Reprinted from

PLANT PROTECTION IN FIELD CROPS

(Lead papers of the National Seminar on Plant Protection in Field Crops, 29-31 January, 1986, CPPTI, Hyderabad)

Edited by

M. VEERABHADRA RAO
Central Plant Protection
Training Institute (CPPTI)
Hyderabad

and

S. SITHANANTHAM
International Crops Research
Institute for the Semi Arid
Tropics (ICRISAT), Hyderabad

Plant Protection Association of India
Rajendranagar, Hyderabad—500 030, India.

January 1987

DISEASES OF PEARL MILLET AND THEIR MANAGEMENT

R.P. THAKUR
Pearl Millet Improvement Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, P.O. Andhra Pradesh, 502 324, India.

1. INTRODUCTION

Pearl millet, *Pennisetum americanum* (L.) Leeke, is an important cereal crop and is grown annually on 26 million ha in the semi-arid tropical regions of the Indian subcontinent and in Africa. In India the crop is grown annually on about 12 million ha, mainly in the states of Maharashtra, Gujarat, Rajasthan, Haryana, Uttar Pradesh, Andhra Pradesh, Karnataka and Tamil Nadu. The growing environment of this crop is characterised by scanty and erratic rainfall often resulting in prolonged dry spells. It grows in light sandy and light black cotton soils with poor water-holding capacity and low fertility. Farmers in such environments are resource-limited and have been surviving with subsistence agriculture for many years. As in other cereals, genetic improvements have also been successful in this crop. Genotypes with grain yields of 3-4t/ha have been reported from experiment stations, but the average yields in farmers' fields are usually low((about 600kg/ha).

Pearl millet, like any other crop, suffers from many fungal, bacterial and viral diseases (Rachie and Majmudar, 1980), but the diseases which are of economic significance are fortunately only few (Table 1) and are only of fungal origin. These are downy mildew (*Sclerospora graminicola* (Sacc.) Schroet.), ergot (*Claviceps fusiformis* Lov.), smut (*Tolyposporium penicillariae* Bref.) and rust (*Puccinia penniseti* Zimm.).

2. ECONOMIC IMPORTANCE

Downy mildew is by far the most important and widely distributed disease of pearl millet. It is mainly soil-borne and is endemic on land-race cultivars. This disease first occurred in epidemic proportion in the early 1970s when it devastated the most popular hybrid, HB 3, which was grown on more than 1 million ha in 1973 and the estimated yield loss was 10-45%(Safeeulla, 1977). In 1983 another epidemic damaged the large acreage of another popular hybrid, BJ 104, which replaced HB 3 in mid 1970s. The grain yield loss estimate in BJ 104 in 1983 epidemic was in the range of 10 to 45% in different farmers' fields in the states of Tamil Nadu, Haryana and Punjab (S.D. Singh and D.P. Thakur, personal communication).

Ergot is generally less wide-spread than downy mildew but can be more severe under favourable weather conditions at the time of flowering of pearl millet. The direct grain yield loss due to ergot may not be very high every year, but it adversely affects the grain quality by contaminating it with neurotoxic, alkaloid-containing sclerotia, thereby rendering it unfit for consumption. The first epiphytotic of ergot was reported from south Satara district of Maharashtra in 1957. Since then it has not been observed in epiphytotic proportion. In recent years this disease has become more important with the cultivation of F1 hybrids. It is usually more serious in the homogeneous F1 hybrids than in the heterogeneous open-pollinated varieties and land-race cultivars. At ICRISAT Center grain yield loss of 55% in varieties and 65% in hybrids have been estimated under high artificial disease pressure (R.P Thakur, unpublished).

Smut can often cause serious damage in the northern states of India but so far the disease has not been observed in an epiphytotic proportion. Smut is also a floral disease and is more severe on hybrids than on open pollinated varieties and causes an estimated grain yield loss of 5-20% in farmers' fields (R.P. Thakur, unpublished).

Rust is generally of limited economic importance, and is most commonly found in southern states and some parts of Maharashtra and Gujarat. The disease generally appears in the later stages of crop growth and does not cause significant economic loss. Rust has been observed at an early stage of crop growth in certain parts of Maharashtra where it reduces fodder quality and grain yield. Rust can be important in seed-production fields when they are planted in the off season.

