

Sheath Rot Disease of Rice

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Sheath rot caused by *Sarocladium oryzae*, hitherto considered as a minor disease of rice, is gaining importance as a major disease of widespread occurrence in almost all the rice growing areas of the world in recent years. Recent findings on various aspects of the disease are reviewed.

Key words : Rice, sheath rot, *Sarocladium oryzae*, review

INTRODUCTION

Sheath rot is an important fungal disease of rice occurring in Japan, South East Asia, Indian sub-continent and also in the U.S.A. Comprehensive reviews have highlighted the importance of sheath rot as a major disease of rice. (Purakayastha and Ghosal, 1982; Gangopadhyay, 1983; Ou, 1985; Manibhushanrao *et al.*, 1986; Ngala and Adeniji, 1986; Alagarsamy and Bhaskaran, 1987; Narain, 1992; and Singh and Dodan 1995). In the present paper, an attempt has been made to give an amount of works so far done on sheath rot of rice in India and abroad.

OCCURRENCE

Sheath rot disease of rice was first reported by Sawada (1922) from Taiwan. Later Kawamura (1940) reported its occurrence in Japan. The occurrence of sheath rot has also been reported from Thailand (Hashioka, 1963; Surin and Disthaporn, 1977), Peru (Jimenez and Panizo, 1977), U.S.A. (Shahjahan *et al.*, 1977), Nigeria (Imolehin, 1989) and Pakistan (Gill *et al.*, 1993).

In India, Sheath rot disease was first reported by Agnihothrudu (1973). Subsequently, several workers reported this disease from different parts of India, namely, West Bengal (Amin *et al.*, 1974), Tamil Nadu (Ahmed *et al.*, 1975; Subramanian and Ramakrishnan, 1975; Srinivasan, 1979), Kerala (Nair and Rajan, 1978; Balakrishnan *et al.*, 1981), Orissa (Naik, 1976), Andhra Pradesh (Koteswara Rao, 1977; Muralidharan and Venkata Rao, 1980), Karnataka (Sanne Gowda,

1979), Bihar (Ghufran *et al.*, 1980), Punjab (Raina and Singh, 1980), Rajasthan (Tripathi, 1982), Madhya Pradesh (Upadhyay and Diwakar, 1984), Uttar Pradesh (Singh *et al.*, 1988; Singh, 1988), Assam (Phookan and Hazarika, 1992) and Manipur (Devi and Singh, 1991, 1995).

SYMPTOMATOLOGY

The disease can be diagnosed by the non-emergence and partial emergence of rice panicles along with dark to chocolate coloured unfilled grains. Brown, dark chocolate brown or grey coloured lesions surrounded by light brown yellow zone appear first on the boot leaf and topmost sheath which covers the panicles. The panicle does not emerge in early infection stage and discoloured panicle remains compressed within the flag leaf sheath in severe infection stage. Within compressed leaf sheath and partially emerged panicle grains become dark brown and remain chaffy for the presence of only aborted brown anthers resulting in the formation of abortive or sterile rice (Surin and Disthaporn, 1977; Hsieh *et al.*, 1977). On opening the flag leaf sheath powdery white masses of spores along with the pinkish white mycelia of the causal organism are visible, (Gangopadhyay, 1983).

YIELD LOSS

Yield losses due to sheath rot diseases have been reported by a number of workers.

The damage caused by the disease has been reported

to vary from 3-20% in normal years and it may sometimes be as much as 85% (Chen, 1957; Prabhakaran *et al.*, 1974). Mohan and Subramanian (1977a, 1979a) working with 16 popular rice cultivars in TamilNadu, reported the extent of damage to be about 57.4%. While Muralidharan and Venkata Rao (1980) and Srinivasan (1980) reported about 85% and 89.8% yield loss in TamilNadu respectively. Chakravarty and Biswas (1978), also, reported 9.6-26.0% yield reduction among 7 cultivars in West Bengal. Severe outbreak of sheath rot occurred in Punjab during 1978-79 wet season and caused heavy yield loss (Raina and Singh, 1980) and Kang and Rattan (1983) reported about 50% yield loss in Punjab. At IRRI, Philippines, Estrada *et al.* (1984) estimated the total yield loss associated with the disease was 52.8%. Singh *et al.* (1985) found that the loss in yield varied between 1.7-54.7% due to sheath rot in Bihar and a yield loss of 10-35% in Manipur (Devi and Singh, 1991). Sheath rot infection greatly influenced different yield components of four high yielding rice cultivars viz. NLR 9672, NLR 9674, NLR 9672-76 and NLR 27999 in Andhra Pradesh. There was reduction of panicle weight, total spikelets, filled grains and germination percentage. Grain discolouration and sterility was more in sheath rot affected panicles than healthy ones. All these together contribute to the yield loss due to sheath rot (Naidu, 1994). This work supports the earlier findings of Estrada *et al.* (1984), Tikoo (1985) Reddy (1991) and Vidyasekharan *et al.* (1984) and Upadhyaya and Diwakar (1984) who reported the effect of sheath rot on different yield components like spikelets per panicle, filled spikelets percentage grain discolouration and relative yield percent resulting in yield loss.

It is quite interesting to note a wide variation in the yield loss estimations. The difference may be attributed to either the existence of pathogenic races of the fungus or variation in the disease intensity or host cultivars or physical factors like fertility of the soil, soil type, environment etc, spatial distribution and sampling method for assessment of the disease incidence. (Surin *et al.*, 1988; Maiti *et al.*, 1992; Mia *et al.*, 1996; Dhal *et al.*, 1998)

CAUSAL ORGANISM

Nomenclature and Morphology

Sawada (1922) first recognised and described the causal organism as *Acrocyllindrium oryzae*. The fungus belongs to Deuteromycotina, Order. Moniliales, Family. Moniliaceae. Tasugi and Ikeda (1956) reported differences in conidial measurements of *A. oryzae*

obtained from the host plant ($2.1-8.5 \times 0.5-1 \times 6 \mu$) and from culture ($1.8-13 \times 1-1 \times 6 \mu$). Subsequently, this organism has been described in detail by Ou (1972, 1985). Usually, the mycelium of the fungus is white sparsely branched, septate and $1.5-2 \mu$ in diameter. Conidiophores develop from the mycelium and are slightly thicker than the vegetative hyphae, branched once or twice each time with 3-4 branches in a whorl. The main axis is $15-22 \times 2-2 \times 5 \mu$, terminal branches are tapering towards the tips, $23-45 \mu$ long, 1.5μ at the base, each one bear one conidium on the tip. Conidia are hyaline, smooth, single celled and cylindrical $4-9 \times 1-2 \times 5 \mu$.

Gams and Hawksworth (1975) transferred *Acrocyllindrium* to a new genus *Sarocladium* and named the sheath rot fungus as *Sarocladium oryzae* after comparing isolates referred to as *A. oryzae* with Sawada's holotype material. They also confirmed that the isolate of *A. oryzae* described by Amin *et al.* (1974) was identical with Sawada's holotype, but the isolate described by Agnihothrudu (1973) was different. *S. attenuatum* has also been reported to cause sheath rot of rice but is now regarded as a synonym of *S. oryzae*. Joe and Manibhushanrao (1995), however, considered *S. oryzae* and *S. attenuatum* as separate taxa.

In recent, years, however, several fungi have, also been reported to be associated with rice sheath rot disease. Those are *Fusarium roseum* and *Hyalostachybotrys* sp. (Shahjahan *et al.*, 1977), *Fusarium moniliforme* (Kang and Rattan, 1983; Kang and Kaur, 1989, Devi and Singh, 1994), *Fusarium equiseti* (Kang and Rattan, 1983), *Fusarium graminearum* (Singh and Devi, 1990), *Curvularia lunata* (Lakshmanan, 1991, 1992 c, 1993 b) and *Fusarium avenaceum* (Devi and Singh, 1994). In our studies also, fast growing fusaria, which masked the growth of *S. oryzae* in culture, were isolated consistently from many sheath rot affected samples from West Bengal. In the present review, more attention has been given to *S. oryzae* as sheath rot fungus.

