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STATUS OF RESEARCH ON CONTROL OF FUNGAL DISEASES OF PEARL MILLET

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Pearl Millet, *Pennisetum glaucum* (L.) R. Br., an important cereal crop in the semi-arid tropical parts of the world, is grown annually on about 26 million ha, 42% of which are in India. The crop suffers from a nnmber of fungal diseases which cause substantial yield losses, and also adversely affect the quality of the produce and thus reduce its market value (Rachie and Majmudar, 1980; Thakur, 1987).

The diseases that are considered economically important in India, in order of their loss-causing potential, are downy mildew [(*Sclerospora graminicola*) Sacc. Schroet., ergot (*Claviceps fusiformis* Lov.), smut (*Tolyposporium penicillariae* Bref.), and rust (*Puccinia penniseti* Zimm.) (Rachie and Majmudar, 1980; Thakur, 1987).

Plant pathological research in pearl millet did not receive adequate attention until the F_1 hybrids, based on a cytoplasmic-genic male sterile line, released for commercial cultivation in India in the mid-1960s became susceptible to downy mildew in the early 1970s. The superiority of hybrid cultivars over open-pollinated varieties for grain yield, uniform growth, and shorter duration resulted in substantial increase in area under hybrid cultivars and this fovoured increased incidence of diseases (Rachie and Majmudar, 1980).

The estimated losses in grain yield in India have been 10-60% from downy mildew (Safeeulla, 1976; Singh *et al.*, 1987b), trace to 65% from ergot, and 5-20% from smut (Chahal, 1984; Thakur, 1987). Ergot infection also reduces grain quality and presents health hazards to humans and cattle because of contamination of grain

with sclerotia which contain neurotoxic alkaloids (Thakur and King. 1988). Rust is generally of less importance in the grain crop, but under conditions favourable for rust development, substantial yield losses can be expected (Sharma and Pathak, 1987). It is however, of major importance in fodder crops where it reduces both quantity and quality of the produce (Monson *et al.*, 1986).

During the last 15 years, a number of research publications, dealing with several aspects of disease control methods in pearl millet have appeared. We attempt here to review and analyze the information and provide guidelines for future research strategies to develop economically viable disease management practices for pearl millet.

Disease Control Methods

Based on available information on the pathogen biology, disease epidemiology and their ecosystem relationships, disease control methods can be divided into four major categories cultural, biological, chemical, and host resistance. Each of these control measures as it applies to the four diseases, individually or in combination, is discussed below.

Cultural methods

Cultural practices such as crop rotation, sanitation, clean seed, nutrition, time of sowing, and cropping patterns help reduce both the amount of initial inoculum, and the rate of disease spread.

Crop rotation : In the semi-arid enviroment farmers in India normally grow only one crop each year, and after the crop is harvested the field either remains fallow, or as in some parts of Haryana, Punjab and Uttar Pradesh where irrigation becomes available, they follow pearl miliet-wheat rotation. The non-availability of host for about 7-8 months greatly reduces inoculum build-up and during the hot summer months sclerotia of ergot, oospors of downymildew and teliospores of smut are destroyed. In India there is a general recommendation of following a 3-4 year crop rotation, using nonhost crops to reduce downy mildew incidence in pearl millet (Safeeulla, 1976). In most parts of Rajasthan, Gujarat, Haryana, and Punjab, the spores are exposed to very high soil temperatures (up to 50 C or more) during the hot summer months when it is likely that most of the soil-borne inoculum is killed. In contrast to farmers fields, on crop research stations, soilborne inoculum survives and multiplies because of continuous cropping, screening material in disease nurseries by artificial inoculation, and maintaining the field fertility and moisture level, even when a non host crop is grown. These may be reasons why diseases are more severe on research stations than in the farmers fields. Monitoring soil inoculum in relation

to crop rotation and determining its effect on disease development in a given agro-ecosystem is important and should receive priority in pearl millet disease research.

Sanitation : Field burning after harvesting the crop will reduce downy mildew, ergot, and smut inocula. Postharvest field burning is the most valuable cultural method of control ergot caused by *C. purpurea* in annual grasses (Hardison, 1972; Wells *et al.*, 1958). Rogueing of the infected seedlings has been found effective in reducing the spread of downy mildew and yield losses (Thakur and Kanwar, 1977; Singh and Williams, 1980) and this practice also helps reduce the initial oosporic inoculum for the next crop.