There are some minor but potentially damaging diseases of pearl millet such as blast (*Pyricularia setariae*), zonate leaf spot (*Dactulophora elongata*), Cercospora leaf spot (*Cercospora fusimaculans*), and seedling blights (*Fusarium* spp. and *Helminthosporium* spp.) These diseases have not received any serious research attention so far.

3. BIOLOGY, EPIDEMIOLOGY AND DISEASE CYCLE

3.1. Downy Mildew

S. graminicola, the causal fungus of this disease, produces two kinds of spores; oospores - the sexual spores, and sporangia - the asexual spores. Oospores are the primary inoculum, and occur in infected leaf-debris. They are thick-walled, dark brown, round, and relatively hard structures which over-winter in the soil and infect young seedlings growing in subsequent seasons. Sporangia are borne on the tips of sporangiophores which emerge through stomata of infected leaves. These are fragile and are easily disseminated by air currents. Upon germination these sporangia produce zoospores which under favourable conditions can germinate and infect leaf tissue.

The disease cycle starts with the oospores which lay in the soil and infect young seedlings. The infection is systemic and 7 to 10 day-old seedlings show downy mildew symptoms as chlorosis on the upper surface of leaf and whitish sporangial growth on the under surface. The downy growth is more clearly visible in the early morning hours than later in the day. Sometimes downy mildew symptoms are not seen on leaves but appear in the form of 'green-ear', a malformed earhead. This is believed to result from infection of the growing point before or during floral differentiation. Leaf symptoms can remain supressed due to unfavourable weather conditions during the vegetative phase of crop growth and downy mildew might not become apparent until earheads with green ear emerge.

As the crop grows oospores are formed in the infected leaves. Subsequently the tissue becomes necrotic. Formation of oospores in a leaf tissue depends on the availability of two sexual compatibility types in the infected leaf. The highly susceptible plants are killed within 10-15 days of infection but those which survive and produce oospores eventually contribute to the soil-and seed incoula for the next crop. Seedborne inoculum is usually in the form of oospores present in the glumes but limited internal seed transmission has also been reported. Such seeds, if not treated with suitable fungicide produce infected seedlings under favourable weather conditions. Secondary spread occurs by means of sporangia produced on the seedlings that are infected initially. Under suitable environmental conditions, millions of sporangia are produced every night on the infected leaves for several days and can be disseminated several hundred meters by wind (Singh and Williams, 1980).

Downy mildew infection and development is favoured by the temperature range of 20 to 25C and relative humidity of 90 to 100%. Once infection is established disease can develop at the normal temperature and relative humidity favourable for better plant growth. The most critical stage of crop growth for infection is emerging seedlings (upto 10 day-old seedlings). Plants that are 14 day-old or more are less susceptible.

S. graminicola is a biotrophic pathogen with a high rate of spore production and efficient dispersal and survival mechanisms. Existence of heterothallism in this fungus further adds to its ability for survival because of the enormous variability that it can generate to keep pace with the changing host genotype in varying environments.

The results of the International Pearl Millet Downy Mildew Nursery and studies at the University of Reading, UK, indicate the existence of different pathotypes in *S. graminicola* in India and west Africa.

3.2. Ergot

C. fusiformis, the causal fungus of ergot, produces both sexual and asexual spores. The sexual spores, ascospores are produced from the germinating sclerotia, which are hard and dark-brown structure of the fungus. Ascospores are long, filiform and hyaline, and are produced in asci in the perithecia of the germinating sclerotia.The asexual spores are macroconidia and microconidia. Macroconidia are single-celled and fusoid with tapering ends while microconidia are single-celled, oval to pyriform and smaller than macroconidia. Macroconidia germinate to produce micro-or macroconidia on the tips of the germ tubes. Microconidia are often produced by budding from the tips of the germ tubes of macroconidia.

The infected inflorescences of pearl millet initially produce numerous macroconidia in the copious honeydew and subsequently macroconidia germinate to produce macro-or microconidia. Within 10 days of the appearence of honeydew, sclerotia develop in florets in place of grains, and within 20-25 days they turn dark-brown to black and are generally larger than grains. Sclerotia are of varying shapes and sizes depending on the host genotype and weather conditions during infection and disease development.