Growth Characteristics

A. oryzae grows best at $30-31^\circ \text{C}$, little at 37°C , not at all at 13°C and is killed after 5 minutes at 50°C (Kawamura, 1940). Tasugi and Ikeda (1956), however, reported good growth at $20-28^\circ \text{C}$, conidia germinated at $23-26^\circ \text{C}$. The isolates of the fungus, however, differed in their responses to temperature, pH, carbon and nitrogen sources as well as in their

pathogenicity (Chen, 1957). According to Chen and Chien (1964), the viability of *A. oryzae* during incubation at 15-28°C was reduced considerably after 10 months and completely lost after 12 months. Shahjahan *et al.* (1977) reported that the fungus grew slowly in culture with optimum growth between 24 and 32°C. Since spore concentration, temperature, pH, age of culture and incubation period usually influence the pathogenicity of a parasite. Datta and Purakayastha (1978) studied the effects of these factors on spore germination and germ tube growth of the pathogen. The spores germinated over a wide range of temperature (15-35°C, optimum 30°C) and pH (5-8, optimum 5.5-6.0) conditions. Spores gradually lost their viability with age. Considerable reduction in germination was detected when spores from 60 and 120 day-old cultures were used. About 3% spores germinated within 6 hr. of incubation at 30°C while 10, 40 and more than 60% spores germinated after 12, 18 and 24 hr respectively. Spore germination was inhibited in a highly concentrated spore suspension (4×10^7 spores/ml). Mohan and Subramanian (1978) observed that the optimum temperature for growth and sporulation of the pathogen was $30 \pm 1^\circ\text{C}$ and optimum pH was 6.5. The isolates from brown sheath tissues and leaf lesions showed a wide temperature range for growth (optimum temperature 30-32°C) (Chien and Huang, 1979). Prabhakaran *et al.* (1974) reported potato dextrose agar (PDA) as the best medium for *A. oryzae* and it was better than the synthetic Czapek's medium. Mohan and Subramanian (1978) observed the fungus, *A. oryzae* grew and sporulated well on PDA and oats agar media. Among the four liquid media tried, maximum growth and sporulation occurred in Czapek's medium. Sucrose and starch were found to be the best among the carbon sources tried while ammonium nitrate and ammonium sulphate promoted better growth and sporulation among the nitrogen sources tested. Subsequently, Chien and Tseng (1981) observed that the best media for the growth of *S. oryzae* are maize agar and rice straw agar and the best nitrogen sources are NaNO_3 and KNO_3 . Sucrose is the best carbon source at optimum pH 5.5-7. A partially selective medium by incorporating 100 ppm Dithane M-45 and 750 ppm Dicrystin in Kirchoff's medium has been developed (Singh and Raju, 1981).

Raychowdhuri and Purakayastha (1980a) found that low concentrations of Gibberellic acid (GA) (0.1 and 1 µg/ml) stimulated mycelial growth while higher concentrations (10 and 100 µg/ml) inhibited the growth of the pathogen *in vitro*.

Enzyme and Toxin Production

The fungus can produce large amount of amylase, cellulase, pectin transeliminase, polygalacturanase,

transeliminase peroxidase (PO) and polyphenol oxidase (PPO) (Raghunathan, 1974; Singh, 1982) indicating the possible role of enzymes during pathogenesis and sheath rot syndrome. Inhibition of polygalacturonase activity of *S. oryzae* by the oxidized products of chlorogenic acid (a polyphenol present in rice) has also been reported by Manibhushanrao and Sreenivasaprasad (1985). Joe and Manibhushanrao (1995), also, showed the activity of various enzymes secreted by the fungus. Association of a toxin with sheath rot symptoms had not previously been established. While studying the effect of culture filtrates of *S. oryzae* on seed germination and seedling vigour of seven rice cultivars, Velazhahan (1991) found the culture filtrate of the fungus showed pronounced inhibitory effect on seed germination in all varieties. The shoot and root lengths of all rice varieties were also reduced significantly. This reduction may be due to the involvement of certain toxin substrates produced by the fungus in culture. This supports the earlier findings of Chung (1975), Sakthivel and Gnanamanickam (1986b), Alagarsamy (1989). Alagarsamy *et al.* (1994), also, observed the same. The toxic metabolite has been identified as cerulenin (a unsaturated amide antibiotic). Vasantha Devi and Gnanamanickam (1993) showed that cerulenin may play a role in the pathogen's virulence in sheath rot induction in rice and in its interaction with other fungal pathogens of rice. Gnanamanickam and Mew (1994) showed that *S. oryzae* inhibited mycelial growth of other stem-attacking rice pathogens. Among those inhibited *Sclerotium oryzae* (stem rot) and *Gaeumannomyces graminis* var *graminis* (crown sheath rot) were the most sensitive while *Piricularia oryzae* (blast) and *Rhizoctonia solani* (sheath blight) were less sensitive. Moreover, an antibiotic metabolite, Helvolic acid, was isolated from the rice sheath rot pathogen, *S. oryzae* by Tschen *et al.*, (1997) at Taiwan. Its antibiotic activity was tested with *Bacillus subtilis*. The toxic effects of helvolic acid on seedlings of Poaceae included growth retardation and chlorosis.

Possibility of Existence of Strains/Races

Mohan and Subramanian (1979b) found that some of the rice varieties react differently with different isolates indicating the possibility of race variations. Shahjahan *et al.*, (1986) studied the growth and virulence of two isolates of *S. oryzae* causing sheath rot in rice. They found that the two isolates viz, 283-p and 1183-w differed in colony colour. The mycelium of the former was slightly pinkish while the later was whitish on potato dextrose agar medium, however, no difference in morphology was found between them.

Growth in Czapek's solution agar (CZA), malt yeast extract agar (MYA) and potato dextrose agar (PDA) were similar, but isolate 1183-w grew better than isolate 283-p in both semisolid and liquid media. Disease severity in 37 entries differed. A significant isolate X variety interaction indicates the possibility that the isolates are distinct strains or race. The mean disease severity of the 37 entries was significantly higher for isolate 283-p (13.1 cm) than the isolate 1183-w (11.4 cm), suggesting that 283-p is more virulent. There was no relation however between growth in culture media and virulence.

Joe and Manibhushanrao (1995) showed that among the several *S. oryzae* isolates tested for pathogenicity on susceptible rice CO 43, the maximum infection (DI 88.3) was designated SO 1 and the least (DI 50.2) SO 5, while the intermediate ones were ranked from SO 2 to SO 4. Similarly, in the case of *S. attenuatum*, isolates that recorded DI from 71.4 to 30.4 were designated SA 1 to SA 5 in order. The mycelial constituents and enzyme activities of these differentially virulent isolates showed a relatedness between them though *S. oryzae* was more aggressive than *S. attenuatum* in its biochemical determinants as well as disease expression. These studies indicate the possibility of existence of strains or races in the sheath rot pathogen.

HISTOPATHOLOGY AND MODE OF INFECTION

Mukherjee and Yadav (1989) carried out, in detail, the histopathological studies of rice plant infected with sheath rot to locate the presence of pathogen in different plant parts and its mode of infection. The studies revealed that the pathogen preferred floral parts than the other vegetative parts but did not attack the ovary directly. Lemma, palea and bracts (husk) were susceptible in all growth stages. Mycelia were present on both outer and inner surfaces involving sclerenchyma and parenchyma, growing both inter and intracellularly. Late infection could colonize only parenchyma of husk. Mycelium grew vigorously on two plumose stigmas and style. Anthers were also attacked. Infection after completion of flowering did not affect grain setting. This indicates that the stage of floral development at the time of infection is an important factor in determining the chaffiness and extent of grain filling. These observations are partly in conformity with the earlier report of Thrimurthy *et al.* (1980). Mature seed i.e. embryo and endosperm did not get the infection. Presence of the pathogen around germinating seeds affect root hair zone only. It does not penetrate the epiblemma and cortical tissue. The outer leaf sheaths were the first to get infection

and site for the inoculum build up for further disease spread during panicle initiation stage and outwards. Leaf was never affected. Inoculum may reach site of infection with help of either mites, borers, some other panicle visiting insect or water. The major infection site is emerging panicles. During booting stage, it was observed that infection took place when the inoculum was made available inside the flag leaf sheath. Both abaxial and adaxial surfaces of sheath were prone to infection. Mycelial and conidial masses were seen within the mesophyll cells. Lacuna had free ends of mycelium and conidiophores.

