inhibition of the growth of *T. viride* with hexaconazole and 48% with pendimethalin (Johnson et al., 2008).
Biological control
Isolation of antagonistic microflora from rhizosphere using serial dilution technique

Upadhyay and Mukhopadhyay (1986) isolated *Trichoderma harzianum* from sugar beet field soil on peptone-dextrose rose-bengal agar medium antagonistic to *S. rolfsii*.

Pande (1996) isolated six potential antagonistic isolates of *Pseudomonas fluorescens* from the rhizosphere of chick pea and wheat infected with *S. rolfsii* on King’s B medium.

Pandey and Upadhyay (2000) isolated rhizosphere fungi of pigeonpea on martin medium viz., *Aspergillus niger*, *A. fumigatus*, *Penicillium* sp., *Fusarium udum*, *Pythium* sp., *Rhizopus* sp., *Trichoderma harzianum*, *Glicoladium virens* and bacteria were isolated on soil extract agar medium which included 3 isolates B1, B2 and B3.

Rangeshwaran and Prasad (2000) isolated eleven antagonistic rhizobacteria including *Pseudomonas fluorescens*, *Pseudomonas* sp., *P. putida*, *Streptomyces* sp., *Bacillus pantothenticus* and *Alcaligenes odorans* from rhizosphere of sunflower infected with *S. rolfsii*.

Anahosur (2001) isolated antagonistic mycoflora viz., *Trichoderma* sp., *Glicoladium virens* and bacteria like *Pseudomonas fluorescens* from rhizosphere of sunflower, which were antagonistic to *S. rolfsii*.


Kavitha et al. (2004) isolated 12 *Trichoderma* isolates from rhizospheric soil samples of different acid lime gardens, antagonistic to *Fusarium solani*.

Srinivasulu et al. (2005) isolated three *Trichoderma* spp. from rhizosphere soil samples surrounding the healthy and diseased plants of elephant foot yam which were antagonistic to *S. rolfsii*.

Shivani Bhatia et al. (2005) isolated 10 strains of fluorescent pseudomonads from the rhizosphere of sunflower, potato, maize and groundnut antagonistic to *S. rolfsii*.

In vitro evaluation of efficacy of antagonists against *Sclerotium oryzae*

Mathur and Sarbhoy (1978) reported the effectiveness of wheat bran preparation of *T. harzianum* and *T. viride* in controlling root rot of sugar beet caused by *S. rolfsii*.

The ability of *Trichoderma* to act as mycorrhizal parasite of hyphae and resting structures of plant pathogens has been demonstrated not only in vitro (Ayers and Adams, 1981) but also in natural soil (Cook and Baker, 1983). The proven ability of *Trichoderma* and *Glicoladium* to produce diffusible substances toxic to other fungi in *vitro* and even in organic substrates in soil also strengthens the hypothesis suggesting the importance of native *Trichoderma* in biocontrol.

Gnanamanickam et al. (1992) reviewed the methodology and recent research on the biological control of *Sclerotium oryzae* stem rot fungus.


Narasimha Rao et al. (2001) tested the antagonistic potential of culture filtrates of *Trichoderma koningii*, *Trichoderma harzianum*, *Trichoderma viride*, *G. virens*, *Penicillium* sp., *Aspergillus niger*, *P. fluorescens* against the *S. rolfsii* isolated from potato. They observed that the filter sterilized culture of *P. fluorescens* showed maximum inhibition of mycelial growth of *S. rolfsii* followed by *T. harzianum*.

Narasimha Rao et al. (2004) tested the antagonism of *Trichoderma harzianum*, *Trichoderma viride*, *P. fluorescens*, *Trichoderma koningii*, *Glicoladium virens*, *Aspergillus niger* and *Penicillium* sp. against *S. rolfsii*. They observed a maximum inhibition of mycelial growth of *S. rolfsii* (81.1%) by *Trichoderma harzianum* and a reduction in sclerotial production by 96.2 per cent.

Sonali and Gupta (2004) evaluated the *in vitro* efficacy of fungi, bacteria and actinomycetes isolated from soil for their antagonistic activity against *S. rolfsii* by dual culture technique and reported that *Bacillus* sp. strain was effective in reducing the radial growth of *S. rolfsii* by 77.4 per cent.

Shivani Bhatia et al. (2005) tested the antagonism of 10 strains of fluorescent pseudomonads against *S. rolfsii* by dual culture technique and found that the strains PS I and PS II inhibited the growth of *S. rolfsii* by 73.0 and 70.0 per cent respectively.

In vitro compatibility of antagonists with the fungicides

Vyas (1987) reported that *Trichoderma* spp. and *B. subtilis* showed high degree of tolerance to thiram and carbendazim.

Singh et al. (1995) screened isolates of *Trichoderma* spp. against fungicides like captan, mancozeb and thiram. The growth of the isolates was not inhibited at 500 ppm concentration with captan and mancozeb, but thiram at 200 ppm completely inhibited the growth.
Vidhyasekharan and Muthamilan (1995) reported that thiram and carbendazim were not inhibitory to *P. fluorescens* in *in vitro* conditions.

Karpagvalli (1997) studied the *in vitro* compatibility of *T. harzianum* and *T. viride* with carbendazim, thiram and copper oxychloride @ 500, 1250, 2500 ppm using poisoned food technique. These results revealed that copper oxychloride was less inhibitory on the radical growth of both the antagonists than thiram and carbendazim.