The disease cycle in ergot initiates with sclerotia as primary inoculum in the soil and/or with seed. Ascospores from germinating sclerotia infect pearl millet heads at protogyny, and honeydew symptoms appear within 4-6 days. The secondary spread occurs through air-borne and rain-splashed conidia from honeydew and with physical contact between infected and healthy inflorescences. The role of insects in ergot spread has also been reported but it needs confirmation. Depending upon frequency of rain showers and wind speed during flowering, the secondary spread can be from a minimal to few hundred meters.

The critical factors for ergot infection are: the short susceptibility period of the host, i,e. 2-3 days of protogynous period when most stigmas emerge and are receptive; pollination interference with infection i.e., either self-or cross-pollination can prevent or reduce infection; and conducive weather conditions during flowering i.e, about 80% relative humidity and moderate temperature of 20-30 C. There is no report on the existence of races in this pathogen.

3.3. Smut

T. penicillariae, the causal fungus of smut, produces two kinds of spores, asexual-teleutospores, and sexual - sporidia. As a characteristic of *Tolyposporium* spp., the teleutospores are held together in a mass called 'sporeball'. These spores over-winter in field soil and on seed for several months. The teleutospores germinate to produce promycelia and basidiospores (in this case sporidia) which are borne in chains on tips and sides of promycelial branches. Sporidia are single-celled, haploid and hyaline. Two compatible mating types are needed to form a dikaryotic mycelium necessary for infection. The fungus can be easily cultured on simple synthetic media such as carrot agar, potato agar, and potato-dextrose agar at 30-35 C.

The sporeballs in soil and on seed serve as the primary inoculum source. Following rain showers during the crop season, teleutospores germinate to produce airborne sporidia. Sporidia, being very light and dry, become easily suspended in the air and land on pearl millet inflorescences at flowering and infect the florets through stigmas and colonize ovaries. Sporidia deposited on the flag leaf or emerging earheads when protected from sun drying and rain wash by bagging the plants at the boot-leaf stage, usually results in more infection. Shiny green smut sori, larger than normal grains appear in the florets 12-15 days after inoculation, which later turn brown or black. The mature sori rupture to release numerous sporeballs in the atmosphere. At harvest, partially infected earheads not discarded by farmers, contaminate grains at threshing and contribute as a source of inoculum for the next crop.

Like ergot, smut infection is also reduced by rapid pollination. Inoculation using an aqueous sporidial suspension at the boot-leaf stage, and preventing cross-pollination by bagging the inoculated boot, produces high levels of infection. Smut infection and development is favoured by relatively high relative humidity (> 80%) and high temperatures (25-35C). There is no information available on the existence of races in this pathogen.

3.4. Rust

Not much information is available on the biology and epidemiology of pearl millet rust. Three species of *Puccinia* have been reported to cause this disease. But the most commonly known species is *P. penniseti*. Like most other *Puccinia* spp, it produces uredospores and teleutospores on pearl millet and the other two spore stages on the alternate host, *Solanum melangena*. There is no information availbale on the existence of races in this pathogen.

4. COMPONENTS OF DISEASE MANAGEMENT

The information on disease distribution, economic significance, biology and epidemiology, control measures, and socio-economic status of the farmers form the basic components of disease management. A disease management system has to be simple and economical to be easily adopted by farmers. Disease management should, infact, form an integral part of a crop management system which involves several aspects of better farming. Effective control of a disease can be achieved by several measures such as cultural, chemical, biological and host-plant resistance. Each of these is discussed separately as it applies to pearl millet diseases.

4.1. Cultural Control

The basic principle involved in cultural control is to reduce the primary inoculum load of the pathogen. This is achieved generally by crop rotation with a nonhost crop, deep ploughing to either expose soil inoculum to hot sunlight or to bury it deep in the soil to prevent germination, inter/mixed cropping to reduce the frequency of susceptible host plants, chemical fertilization and irrigation etc.

Deep ploughing after harvest has been suggested to bury ergot sclerotia deep in the soil to prevent their germination and the same will apply to downy mildew and smut spores as well.