Histopathological studies by Shahjahan *et al.* (1977) showed that the fungus entered the host through stomata or wounds and grew intercellularly in the vascular bundles and in the infected sheath mesophyll tissues.

Mukherjee and Yadav (1989) also found that spikelets did not need wounds to get infection. Choaking symptoms (unemerged panicle) appeared due to damaged rachis. This was due to fungal invasion which could be seen in epidermis, cortex and vessels inter- and intercellularly. Infection in the rachis, under favourable conditions, may extend to the stem affecting ground tissue and vessel elements. Large amounts of mycelial and spore mass in the xylem vessels of diseased stems suggested that a defective vascular transport system, which may result in decline and eventual death of the complete panicle.

Vinod *et al.* (1990) observed that sheath rot infection in F1 rice hybrids was severe in poorly exerted panicles due to the presence of half opened leaf sheaths favouring infection.

DISEASE CYCLE AND EPIDEMIOLOGY-SURVIVAL AND TRANSMISSION OF THE PATHOGEN

Role of Infected Residues and Seeds

In Taiwan, the pathogen could survive for 75 days in rice stubbles standing in the field but it failed to survive for more than 25 days if buried in soil and puddled (Hsieh *et al.*, 1980). In a study of the recovery of the pathogen from diseased samples (Singh and Raju, 1980, 1981) indicated that it survived upto 4 months in seeds and 7 months in sheath at room temperature while upto 10 months in sheath kept under field conditions of Northern India. In a study of survival of *S. oryzae* under monocropped rainfed ecosystem of Hazaribag, Bihar (India) Maiti *et al.* (1991) found that

the pathogen could not survive for more than two months after harvest (September) in infected rice stubbles in field conditions. This difference in survival period may be due to differences in environmental conditions or variations in strains of the pathogen. Hence it may be concluded that the stubbles and straw of the infected plants left in the field may serve as a primary source of inoculum for the next crop season in monocropped area.

Gangopadhyay (1983) was of opinion that the fungus was present on sterile panicles and the disease was not seed borne. Shahjahan *et al.* (1977), however, found that the pathogen is seedborne externally and internally. Seed borne nature of the disease has also been recorded by Rajan (1981). The artificially inoculated seed with *S. oryzae* showed considerably reduced seed germination of seven rice varieties, moreover, the shoot and root lengths of all the varieties were reduced (Velazhahan *et al.* 1989). Sheath rot symptoms on rice seedlings grown from infected rice seeds were observed by Chuke (1983). Milagrosa (1987) found disease in mature plants grown from naturally infected seeds of variety IR 36 in the greenhouse. In another experiment, she found that apparently healthy seeds also produced plants infected with *S. oryzae*, which she attributed to other sources of inoculum such as air borne spores. Maiti *et al.* (1991) found that the fungus survived for 10 months in infected rice seeds under storage conditions. Shamsi *et al.* (1995) found prevalence of *S. oryzae* in different parts of rice grains in Bangladesh. Laboratory tests by Singha *et al.* (1996) showed that *S. oryzae* is found only on discoloured rice seeds and is mainly carried externally (77.5%).

Role of Air

Amin *et al.* (1974) was of opinion that the conidia of sheath rot fungus can be moved long distances by the wind. Gangopadhyay (1983), however, opined that the conidia of *S. oryzae* are not air borne.

Role of Soil

S. oryzae has been found to survive in rhizosphere soil of rice during wet crop season (June to September/ October) upto six months after sowing infected seeds (Maiti *et al.* 1991).

Deka and Phookan (1998) studied the survival behaviour of the pathogen in the acidic soil of Assam (India). Results revealed a considerable variation in the survival of the pathogen amongst various types of soils. The fungus was found to survive best (210 days) in sterilized inoculated soils under controlled temperature (30+1°C). This was followed by naturally infected field soil and sterilized inoculated soil type kept in outdoor

condition (180 days). There was no difference in longevity of the pathogen (90 days) between artificially inoculated unsterilized soil kept in controlled temperature and artificially inoculated unsterilized soil kept in outdoor condition. Results of this investigation revealed that the areas where only monocropping was practiced soil did not play a significant role in perpetuation of the disease. However, the soil might play a very important role in carrying the pathogen from one crop to the next to cause infection under existing double cropping system that prevails in most parts of Assam.

Role of Alternate Hosts

Ou (1972, 1985) and Purakayastha and Ghosal (1982) noted that the fungus was found unable to infect other members of the Graminae tested. On the contrary, two field weeds- *Cyperus difformis* and *Echinochloa crusgalli* were infected naturally with *A. oryzae*. The inoculation test showed that *Elusine indica*, *Monochoria vaginalis*, *Cyperus iria* and *C. teneriffae* were found to serve as hosts of the pathogen for the first time (Balakrishnan and Nair, 1981). Rahman *et al.* (1982), in Bangladesh found that *Echinochloa colona* also serves as an alternate host of *A. oryzae*. Boa and Brady (1987) found that *S. oryzae* is associated with blight of bamboo in Bangladesh. Deka and Phookan (1992) reported that seven common rice field weeds namely *Oryza rufipogon*, *Echinochloa colona*, *Elusine indica*, *Monochoria vaginalis*, *Leersia hexandra*, *Panicum walense*, and *Hymenachne assamica* have the role of collateral hosts in perpetuating the pathogen. Maiti *et al.* (1991) found that *S. oryzae* survived for seven months in infected leaf and inflorescence of *E. colona* under storage conditions. It could not survive for more than two months in *E. colona* plant parts in the field after harvest (September) in rainfed monocropped ecosystem of Hazaribag, Bihar, India. Groth (1992) reported that the isolates of sheath rot fungus from weeds have been shown to infect rice. Hence, it may be concluded that these alternate or collateral hosts may be responsible for spreading the inocula to healthy rice plants during panicle initiation to boot stage.

Role of Insects

Kawamura (1940) and Tasugi and Ikeda (1956), examining sheath rot infected plants in South East Asia found that almost all these plants were also infested by stem borers or had other injuries on the stems below. Wounding of the plants facilitated infection. Ou (1963), also found that the disease is often associated with borer damage. Chen and Chien (1964) found 56-

57% of the diseased tillers to be infested by stem borers. Varieties susceptible to stem borers were also severely affected by sheath rot, resulting in heavy damage of the crop in some areas (Agnihothrudu, 1973, Amin *et al.* 1974) Chin (1974) found that while the disease occurred in both injured and uninjured plants, severe development occurred only in injured plants or those attacked by stem borers. Surin and Disthaporn (1977) from Thailand, also reported sheath rot disease associated with stem borers. Estrada and Crill (1980) found that wounding of rice plants with carborundum before inoculation greatly increased disease development. Plants not treated with carborundum remained disease free. On the contrary, Subramanian and Ramakrishnan (1975) were of the opinion that the fungus was capable of penetrating the tissues directly and wounding of tissues was not a pre-requisite for pathogenicity.

In a study (Hsieh *et al.*, 1977) on the sterility of rice plants and their association with sheath rot fungus, the fungus was consistently isolated from sterile rice plants collected from different locations in Taiwan and sterile plants showed typical symptoms of sheath rot. Moreover, sterility was induced by inoculating the plants with the pathogen. Also the body of the mite (*Steneotarsonemus madecassus*) which was always associated with sterile rice plants harboured a large number of conidia of the sheath rot fungus. Similar observations were made by Chien and Huang (1979) regarding the association of mite (*S. spinki*) injury of plants with sheath rot disease. Rice plants inoculated with rice tungro virus (RTV) and sheath rot fungus showed significantly high sheath rot incidence than those plants inoculated with sheath rot fungus alone (Reddy and Ghosh, 1985). Synergism between RTV and *S. oryzae* was also reported by Venkataraman *et al.* (1987). They found that a cultivar susceptible to RTV became highly susceptible while a resistant cultivar turned moderately resistant to sheath rot disease. Also RTV infected rice showed difference between mild and severe intensities of sheath rot disease but this difference was not discernible in the absence of RTV infection. The average yield reduction due to synergism was significantly more than a single infection by *S. oryzae*. Naidu and Reddy (1989) also observed severe sheath rot incidence at maturity in the RTV affected plants of three rice cultivars. In cultivars free of RTV, sheath rot incidence was only 5-8%, but with RTV it was 17-36%. Higher incidence of sheath rot in RTV affected plants could be due to easy entrance of the sheath rot pathogen into physiologically weak hosts.