Rajeevpant and Mukhopadhyay (2001) evaluated the effect of three fungicides *viz.*, carboxin (10, 25, 50 micro grams a.i. ml^{-1}) thiram (10, 25, 50 micro grams a.i. ml^{-1}) and bavistin (10, 25, 50 micro grams a.i. ml^{-1}) against *Gliocladium virens* and *T. harzianum* and reported that carboxin had no effect on both the antagonists while carbendazim was found to be highly inhibitory to them.

Compatibility of *Trichoderma* spp. with mancozeb have been noticed by many workers (Moity *et al.*, 1982; Wongwathanarat and Sivasithamparam, 1991; Shanmugam, 1996; Rajan and Sharma, 1999; May and Kimati, 2000; Akbari and Parakhia, 2001).

Combination of fungicides and biocontrol agents for controlling soil borne pathogens have been successfully used by many workers (Papavizas and Lumsden, 1980 and Poddar *et al.*, 2004).

Gupta (2004) reported that bavistin completely inhibited the mycelial growth of *Trichoderma harzianum* at concentrations 1, 10,100 and 1000 ppm concentrations.

Vijayaraghavan and Abraham (2004) tested the *in vitro* compatibility of *Trichoderma harzianum*, *Trichoderma viride* and *Trichoderma longibrachiatum* with nine fungicides and found that mancozeb was compatible with all the three antagonists at 0.2, 0.3 and 0.4 per cent.

Out of three fungicides tested *viz.*, mancozeb, carbendazim and copper oxychloride against *Trichoderma harzianum*, carbendazim at 0.1 per cent completely inhibited the mycelial growth of *Trichoderma harzianum* while mancozeb and copper oxychloride showed compatibility with the antagonist at 0.2 and 0.1 per cent (Naseema Beevi *et al.*, 2005)

*Trichoderma viride* was found significantly superior over other antagonists in inhibiting the growth of *Sclerotium rolfsii*. (Johnson *et al.*, 2008).

**Mass multiplication of antagonists**

Mass multiplication of *T. harzianum* on mixture of FYM and Banana Peeled Skin (BPS) produced maximum number of spore suspension and maximum number of propagules at 15 days of incubation (Pranab Dutta and Das, 1999).

Multiplied *Pseudomonas fluorescens* and *Bacillus subtilis* was multiplied in Kings B and Nutrient broth medium (Padmodaya and Reddy, 1998; Umamaheswari *et al.*, 2002 and Gogoi *et al.*, 2002).

Pre-boiled and sterilized sorghum grains supplemented with 5 per cent anhydrous dextrose was used for mass multiplication of *G. virens* and *T. harzianum* (Rajeevpant and Mukhopadhyay, 2001).

Sharma *et al.* (2002) reported that FYM + Jhingora (Barnyard millet) in 3:1 w / w was more suitable for mass multiplication of *Trichoderma harzianum*.

Wheat bran has been used as best substrate for mass multiplication of *T. viride* (Henis *et al.*, 1978; Dubey and Patel, 2001; Patibanda *et al.*, 2002; Upadhay *et al.*, 2004 and Gaur *et al.*, 2005).


Zaidi and Singh (2004) reported that cow dung and poultry manure supported good growth of *Trichoderma harzianum*.

**Efficacy of fungicides, herbicides and antagonistic Microflora in green house**

Papavizas (1985) emphasized the importance of integration of *Trichoderma sp.* or *Gliocladium* with compatible fungus or other practices in controlling soil borne pathogens.

Sharma and Verma (1985) reported that in pot experiments bavistin and topsin-M were effective in controlling the stem rot of rice disease and increasing the yield, when compared to seventeen fungicides, namely, Demosan, Dithane M-45, Dithane Z-78, Difolatan, Haxacap, Hexathiir, Hinosan, Kitazin, Thiovit, Topsin M, Vitavax Bavistin, Benlate, Blitox, Brassicoll, Calixin and Cuprasol.

Ram Singh *et al.* (1988) reported that field trials showed that stem rot incidence can be economically minimized by spraying the crop once with thiophanate-methyl at the rate of 875 g/ha at the time of disease initiation.
Brahmabatt et al. (1989) reported excellent control of tobacco damping off by a combination of Trichoderma inoculum and metalaxyl seed treatment.

Integration of cultural, biological and chemical means of control has proved to be a very promising way of management soil-borne pathogens such as S. rolfsii (Upadhyay and Mukhopadhyay, 1986; Natarajan and Manibhushan, 1996 and Saralamma, 2000)

Many workers reported that soil application of Trichoderma sp. and P. fluorescens effectively checked the diseases caused by soil borne plant pathogens and also a synergistic effect in the growth of plants was observed (Selvan, 1997; Manoranjitham et al., 1999, 2000; Bharti et al., 2004 and Poddar et al., 2004).

Paul et al., (2005) studied the effect of combination of P. fluorescens strains and some fungicides for controlling foot rot of black pepper caused by Phytophora capsici and found 100 per cent survival of the infected plants when bacterial treatment was combined with metalaxyl – mancozeb @ 2 g l⁻¹.

Saralamma and Vithal Reddy (2005) studied the integrated management of root rot of groundnut and found that integration of bio-agent T. harzianum along with neem cake and fungicide (Thiophanate-methyl) increased the efficacy of disease control as compared to their individual treatments.

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