Intercropping pearl millet with mungbean has been reported to reduce ergot infection. Ascospores released from the germinating sclerotia in the soil are probably trapped in the thick leaf-canopy of mungbean plants and do not reach the flowering earheads of pearl millet. This control measure can also be effective in controlling smut.

Transplanted crop of pearl millet from seedlings raised in nurseries has been reported to have reduced downy mildew incidence compared with direct seeded crop. This can be due partly to elimination of infected seedlings at transplanting and the faster growth of the transplanted seedlings which keeps the pathogen away from the growing points. Using seed from disease-free crops helps reduce the initial inoculum load.

4.2. Biocultural Control

Excellent control of ergot in pearl millet has been achieved by pollen management. The pollination-mediated resistance principle (Thakur and Williams, 1980) is utilized by inter-planting or mixed-planting an early-maturing, less ergot-susceptible line as a pollen donor to a highly susceptible hybrid. Rapid pollination of hybrid plants from the pollen-donor line reduces ergot infection. This has resulted in significant control of ergot and increased grain yield at ICRISAT Center (Thakur *et al.* 1983). This, however, needs to be tested on at larger scale before recommending its use in farmers' field.

4.3. Chemical Control

Although there are many reports (Table 2) on the control of downy mildew, ergot, smut and rust by spraying fungicides at different stages of crop growth, they are not economically and technically feasible at the farmers' level. Disease control in pearl millet proves economical only when the fungicide is used as a seed-dressing. Since ergot and smut are floral diseases caused by the air-borne spores, their control by seed-dressing fungicide is not possible.

Downy mildew has effectively been controlled by treating seed with metalaxyl (Ridomil 25 w.p. and Apron s.d. 35) @ 2g a.i./kg seed. In case of severe infection it is suggested to spray the fungicide once on 30 to 40 days-old plants. Treating seed of downy mildew-resistant cultivars with metalaxyl will help prolong the durability of the cultivars and thus a long term benefit can be expected Recently, based on the recommendation of the All India Coordinated Millets Improvement Project (AICMIP), the Govt. of India has agreed to register this fungicide and make it available for commercial use in the country (G. Harinarayana, personal communication).

Rust has been reported to be controlled by three sprays of mancozeb plus dinocap (70% + 60% water suspensions) at 10-day interval starting at ear emergence. This, however, would be economical only in the seed-production plots.

4.4. Biological Control

Species of *Fusarium* and *Cerebella* have been reported to parasitize ergot honeydew and sclerotia under field conditions. But the effectiveness of this control measure is yet to be determined.

4.5. Control Through Host-Plant Resistance

Use of disease-resistant cultivars is the most effective and economical control measure for most plant diseases. In recent years major efforts have been on identifying resistance and breeding resistant varieties of pearl millet. This approach has received momentum with the development of highly effective field-screening techniques for downy mildew, ergot and smut. A large number of germplasm accessions from the world collection have been screened for these diseases and sources of resistance have been identified which are being utilized in the breeding programs.

4.5.1. *Downy Mildew.* Significant progress has been made towards breeding for downy mildew resistance. Quick replacement of a hybrid, HB 3, the most popular hybrid in the late 60s and early 70s, which became susceptible to downy mildew in 1973-74, by another hybrid, BJ 104, resistant to downy mildew is one of the achievements of resistance breeding in pearl millet in India. This has been the result of excellent interdisciplinary efforts by pathologists and breeders. Now BJ 104, has also succumbed to downy mildew but there are sereval other hybrids and varieties resistant to downy mildew available for cultivation.

An effective downy mildew screening technique, which involves highly susceptible genotypes as infector rows to provide inoculum to the test rows (Williams *et al.*, 1981), is being widely used. At the ICRISAT Center every year a 12ha downy mildew nursery is operated, 6 ha each in the rainy and postrainy seasons. This enables to screen a large number of breeding lines and germplasm accessions. Because of this extensive screening system almost all the advanced breeding lines of ICRISAT now posses very high levels of resistance to downy mildew. The screening technique is also being effectively used in the Indian programs and many sources of resistance to downy mildew are available. Several downy mildew-resistant varieties and hybrids are in the final stages of testing in the AICMIP system. Some of the AICMIP released varieties and hybrids resistant to downy mildew are listed in Table 3.