Naidu (1985) observed that a high incidence of sheath

rot has been associated with infestations of Brown plant hopper (BPH=*Nilaparvata lugens*). Milagrosa (1987) from the Philippines reported that plants infested with BPH had higher percentage on infection because BPH can carry the inoculum of *S. oryzae*.

Singh (1988), also showed that green leaf hopper (GLH=*Nephotettix virescens*), BPH and stem borer (SB) infestations and tungro (RTV) infections contributed to sheath rot incidence in Eastern U.P. (India). Saroja *et al.*, (1987) found that leaf folder (*Cnaphalocrocis medinalis*) and sheath rot incidence correlated positively.

A survey conducted in TamilNadu state of India showed that sheath rot was most severe in fields planted with rice cultivar IR20 where mealy bug (*Brevinnia rehi* Lindinger) populations were at a level of 3-10 bugs per sheath. Mealy bug predisposes the rice to *S. oryzae* infection (Lakshmanan *et al.*, 1988). Lakshmanan (1992a) reported that the activity of the mealy bug also had an important role in spreading the sheath rot pathogen. He found that 72% of plants inoculated with field-collected mealy bugs (*Brevinnia rehi*) exhibited typical sheath rot symptoms within 15 days. Mealy bugs collected from the diseased sheaths revealed that *S. oryzae* conidia were present on the body surface as well as internally. This showed that mealy bugs have an important role (as vector) in the spread of the sheath rot pathogen. Sheath rot severity was positively correlated ($r=0.99$) with mealy bugs population. Their interaction greatly reduced grain weight, grain yield (9-77%) and percentage of healthy grains, it increased chaffy and discoloured grains. Seed germination and root length were significantly reduced, but shoot length was not (Lakshmanan *et al.* 1991). Lakshmanan *et al.* (1992) observed high incidence of sheath rot due to a high infestation (15-20/panicle) of rice bug (*Leptocorisa acuta*).

It may be concluded that the dispersion and severity of the sheath rot disease may be related to the biological relationships between *S. oryzae* and insects like stem borers, mites, GLH, BPH, leaf folders and mealy bugs.

FACTORS AFFECTING DISEASE DEVELOPMENT AND HOST METABOLISM

Host Nutrition

Hashioka and Makino (1956) studied the effect of nitrogen metabolism of rice plants on the development of sheath rot. The causal organism (*A. oryzae*) was

grown in a culture medium containing varying amounts of nitrogen as well as on rice plants grown at different levels of nitrogen. The development of the fungus both *in vitro* and *in vivo* was somewhat proportional to the nitrogen supply. However, reports on the influence of nitrogen fertilization on host susceptibility are conflicting. Intensity of sheath rot decreased with increase in nitrogen fertilizers (Tasugi and Ikeda, 1956). According to Chen and Chien (1964), the disease incidence increased with increase in nitrogen level, but decreased with increase in potassium level. On increased application of nitrogen, the levels of both reducing and non-reducing sugars increased in both Kannagi (Highly susceptible) and Bhavani (moderately resistant) cultivars. The quantity of reducing and non-reducing sugars was higher in Kannagi than in Bhavani. The presence of more sugars in the tissue tends to increase susceptibility to invading pathogens as they serve as sources of energy to the pathogen. So *A. oryzae* may be considered as a "high sugar" disease with the possibility of evidence that reduction of sugar in the infected sheaths might be due to utilization of these compounds by the pathogen and to the decreased synthesis in the severely infected plant parts (Mohan and Subramanian, 1977 a). At higher dosages of nitrogen, accumulation of phenols decreased in the infected plant parts with concomitant decrease in reducing and non-reducing sugars. Total ammoniacal and protein nitrogen had lower concentration in Bhavani (Mohan and Subramanian, 1979 b).

Velazhahan and Ramabadran (1992) found that increase in potassium level from 0 to 200 kg/ha caused significant reduction of disease intensity with a concomitant increase in grain yield. It is also clear that increased application of potash results in increased levels of phenolic content. The reduction in disease in plants supplied with more potassium might be due to mobilization of phenolic compounds towards the diseased portion of the plant inhibiting the multiplication of the pathogen and thereby preventing pathogenesis which results in host resistance to the disease.

Plant Hormones

The effects of plant hormones on the susceptibility of dwarf cultivars of rice to sheath rot disease was investigated by Raychoudhuri and Purakayastha (1980 a,b). Foliar application of gibberellic acid (GA) (50 and 100 µg/ml) on 9-wk-old rice plants significantly reduce sheath rot disease and altered the growth pattern of plants.

Time of Planting and Weather

Amin *et al.* (1974) reported that the incidence of dis-

ease was higher during the months of December to May (dry season) than during June to November (Monsoon) in Andhra Pradesh (India). During the dry season, early transplanted varieties were more severely affected than varieties transplanted later. Subramanian and Ramkrishnan (1975) noticed the disease in a number of varieties in all seasons at Coimbatore (TamilNadu, India). Pal and Das (1976) observed during 1973-74 that the period of susceptibility to sheath rot was from December to May while the crop is susceptible to sheath rot at the flowering stage at Chinsurah (West Bengal, India). Srinivasan (1981) studied the seasonal incidence of sheath rot in Tamil Nadu. He found that sheath rot incidence was extremely high on crops planted from mid-June to mid-August. Suriachandraselvan and Ranganathan (1989) found that the early planted crop in August and late planted crop in October suffered more severely due to sheath rot disease in a field trial conducted for two years at Tirur (TamilNadu, India).

Muralidharan and Venkata Rao (1980) observed that unusual rains in December, in addition to cool moist weather with relative humidity of 95 % and above on many days, helped the spread of the sheath rot disease in Andhra Pradesh. Disease development was reported to be maximum when the minimum temperature was 17-20°C and the minimum relative humidity was 40-50% at flowering. Maximum temperature, maximum relative humidity, rainfall and sunshine had no direct influence on the severity of the disease (Singh and Raju, 1979, 1981). Usually dry weather with a minimum temperature of 23.1°C, maximum temperature of 41°C, and relative humidity of 77 % and 8.9 hrs of sunshine favoured sheath rot incidence (Misra and Mathur, 1983). Most severe infection was recorded at 20-30°C and 65-85 % relative humidity. Moreover, cloudy days during booting also encouraged the disease (Upadhyaya and Diwakar, 1984). Singh *et al.* (1986) observed that sheath rot has becoming an important disease in rainfed lowland rice of Bihar (India), especially in delayed monsoon (wet) plantings. Its occurrence was high in 50- days old seedlings as compared to 25- days old seedlings. Low temperatures and high relative humidities at the flowering stages of August-November sown crops suffered higher sheath rot disease incidence in Andhra Pradesh (Reddy and Subbayya, 1988). Singh (1988) from Eastern U.P. (India) also reported that the drought and excess rain contributed to sheath rot disease incidence. The study carried out to assess the occurrence of sheath rot disease of rice in semideep water condition in Orissa, India by Dhal *et al.* (1998) found that the disease appeared in the field at heading stage of the crop during the last week of November at temperature of 17.7°C and relative humidity of 50%.

Spore Density

Reddy (1989) reported that a spore concentration of 8×10^4 spores/ml was needed for effective infection and disease development by *S. oryzae*, while higher concentration of spores (10×10^4 spores/ml) resulted in low infection and this may be due to autolysis effect of spores in highly concentrated inoculum.