4.5.2. *Ergot.* An effective ergot screening technique, which involves bagging the earheads at the boot-leaf stage, inoculating the earhead by spraying the honeydew conidial suspension at full stigma emergence and replacing the bag to prevent cross-pollination, and providing high humidity by overhead sprinkler irrigation (Thakur *et al.*, 1982) is being used at the ICRISAT Center. Resistance to ergot has not been detected in the large and varied germplasm accessions and breeding lines that have been screened for several years at ICRISAT Center. All hybrids and varieties are susceptible to ergot but varieties generally get less infection than hybrids because of better pollen protection mechanism operating in varieties. Resistance has, however, been developed by intermating relatively less susceptible plants and selecting resistant plants in the progeny rows under high disease pressure (Thakur *et al.*, 1982). At ICRISAT Center, several ergot-resistant sib-bulk populations have been developed and these have shown high yield potential. Recently through recurrent selection a few ergot-resistant varieties have been developed at the Punjab Agricultural University, Ludhiana.

Ergot resistance is being utilized at ICRISAT Center and in the AICMIP program to breed resistant hybrids and varieties. We hope that in the near future ergot-resistant hybrids and varieties will become available for commercial cultivation.

4.5.3. *Smut.* Smut screening technique, which involves inoculating plants at the boot-leaf stage with aqueous sporidial suspension and bagging the inoculated boot, and providing high humidity by overhead sprinkler irrigation (Thakur *et al.*, 1983), has effectively been used at the ICRISAT Center. A large number of germplasm accessions from world collection and advanced breeding lines have been screened. Most of the present hybrids and varieties are susceptible to smut. As with ergot, varieties are less susceptible than hybrids because of the pollen-protection mechanism. Sources of resistance to smut have been identified and these have been successfully utilized at ICRISAT Centre to breed smut-résistant synthetics and population varieties. Two synthetic varieties and two population varieties have shown high resistance to smut and downy mildew. These varieties have shown high grain yield in the 1984 multilocational testing. Three of these have been tested in the 1985 AICMIP trial. In the near future, several smut-and downy mildew-resistant high yielding varieties should become available for commercial cultivation.

Effoıts are also underway to breed smut-resistant hybrids by transferring resistance into the seed and pollen parents of the hybrids and by producing new smut-resistant male sterile seed parents and pollinators.

4.5.4. *Rust.* Several sources of resistance to rust are available and resistance breeding has recently been initiated at ICRISAT Center. Varieties and hybrids under cultivation at present have not shown any serious sign of susceptibility to warrant their cultivation. But it would be desirable that the future varieties and hybrids possess resistance to rust. It is fortunate that there are sources of resistance to other diseases that also have resistance to rust. A single dominant gene for rust resistance has recently been identified at ICRISAT Center. This resistance is being utilized in the breeding program.

4.5.5. *Multiple disease resistance.* Several sources of multiple disease resistance (to downy mildew, ergot, smut and rust) with relatively high grain yield potential have been developed at ICRISAT Center. Such resistance sources offer the opportunity of breeding varieties with multiple disease resistance. As pearl millet is a cross pollinated crop, recurrent selection can effectively be used to breed such varieties.

5. DISEASE CONTROL SCHEDULE

A disease control schedule (Table 4) for pearl millet should include:

a. Growing disease-resistant varieties recommended for cultivation in the particular area.

b. Treating the seed with metalaxyl @ 2g a.i./kg seed, as dry seed-dressing to control downy mildew.

c. Sowing the seed in a well prepared field which had been deep ploughed to burry sclerotia and oospores deep in the soil.

This control schedule is quite simple and economical, and can easily be adopted by farmers if properly taken to farmers by the extension agencies.

6. NEED FOR FUTURE RESEARCH

Future research in pearl millet diseases should focus mainly on host-plant resistance. A major resistance breeding effort should continue to breed disease-resistant hybrids and varieties depending on the importance of a disease in a particular region. There are cultivars which have potential of yielding 2.5 to 3.5t/ha on experiment stations but the same varieties yield much less in farmers' fields. Diseases are one of the major constraints preventing farmers from obtaining the high yields. The major problem at present is not of increasing yield potential of varieties but to sustain the attainable yields by proper management practices to overcome the factors preventing the realization of the yields in the farmers' fields.

To prolong the life of a popular disease-resistant variety, it is important that fungicidal seed treatment against downy mildew should be included in the regular control schedule. Development of safe and economic fungicides as seed-dressings should receive priority by our pesticide industries.

ACKNOWLEDGEMENTS

The author is thankful to S.B. King, Principal Pathologist and Program Leader, S.D. Singh, Plant Pathologist, Pearl Millet Improvement Programme, for their useful comments on the manuscript and to J.S. Kanwar, Director Research, for his permission to attend the seminar and present this paper.

REFERENCES

Dang, J.K., Thakur, D.P. and R.K. Grover. 1983. Control of pearl millet downy mildew caused by *Sclerospora graminicola* with systemic fungicides in an artificially contaminated plot. *Ann. appl. Biol.* 102:99-106.

Nene, Y.L. and S.D. Singh, 1976. Downy mildew and ergot of pearl millet. PANS 22:366-385.

Pathak, V.N. and S.C. Gaur. 1975. Chemical control of pearl millet smut. *Plant Dis. Rep.* 59:537-538.

Rachie, K.O. and J.V. Majmudar. 1980. Pearl Millet. The Penn. State Univ. 307 p.

Safeeulla, K.M. 1977. Genetic Vulnerability: the basis of recent epidemics in India. Part I Pages 72-85 in : .PR. Day ed. The genetic basis of epidemics in agriculture. *Ann. N.Y. Acad. Sci.* Vol. 287.

Sharma, K.B. and C.L. Sharma. 1976. Chemical control of pearl millet rust and smut. *PANS* 22: 410-411.

Singh, S.D. and R.J. Williams. 1980. The role of sporangia in the epidemiology of pearl millet downy mildew. *Phytopathology* 70:1187-1190.

Thakur, D.P. 1983. Epidemiology and control of ergot disease of pearl millet. *Seed Sci. & Technol.* 11:797-806.

Thakur, R.P. and R.J. Williams. 1980. Pollination effects on pearl millet ergot. *Phytopathology* 70:80-84.

Thakur, R.P., Williams, R.J. and V.P. Rao. 1982. Development of resistance to ergot in pearl millet. *Phytopathology* 72:406-408.

Thakur, R.P., Williams, R.J. and V.P. Rao. 1983. Control of ergot in pearl millet through pollen management. *Ann. appl. Biol.* 103:31-36.

Wells, H.D. 1967. Effectiveness of two 1, 4 oxathiin derivatives for control of *Tolyposporium* smut of pearl millet. *Plant Dis. Rep.* 51:468-469.

Williams, R.J. and S.D. Singh. 1981. Control of pearl millet downy mildew by seed treatment with metalaxyl. *Ann. appl. Biol.* 97:263-268.

Williams, R.J., Singh, S.D. and M.N. Pawar. 1981. An improved field screening technique for downy mildew resistance in pearl millet. *Plant Dis.* 65:239-241.

Table 1. Important diseases of pearl millet in India

Disease	Pathogen	Plant parts infected	Extent of yield loss(%)	Distribution (states)	Mode of survival of pathogen
Downy mildew and green ear	*Sclerospora graminicola*	leaf and earhead	10–45[a,b]	All pearl millet growing states	Oospores in soil and leaf-debris and on seed
Ergot	*Claviceps fusiformis*	earhead	41-70[b]	All pearl millet growing states, mainly in Maharashtra, Gujarat, Rajasthan, and Karnataka	Sclerotia in soil or mixed with seed and collateral hosts. *Cenchrus ciliaris* and *Panicum antidotale*
Smut	*Tolyposporium penicillariae*	earhead	5-20[c]	Mainly in the states of Haryana, Rajasthan, Madhya Pradesh and Punjab	Teleutospores in soil or on seed.
Rust	*Puccinia penniseti*	leaf and stem	not known	All states, mainly in the states of Maharashtra, Gujarat and Tamil Nadu	Teleutospores and alternate host, *Solanum melangena*
Blast	*Pyricularia setaria*	leaf and stem	not known	Mainly in Maharashtra, Haryana and Delhi	Soil, leaf-debris

[a]Source : . Safeeulla, 1977, Nene and Singh 1976
[c]Source: Nene and Singh, 1976.
[c]Author's estimate.