Varietal Resistance

Varietal differences in susceptibility of rice plants to sheath rot in Taiwan were noted by Chen and Chien (1964). They reported that *indica* varieties were slightly more susceptible than *japonica*. Out of ten varieties studied by Pal (1975) Kanchi was least susceptible in West Bengal (India). Subramanian and Ramakrishnan (1975) in India also assessed the reaction of some of the newly released and improved varieties to sheath rot under field conditions at their booting stage based on percent incidence of the disease. Cultivar Annapoorna is comparatively more susceptible to the disease than TNI, TKM 6, Tella hamsa, Kanto and Sigadis. Amin (1976) reported that the tall rice varieties Tetep, ARC 7117, Ramtuli, Manoharsali, D 25-4, Sigadis, SR 26B, Intan, Zenith, Dissi Hatif. Raminad str 3 and Tadukan were highly resistant to sheath rot. Twenty advanced dwarf lines of IR 1544 (IR 24x Tetep) were also resistant and Shahjahan *et al.* (1977) found Bluebelle, Brazos, Labelle, Lebonnet, Nova 66, Starnounet, Saturn and Vista susceptible in Louisiana (U.S.A.). Raju and Singh (1978) found that the cultivars Sigadis and Homthong were resistant to sheath rot whereas Kannaiyan *et al.*, (1978) found that six varieties viz, As 5821, As 6975, As 2992, Cult 1287, Cult 3726, Cult 6403 were completely disease free and 18 were relatively resistant. Chien and Huang (1979) found that *japonica* were more susceptible than *indica* cultivars which is contrary with the earlier findings. Mukherjee and Singh (1980) tested 170 local collections in U.P. (India), all of which were infected with varying degree of susceptibility. Five varieties namely Mahsuri, Vishnubhog, Gajgor, Kala Namak and Usha were highly resistant to sheath rot disease while variety Annandi was highly susceptible. Out of 169 indigenous rice varieties tested, Kala Namak, Vishnubhog, two selections of Mahsuri (from Ballia and Ghazipur) and Hansraj reacted as resistant in U.P. (Mukherjee *et al.* 1981). The cultivar PR 106 was highly susceptible to this disease in Punjab, India (Raina and Singh, 1980). Raina *et al.*, (1980) also found that two breeding lines PAU 122-73-1-4-1 and Pusa 37-6-2-3 were resistant to sheath rot, Basmati 370, CB II, Hom Thong, Sigadis and TKM 6

were resistant to sheath rot disease (Singh and Raju 1981). Balakrishnan *et al.*, (1981) reported that rice cultures like M 23-17-1-1 and M 23-69-1-1 were found to tolerate sheath rot in Kerala (India). Manuel *et al.*, (1985 a,b) evaluated 46 rice varieties where AS 688 and AS 19703 were found resistant. Out of 15 rice (ASD) varieties screened, ASD 5 and ASD 11 showed multiple disease resistance along with sheath rot. Fifty nine rice cultures were screened for resistance to sheath rot under field conditions at Aduthurai (Tamil Nadu, India), where disease pressure was very high. Monaharsali and nine cultures viz. RB 2069-2-6-1, RP 2071-18-1-1, CR 331-1-1-3, IR 9202-21-1, RP 1057-35-1-1, VRS 286-4-1, VRS 163-2-2-2-3, ARC 14529 and IET 8584 showed high resistance (Lewin and Vidhyasekaran, 1987a). Saroja *et al.*, (1987) evaluated 64 rice entries where 13 were resistant, 14 intermediate and 37 were susceptible to both sheath rot and leaf folder. BPMS 69, BPMS 40A, Kala Namak, KSR white BPMS 1, KSR 49-89-10, RP 967-11-1-4-2, Basmati 370, HAU 11-12, PAU 269-1-9-2-1, HPU 8106, TR-B-63 were resistant to sheath rot in U.P. (India) (Singh, 1988). Shashidhar *et al.*, (1988) evaluated 18 stabilized lines and 18 rice cultivars. Selections from Jaya/ Mahsuri were free of sheath rot infection whereas maximum infection was in Pragathi and selections of Jaya/ Type 3. Jones *et al.*, (1989, 1990) found that IR 7167-33-2-3, TOX 3344-3-4 and TOX 3145-TOC-34-2-3, were resistant to sheath rot in Cameroon. Lakshmanan and Velusamy (1991) evaluated 87 breeding lines derived from *Oryza officinalis* for resistance to sheath rot. Fifteen derived lines were completely disease free under natural infection, and nine lines exhibited high resistance under artificial methods. In the wet season of 1994, 60 deep water cultivars were evaluated for their reaction to sheath rot under field conditions at Bhubaneswar (Orissa, India). The cultivars NDR 40049, CN 1035-61 and OR 090-3-158 recorded resistant reaction to this disease having less than 1% infection in panicle (Mohanty *et al.*, 1996). Sahu and Parida (1997) screened 60 semideep water rice selections for reaction to sheath rot under natural condition. Three were highly resistant and 18 were moderately resistant to sheath rot. Chauhan and Bhatt (1986) in a study on inheritance of resistance to sheath rot of rice confirmed that the resistance to sheath rot is governed by a single recessive gene in the cultivar VL 8 (a *japonica* type). In view of the simple inheritance pattern, it is suggested that any conventional breeding method can be used to incorporate resistance to sheath rot from VL 8 into other desirable genotypes.

Inoculation Techniques

There is an urgent need to identify resistant varieties

for sheath rot disease. Different methods of artificial inoculation for screening varieties for sheath rot resistance have been attempted by various workers with varying degree of success.

Five different methods viz. inoculation by spraying spore suspension, by agar culture, by diseased sheath portion, by culture grown on bajra grains and by injecting spore suspension, were tried to know their relative efficiency on five susceptible varieties (Anupama, IET 3359, IR 20, Jayanthi and Vijaya) against sheath rot of rice caused by *S. oryzae*. Inoculation by the fungal culture grown on bajra grains was observed to be the best and gave maximum percentage of diseased panicle as well as disease index (Raju and Singh, 1978).

Estrada *et al.*, (1979) compared three methods of screening for resistance of rice to sheath rot: (1) inserting single infected grain between leaf sheath and culm, (2) injecting spore suspension through the sheath and (3) spraying spore suspension on plants at different growth stages. Inoculation tests using single grain insertion method at the tillering to panicle initiation stage consistently produced severe infection. Disease incidence was higher in plants inoculated by infection method at the early stage of the growth. The symptoms were atypical and consisted mainly of light to dark brown stripes. Estrada and Crill (1980) successfully induced typical symptoms with *S. oryzae* spore suspension prepared in 25% beef extract-peptone solution.

In another study, five different methods of inoculation were tested on rice variety Pusa 2-21 during wet season (Mukherjee and Singh, 1980). Placing a single grain of rice, previously autoclaved and inoculated with the pathogen for 10 days, inside the leaf sheath enclosing the panicle was found to be the most effective method of inoculation. Disease reaction on test entries was noted 15 days after inoculation on the basis of average lesion area of three inoculated leaf sheaths.

Mukherjee *et al.* (1981) attempted three methods namely (1) Grain inoculation method, (2) agar disc method and (3) spore suspension method (a) from PDA culture, (b) from Richard's medium and (c) from modified Richard's medium. Of which the grain inoculation method was most effective like the previous report.

Although Kang and Rattan (1983) reported the development of disease symptoms with injection or insertion of mycelial pieces from PDA culture, insertion of grain culture seems to be most feasible method as it produces disease symptoms with discrete lesions which would facilitate scoring.

Eleven different artificial methods of inoculation of rice plants (cv. IR 50) with *A. oryzae* were evaluated by Reddy and Subbaya (1989). Inserting single leaf bit inoculum in between the culm and leaf sheath produced satisfactory infections.

Inoculation of unemerged rice panicles by pin prick method with cut ends protected within two hours by waxing and incubating in plastic tub moist chambers was found to be a quick and easy method of inoculation developed by Reddy and Subbaya (1990a). This laboratory screening technique gave successful results and the possibility of its adoption for large scale testing of varieties based on the lesion lengths produced. Lakshmanan (1993 a, 1994) provided an efficient and improved method of assessing resistance to sheath rot in rice by mealy bug inoculation method where mealy bugs are common and the sheath rot-mealy bug complex is important.

Scoring System

The Standard Evaluation System (SES) designed by IRRI (Anon, 1988, 1996) for sheath rot disease is based on percentage of tillers infected where 0= Highly resistant (HR) (no incidence), 1=Resistant (R) (less than 1%), 3= Moderately resistant (MR) (1-5%), 5= Moderately susceptible (MS) (6-25%), 7= Susceptible (S) (26-50%) and 9=Highly susceptible (HS) (51-100%). But, this SES does not adequately identify resistant donors because the scale is based on the percentage of tillers affected. That gives insufficient information on resistance or susceptibility because if all tillers in a clump are infected to a low degree, the genotype is graded as '9' - regardless of panicle damage. Furthermore, the percentage of affected tillers show the prevalence of the disease- not its severity or intensity. As such, different scales have been suggested by different workers time to time showing the coverage of the lesions on the boot leaf sheath and their effect on the emerging panicle (i.e., extent of panicles exertion) which would more appropriately determine the exact degree of sheath rot infection and identify the resistant lines.

In the above mentioned line of thought, Amin (1976) developed a scoring system of disease index of 1-9 to classify the disease reaction into nine groups whereas Satyanarayana and Reddy (1979) suggested a 1-9 scale scoring system to classify the reaction into five groups, where 1=Resistant (Small brown lesions on the leaf sheath, normal panicle emergence and grain setting normal), 3=Moderately resistant (Lesions tend to enlarge, coalesce and cover about half of the leaf sheath, glumes are discoloured, grain filling is normal), 5= Toler-

ant (Lesions tend to cover the entire sheath, glumes discoloured, incomplete exertion of the panicle with stray sterile spikelets), 7= Susceptible (Panicle struggles to emerge with 25-50% of the spikelets sterile, severe glume discolouration, entire sheath rots), 9=Highly susceptible (No panicle emergence from the sheath, sheath rots while enclosing the panicle). But, this system is, at best, qualitative in assessing the intensity of the disease.

Roychoudhuri and Purakayastha (1980a) developed a method for quantifying the disease severity. According to this method, the necrotic spots on the leaf sheath were graded into four groups: very small, small, medium and large with an approximate diameter of 1, 2, 4 and > 4 mm respectively. These were provided with numerical values of 0.25, 0.5, 1 and 2, respectively in order to approximately quantify the disease intensity. Disease index can be expressed as the product of the score for the type and number of spots.

Mukherjee *et al.* (1981) used a 0-5 scale scoring system and classified the test entries on the basis of lesion area affected, the lesion area was calculated by multiplying the length and width of the lesion and the data averaged. In this system, 0 = no infection (Nil), 1=R (upto 6 mm²), 2=MR (7-12 mm²), 3=MS (13-250 mm²), 4=S (150-600 mm²) and 5= HS (601 mm² and above).

Narayanasamy and Viswanathan (1990) developed a new qualitative and quantitative 1-9 scoring system of 5 grades viz., 1, 3, 5, 7 and 9 where

Small brown lesions on boot leaf sheath and panicle emergence normal = 1

Lesions enlarge or coalesce and cover about 5% of the leaf sheath and panicle emergence normal = 3

Lesions cover about 6-15 % of the leaf sheath area and 75% of panicle exerted = 5. Lesions cover about 16-50% of the leaf sheath area 50% of panicle exerted = 7. Lesions cover more than 50% of the leaf sheath and panicle emergence completely affected or only about 25% of panicle exerted = 9. The disease index is worked out using the formula- Disease index = (1xA) + (3xB) + (5xC) + (7xD) + (9xE), where A = % of tillers showing grade 1, B = % of tillers showing grade 3, C = % of tillers showing grade 5, D = % of tillers showing grade 7 and E = % of tillers showing grade 9. The varietal reaction to the disease can be determined based on the disease index as detailed below :

0-99 = HR; 100-199 = R,

200-299 = MR; 300-499 = MS;

500-699 = S; 700-899 = HS.

CONTROL MEASURES

Cultural Method

Effect of Manures and Fertilizers

Use of manures and fertilizers and plant protection yield are vital components for increasing crop.

Neem cake @ 1.0 t/ha is efficient in suppressing sheath rot disease (Rajan, 1980). Increasing N application significantly increased sheath rot disease incidence in Bangladesh (Akanda *et al.*, 1984). The same conclusion was also drawn by Misra and Mathur (1983) and Jayasekhar and Prasad (1988, 1989) in India. The later workers also found that the sheath rot disease incidence decreased with increase in K application. Grain and straw yields, tiller height, length of the panicle and 1000 grain weight were found to increase in application of K and N. Stem-borer and sheath rot incidence was significantly lower with neem cake-coated urea at N-levels 75 and 100 kg/ha. However, differences in grain yield were not significant (Alagarsamy *et al.*, 1985). The form and level of nitrogenous fertilizers are also known to influence the disease development. Sheath rot incidence was significantly lower with ammonium chloride at all three N levels namely 60, 120 and 180 kg/ha in comparison to ammonium sulphate and urea. At 120 kg/ha, ammonium chloride recorded maximum yield (Alagarsamy and Bhaskaran, 1986a). Soil application of organic manures and urea as a source of N with K (last split of both N and K as foliar spray) and carboxin (0.1% spray) was reported to provide high yield, whereas soil application of organic manure alone with carboxin (0.1% spray) gave low disease intensity (Nair *et al.*, 1988).

Besides manures and macronutrients, foliar sprays of micronutrients in the form of calcium sulphate and zinc sulphate gave most effective control of sheath rot and increased grain yield during wet season (Alagarsamy, 1986). Foliar spray with copper sulphate (0.2%) produced increased yield and decreased sheath rot incidence but foliar spray with urea (2%) has no effect on the disease incidence or grain yield (Alagarsamy and Bhaskaran, 1986b). Among the nine salts sprayed (0.2%) at boot leaf stage, MgSO₄, CaSO₄, FeSO₄ and CuSO₄ showed significantly lower degree of disease when compared to check (Narasimhan *et al.*, 1990). Further, Narasimhan *et al.* (1994) found that soil application of gypsum (calcium sulphate) @ 500 kg/ha-50% basally and 50% at 35 DAT can reduce sheath rot incidence and increase grain yield.

Effect of Spacing and Plant Type

Srinivasan (1980) observed that in field experiment the incidence of sheath rot increased when closer spacing (10 x 10 cm) was adopted whereas the incidence was less in wider spacing (40 x 40 cm) treatments even with high nitrogen application. Reddy and Subbayya (1990b) found that wider spacing of 20 x 15 cm or 20 x 10 cm resulted in low percent disease index (PDI) percent tiller infection and increased grain yield, while closer spacing of 10 x 10 cm caused high PDI besides lowering grain yield and other yield parameters in both resistant (NLR 9672) and susceptible (PLA 1100) varieties of rice.

Amin *et al.* (1974) noticed that sheath rot was found to be most severe in densely planted high yielding dwarf rice cultivars in Andhra Pradesh and West Bengal and other states of North and South India.

It is of common occurrence in the field that semidwarf rice cultivars are highly susceptible while the tall ones are resistant to sheath rot caused by *A. oryzae* (Purakayastha *et al.*, 1983 a,b). Singh *et al.* (1986) also found that, in general, photoperiod sensitive tall varieties were more resistant to sheath rot disease than photoperiod insensitive ones.

Biological Method

Effect of Plant Products (Botanicals)

The plant products are extensively used for controlling the plant disease in view of their relatively low cost, quickly degradable and non-toxic nature. Effect of various plant products or extracts on sheath rot disease control was studied by various workers in India in recent years.