Table 2. Chemical control of important diseases of pearl millet

Disease	Chemical (Common name)	Method of application	Dosage	Reference
Downy mildew	Metalaxyl (Apron 35 sd)	Seed dressing	2g a.i./kg seed	Williams and Singh (1981)
	(Ridomil 25 wp)	Spray 20 days after emergence	1000 ppm	Dang *et-al* (1938)
Ergot	Captafol	Spray at boot	2000 ppm	Thakur (1983)
	Ziram .	2 sprays, at boot and at 50% flowering	2000 ppm	Thakur (1983)
Smut	Oxathiins: Oxycarboxin Carboxin	Sprays at boot and ear emergence	2 1/2 pounds in 1000 gallon water	Wells (1967)
	Benomyl Captafol	Sprays at boot and weekly interval 3-4 sprays	2 ppm	Pathak and Gaur (1975)
Rust	Mancozeb + Dinocap	3 sprays at 10-day-interval, starting at ear emergence	70% + 60% suspensions	Sharma and Sharma (1976)

Table 3. Disease resistant cultivars of pearl millet recommended for cultivation in different states of India

State	Downy mildew	Ergot and Smut	Rust
Rajasthan	Hybrids: PHB 57, CM 46, MBH 110 Varieties: RHR 1, PSB 15, RCB 2	All hybrids are highly susceptible. Varieties are generally less susceptible than hybrids. There is no specific recommendation for resistant cultivars.	There is no specific recommendation for resistant cultivars as rust usually appears late stage of crop growth
Maharashtra	Hybrids: CM 46, X 5, MBH 118 Varieties: WC-C 75, ICMS 7703,		
Gujarat	Hybrids: X 5, CM 46, MBH 118 Varieties: ICMS 7703, RHR 1, RCB 2		
Uttar Pradesh	Hybrids: PHB 47, CM 46, MBH 118 Varieties: HC 4, RHR 1		
Haryana	Hybrids: PHB 47, CM 46, MBH 110, Varieties: HC 4, ICMS 7703, RCB 2		
Andhra Pradesh	Hybrids: X 5, CM 46, MBH 118 Varieties: ICMS 7703, RCB 2		
Tamil Nadu	Hybrids : X 5, CM 46, MBH 118 Varieties: HC 4, ICMS 7703, CO 6		
Karnataka	Hybrids: CM 46, PHB 47, MBH 110 Varieties: RHR 1, RCB		
Madhya Pradesh	Hybrids: PHB 47, X 5, MBH 118 Varieties: WC-C 75, PSB 15, RHR 2		
Punjab	Hybrids: PHB 47, CM 46, MBH 118 Varieties: PSB 8, ICMS 7703		
Bihar	Hybrids: MBH 110 Varieties: WC-C 75		

Source : G. Harinarayana (unpublished)

Table 4. Management schedules for diseases of pearl millet

Crop growth stage	Target disease	Control practice	Remarks
1. Seed	Downy mildew	Metalaxyl: Ridomil 25wp. Apron 35sd Seed treatment 2g a.i./kg seed	
2. Tillering stage (20-day old seedling)	Downy mildew	Rogue out infected plants and spray with Ridomil 25wp 1000 ppm	Grow disease resistant cultivars (Table 3)
3. Boot leaf stage (20-45 day-old plants)	Rust	Mancozeb + Dinocap sprays as indicated in Table 2	Rust-resistan cultivars are not commercially available
4. Grain filling	Ergot and Smut	Harvest infected earheads and destroy them outside the field by burning	Cultivars resistant to ergot and smut are not commercially available
5. Crop maturity	Downy mildew Ergot and smut	Harvest only clean earheads for seed or consumption purposes, destroy the infected ear heads by burning them	
6. Post harvest	Downy mildew, Ergot and Smut	Grain saved for seed for next crop should be free from oospores, ergot sclerotia and smut spores	