Thangamani and Narayanasamy (1988) reported that neem oil and neem seed 2% spray reduced the incidence of sheath rot in rice. Jeeva and Ramabadrana (1992) found that water extracts of 7 out of 23 plant species screened *in vitro* inhibited conidial germination of *S. oryzae*. Water extracts of *Caesalpinia pulcherrima* and *Ipomoea crassicaulis* at 10 and 5% sprayed before inoculation after inoculation and after disease development reduced the sheath rot disease in pot culture experiments 10% percent concentration was more effective than 5% and the extracts sprayed both before and after inoculation showed the lowest disease incidence. Narasimhan *et al.*, (1993) observed that foliar spray of neem seed kernel extract (NSKE) 5% during booting and 10 days later is promising for reducing sheath rot and increasing grain yield,

even it is better than carbendazim. Jeeva and Ramabadrana (1993) while studying the effect of different extracts of non host plants on conidial germination of *S. oryzae*, found that 20% cold water extracts of *Arachis hypogea* *Caesalpinia pulcherrima*, *Euphorbia hirta* and *Ipomoea crassicaulis* inhibited the conidial germination best over hot water extract and ethanol extract. Jeeva and Ramabadrana (1995) also, studied the effect of plant products on seed germination, seedling vigour and seedling abnormalities of seeds of ADT 37 rice variety infected by *S. oryzae*. They found that *C. pulcherrima* and *I. crassicaulis* extracts at 10% concentration increased the percentage of seed germination. Both the extracts showed increased shoot and root length and vigour index, however, maximum was observed in seeds treated with *C. pulcherrima*. In case of seedling abnormalities, *I. crassicaulis* extract treated seeds considerably reduced abnormalities. Jagannathan and Sivaprakasam (1996) showed that neem seed kernel extract (NSKE) 5% is best among the botanicals tested for reducing sheath rot incidence in a susceptible cultivar ADT 36. Eswaramurthy *et al.*, (1996) observed that foliar spray of *Ipomoea dorena* leaf extract (10%) at booting and 15 days later is best among various plant products tried for controlling sheath rot disease in ADT 36. Foliar spray (Twice) at a two week interval beginning at booting using scented hybrid rice JJ 92- higher yields were recorded with neem oil (3%) and neem seed kernel extract (NSKE) 5% in comparison to chemical pesticides (Sivaprakasam and Jagannathan, 1996). Rajappan *et al.*, (1997) found that dried leaf extract of *Ipomoea* spp, effectively checked the growth of *S. oryzae*, while the growth of beneficial biocontrol agents viz., *Bacillus subtilis* *Pseudomonas fluorescens* and *Trichoderma viride* was not affected at 4% concentration of leaf extract *in vitro* conditions. Narasimhan *et al.*, (1998) evaluated 3 new formulations viz., neem oil 60 EC (acetic acid) [NO 60 EC(A)], neem oil 60 EC (citric acid) [NO 60 EC (C)] and neem oil + pungam oil 60 EC (citric acid) [NO + PO 60 EC (C)], for their efficacy against sheath rot. All 3 formulations effectively inhibited the mycelial growth of the pathogen *in vitro* conditions. They controlled sheath rot and led to increased yield. 10 plant extracts tested by Pramanick and Phookan (1998) for efficacy against *S. oryzae* inhibited mycelial growth *in vitro*. An aqueous extract of *Ocimum sanctum* was the most effective followed by *Eucalyptus citriodora* and *Azadirachta indica*. Lesions formed by the pathogen in IR 36 were also significantly restricted by pre inoculation spraying with these 3 plant extracts.

The reduction in disease incidence might be due to the inhibitory action on the conidial germination and de-

struction of germ tube which prevented the invasion of pathogen and inhibition of sporulation. The presence of antifungal compounds in the plant extracts are actually the inhibitory principles of the extract.

Effect of Bioagents (Biocides)

In recent years, application of biocontrol agents on plant disease control is coming to time light. Such effects have also been made to control the sheath rot disease. Sakthivel and Gnanamanickam (1986 a,b) isolated strains of *Pseudomonas fluorescens* from the rhizospheres of rice, citrus, cotton, peanut and other crops that reduced sheath rot. In *in vitro* assays, *P. fluorescens* isolated from citrus restricted *S. oryzae* growth.

Sakthivel and Gnanamanickam (1987), in greenhouse tests, found that *P. fluorescens*- treated rice plants of IR 20 showed a 54% reduction in lesion length. In three field tests, treatment with *P. fluorescens* reduced the severity of sheath rot by 20 to 42% in five rice varieties and enhanced plant height, number of tillers and grain yields from 3 to 160%.

Among seven phylloplane fungi, a fungal isolate (*Bipolaris zeicola*) obtained from IR 20 inhibited mycelial growth of *S. oryzae* *in vitro* (Viswanathan and Narayanasamy, 1990). Hence, *B. zeicola* is a potential antagonist of rice sheath rot pathogen.

The antagonistic interaction of some soil fungi, *Aspergillus candidus*, *A. flavus*, *A. fumigatus*, *A. nidulans*, *A. niger*, *A. sulphureus*, *A. terreus*, *A. varicolor*, *Gliocladium* sp., *Penicillium citrinum*, *P. funiculosum* and *Trichoderma viride* against the sheath rot pathogen was studied by Panneerselvam and Saravanamuthu (1996) *in vitro* in dual culture and in petriplates on nutrient medium amended with culture filtrates of the test fungi. Similar trends in the inhibition of *S. oryzae* by the antagonistic fungi were observed in the two tests. The maximum percentage inhibition of growth was observed with *T. viride* followed by *Gliocladium* sp.

Chemical Method

Seed Treatment

Sheath rot infected seeds treated with fungicides like benomyl and panactine- improved germination both immediately after treatment and after six months storage. (Viswanathan and Mariappan, 1980). Rajan (1981), however, showed that reduction in sheath rot at a 15% salt concentration was significant compared to that at lower concentrations. Seeds that sank to the bottom in this solution were washed in three changes

of clean water and broadcast. Mechanical separation of seeds by this method is cheap, simple and can easily be used by farmers as seed treatment with fungicides generally does not kill fungi present inside the glumes. Mechanical separation (seeds sunk in 20% common salt soln.), also, resulted in best disease management and produced highest yield in a field experiment conducted by Maiti et al., (1990) and recommended it as a low cost technology for controlling sheath rot. Singha et al., (1996), also, found that hot water treatment of seeds at 52°C for 30 minutes can be used to control the fungus. Surface sterilization controlled only the externally borne pathogen. From the studies of Singh and Mathur (1992) and Singha et al., (1996) it is imperative that rice seeds must be tested for the infection of *S. oryzae* before planting and be treated to control the seed borne inoculum. Infected seed may have also been responsible for transport of pathogen from infected non-infected areas. There is already a report that *S. oryzae* may have come to Brazil with imported seed (Mathur 1981).

In Vitro Test

Raghuathan and Vijayragavan (1976) found that the growth of the rice sheath rot fungus was effectively inhibited by Benlate and Hinosan at 0.005 and 0.05% respectively. Maneb and Zineb were inhibitory only at higher concentrations. Quinolphos, an insecticide, inhibited the growth of the fungus at 0.4%. Purakayastha and Raychoudhuri (1977) tested six systemic fungicides viz. Benomyl, MBC, Vitavax, Kitazin, DDVP and Aureofungin against *A. oryzae*. MBC was most effective being toxic even at a concentration of 5 ppm. Ten fungicides were tested at 0.1 and 0.2% concentrations against *S. oryzae*. Both concentrations of Benomyl, Carbendazim, Ediphenphos and Mancozeb M- 45 inhibited the growth of *S. oryzae*, but 0.2% level was much more effective (Mohan and Subramanian, 1977b). Reedy et al., (1985) found that of all the eleven fungicides tested, Bavistin to be the best inhibitor of *A. oryzae*. Viswanathan and Narayanasamy (1992) studied the effect of Tricyclazole and Mancozeb on *S. oryzae* *in vitro*. They found that Tricyclazole at 1500 ppm completely inhibited mycelial growth, however, spore germination, germ tube elongation and sporulation were inhibited at 1000 ppm. Mancozeb even at 200 ppm entirely inhibited mycelial growth and sporulation. However, complete inhibition of spore germination and germ tube elongation could be seen at 1000ppm indicating that Mancozeb was more effective than tricyclazole in inhibiting vital functions of this pathogen.

Foliar Spray

Rajan and Nair (1978) reported that Benlate and Bavistin controlled the sheath rot of rice effectively and were better than most of the conventional protective fungicides used in plant disease control. Aureofungin and Vitavax were not effective in controlling the disease. Eight fungicides viz., Hinosan EC, Benlate, Bavistin, Difolatan, Miltox, N.F. 48 and Daconil at 0.2% concentrations were sprayed on the plant twice at 10 days intervals during the flowering stage of IR 20 in a pot culture experiment (Kannaiyan, 1979). Those plants treated with Benlate showed 6.3% disease incidence followed by N.F. 48 and Daconil showed 6.6 and 6.8% disease incidence respectively. In unsprayed control, the disease incidence was 41.4%. Efficacy of Bavistin (Carbendazim), Busan (TOMTB) and Benlate (Benomyl) was also recorded by Chen and Huang (1979). Raina and Singh (1980) reported effective control of sheath rot by 0.1% Carbendazim. Vasavan *et al.*, (1980) observed from field tests in Kerala that foliar application of a herbicide Benthocarb (Saturn) at 2kg a.i./ha reduced sheath rot disease. Raychoudhuri and Purakayastha (1980b) found that two consecutive foliar sprays of gibberelic acid (100 µg/ml) applied at 7 and 3 days before inoculation to 9 wk old semidwarf rice varieties Jaya and TN1 significantly reduced sheath rot disease. Three sprays of Carbendazim (0.05%), Benomyl (0.05%) and Brestanol (0.1%) gave a good control for sheath rot in the field (Singh and Raju, 1981).

In field experiments conducted with ten fungicides against sheath rot disease, Raju and Singh (1981) found that three sprays of either Bavistin (0.05%) or Benlate (0.05%) or Brestanol (0.1%) gave good control of the disease, reduced the percentage of chaffy grains and increased the yields. Lakshmanan (1984) reported that two sprayings of Tridemorph at 100 ml plus Carbenadzin at 100g/ha or Tridemorph at 200 ml/ha at 40 and 60 DAT performed best in controlling sheath rot. Alagarsamy *et al.*, (1986) tested the efficiency of seven fungicides and three spraying schedules against sheath rot. Captafol 0.125% had the lowest disease severity (29.3%) and maximum yield (4.3%t/ha). Spraying 30-50-70 DAT controlled disease severity best. Hinosan, Bavistin and Dithane M-45 significantly reduced sheath rot infection when used as seed treatment and two foliar sprays (Thrimurthy, 1986). Complete protection throughout the crop period against sheath rot was recorded when 0.1% Carbendazim sprayed every 3 or 5 day intervals (Vidhyasekaran and Lewin, 1987). Unlike, the above mentioned reports, spraying with several fungicides at panicle initiation

and 15 days later on cultivar Co 43 was recorded to be ineffective (Lewin and Vidhyasekaran, 1987b). Carbofuran granules at 1 kg a. i./ha at 60 DAT have economically controlled the disease in cultivar Jaya. Similar results were attained with 3 sprays of monocrotophos or ediphenphos at 0.5kg a.i./ha at 15 days intervals, beginning 60 DAT. Carbendazim, sprayed as above, controlled the disease but was not economical (Singh, 1988).

Combined spraying of monocrotophos (500 ml/ha) with carbendazim (250 g/ha) at 20, 40 and 60 DAT resulted in the lowest incidence of sheath rot and highest yields in Co 43. This treatment also kept leaf folder infestation well below economic injury level (<5%) (Raju *et al.*, 1988). Greenhouse and field experiment results showed that Tridemorph 0.1% and Phosphomidon 0.03% protected rice crop against sheath rot associated with mealy bug in IR 20. Yield was also greatly increased (Lakshmanan, 1992b). Viswanathan and Narayanasamy (1993) assessed the efficacy of mancozeb, ediphenphos and tricyclazole on three rice varieties viz., IR 20, Co43 and IR50 against sheath rot of rice and their influence of yield. Spraying of mancozeb (0.25%) and Tricyclazole (0.08%) at mid-tillering and late boot leaf stages was superior to other chemicals, it reduced the disease level by 40.6 to 41.91% and increased the grain yield to the maximum extent of 16.3%. This treatment was not phytotoxic on any of the three varieties tested and did not have residues at toxic level either in grains or in straw. Propiconazole and carbendazim sprayed @ 0.1% at 75 and 90 DAT provided 71.4 and 54.3% disease control with a corresponding increase of 12.7 and 11.1% in yield over a check respectively in a susceptible variety CR 333-6-1 (Dodan *et al.*, 1993).

Sivaprakasam and Jagannathan (1996) observed that Carbendazim (500 g/ha) and monocrotophos (1250 ml/ha) plus mancozeb (1 kg/ha) effectively reduced sheath rot incidence. Dodan *et al.* (1996) evaluated the efficacy of five fungitoxicants viz., carbendazim, propiconazole, mancozeb, ediphenphos and tricyclazole against sheath rot of rice on two susceptible rice cultures namely CR 333-6-1 and PR 106. It was revealed that propiconazole (0.1%) was the most effective treatment, reducing sheath rot incidence by 46.5% with a corresponding increase of 8.7% in yield when sprayed twice at the boot stage and 15 days later.

Genetical Method

Of the several disease management strategies, use of disease resistant varieties of rice is considered as the

best alternative being most effective and eco-friendly also. Several rice varieties and breeding lines from different countries with potential for resistance have been identified which may prove effective in combating the disease.

In West Bengal (India), IET 2815 (Sashyasree), IET 6223 (Annada), IR 42, IET 5656 (Swarnadhan), NC 492 (Sabita) are found to be resistant while IR 20, IR 36, IR 50, IET 4094 (Khitish), Jaya, Mahsuri, Swarna, etc. are susceptible to sheath rot disease. Cytoplasmic male sterile (CMS) lines of hybrid rice namely IR 62829 A, IR 58025A etc. are also susceptible to sheath rot disease. Compared with conventional varieties, hybrids are more responsive to fertilizers, more vigorous in growth with high tillering capacity. These attributes are closely associated with disease outbreaks. Out of 94 hybrids and 10 CMS lines evaluated at Directorate of Rice Research (DRR), Hyderabad (Andhra Pradesh, India), none was found resistant to sheath rot disease (Reddy, 1993).

In every year, hundreds of entries are tested at several locations of India for sheath rot resistance through the All India Coordinated Rice Improvement Project (AICRIP) of DRR, Hyderabad. But, a few of them have been found resistant to the disease at all the locations. In future, suitable varieties may come out from this project which may combat the disease successfully.

From, all the above four types of methods for controlling sheath rot disease, it is concluded that an integrated approach has to be evolved for the effective management of the disease. A low-input and technically feasible integrated sheath rot management strategy for rainfed upland rice has been developed by Maiti et al., (1995). It includes (i) use of a short- duration (90-95 days) moderately resistant (like Vandana) or at least moderately susceptible (like Aditya) variety, (ii) early sowing (2nd to 3rd wk of June) depending on the onset of monsoon, (iii) use of mechanically separated, sanitized healthy seeds and (iv) need-based spray of Bavistin 50 WP @ 0.1% once at the time of disease appearance in susceptible variety.

FUTURE LINES OF WORK

The studies conducted, so far have been centered around the etiology of the disease, and chemical control. Losses due to this disease, however, vary from one area to another and from year to year depending on the environmental conditions and genetic make-up of the host cultivars and the pathogen. At present, most

of the promising varieties were found to be susceptible to this disease, only a restricted number of resistant varieties have been identified from the germplasm materials screened so far. These may be used in the future breeding programme. CMS lines resistant to sheath rot disease may also be evolved for hybrid rice varieties.

Accumulated data indicate that very little research has been done so far on the physiology and genetics of sheath rot. In fact, very little information is available on the mechanism of disease resistance in rice against sheath rot. More work is needed in this aspect. Since sheath rot is becoming more and more destructive in several countries, the present measures for management of the disease need further support with additional work on the lines of cultural practices which may provide a basis of modifying current agricultural practices to reduce the severity of the disease. Moreover, more work should also be done on the aspect of biological control like use of botanicals and bioagents to develop an integrated management of sheath rot disease of rice.

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