Field sanitation by postharvest ploughing can also reduce the amount of initial inoculum for the next crop. Ergot sclerotia, downy mildew oospores, and smut teliospores that are buried more than 5 cm deep in the soil seldom germinature and those which are left on the soil surface may be killed by high temperatures during the summer months. Although there are no published data in relation to pearl millet diseases, deep ploughing is a common practice followed for many years by farmers and does contribute substantially to suppressing the disease.

The eradication of collateral and alternate hosts can help reduce both primary and secondary inocula. A number of collateral/alternate hosts are reported for downy mildew (Safeeulla, 1976), ergot (Thakur and Kanwar 1978; Singh *et al.*, 1983; Dhindsa *et al.*, 1986), and rust (Ramakrishan and Soumini, 1948; Ramakrishnan and Sundaram, 1956). Complete eradication of these hosts is generally impractical and uneconomical, but a long term well-planned strategy to reduce the population of alternate and collateral host plants could contribute to suppress pearl millet diseases.

Clean seed : Use of disease-free seed is one of the simplest methods of managing diseases. Downy mildew is known to be both internally and externally seedborne. External seed contamination is by oospores carried on the seed surface, in in the glumes, and pericarps (Shetty, 1987). *S. graminicola* mycelium present in the embryo causes seedling infection in pearl millet (Shetty *et al.*, 1980). A procedure to eliminate the possible seed transmission of downy mildew has been established (Williams, 1984). This procedure involves : harvesting physiologically mature seed from downy mildew free plants, sun drying the seed to 10% moisture, removing all glumes, husks and debris, surface sterilization with 0.1% $HgCl_2$ for 10 min followed by several washes in sterile distilled water, redrying the seed and finally treating with systemic fungicide Ridomil 25 WP (metalaxyl) at 2 g.a.i. kg^{-1} seed.

Contamination of pearl millet seed with ergot sclerotia on the threshing floor and using such seed is reported to increase the soil inoculum (Sundaram, 1975).

Ergot sclerotia, which produce ascospores on germination also contain conidia in the sclerotial cavities, serve the major source of primary inoculum. There are several methods to separate sclerotia from seed, e.g. by the use of 10% brine solution (Nene and Singh, 1976), or various types of mechanical separators (Nicholas, 1975; Pathak *et al.*, 1984).

Time of sowing: By adjusting sowing time, environmental factors can be manipulated to reduce disease incidence. Ergot infection is usually more severe in late sown cultivars (Singh and Singh, 1969; Thakur, 1983) probably because cooler weather at the time of flowering is morr conducive for disease development than warmer weather. Ergot is not generally a problem in the early sown crop in the northern India, but it is a problem in central India. In northern India smut becomes severe on early-sown crops and ergot on late-sown crops. The distribution of ergot and smut seems to be very well related to the prevailing temperature during the flowering period. In the states of Haryana, Rajasthan, Delhi, Uttar Pradesh, and Madhya Pradesh, where temperature at flowering are usually higher (mean $>$ 30 C) smut incidence is also higher than in the states of Maharashtra, Andhra Pradesh and Karnataka where temperature is moderate (mean temp. $<$ 25 C) and is more favourable for ergot development. Downy mildew and rust appear in almost every state in India because these two diseases are well adapted to a wider temperature range than ergot and smut. In northern India downy mildew incidence is severe on the late-sown crop (Chahal *et al.*, 1978), and therefore, the disease can be checked by sowing the crop early in the season.

Chemical fertilization: A balanced chemical fertilization to a crop is essential to eliminate chances of nutritional deficiency in plants that lead to increase disease susceptibility. Unfortunately very little information is available on the nutritional effects of host susceptibility. Most of published information on the relationship between plan nutrition and disease development are unclear, suggesting the need for research in this important area.

Inter- and mixed-cropping: Intercropping pearl mllet with mungbean has been reported to reduce ergot incidence (Thakur, 1983). The crop canopy of mungbean probably intercepts ascospores, released from germinating sclerotia, from reaching the panicles at flowering, and thus prevents infection. Growing hybrid mixtures and genocropping systems have been advocated to contain or reduce downy mildew incidence and stabilize production of pearl millet (Harinarayana. 1986).

Transplanted crop of pearl millet from seedlings raised in nurseries is reported to have reduced downy mildew incidence compared with the direct seeded crop (Chandrasekhara Rao *et al.*, 1987; Thakur, 1980). This is probably because most of

the diseased seedlings are killed at the young stage in the nursery itself or get eliminated during translanting. Transplanting is although laborious, could be effective in reducing downy mildew incidence at small scale.

More research efforts are needed to understand the effects and implications of various cultural practices and their integration in relation to disease epidemiology and crop management practices in pearl millet.

Biological control

Downy mildew: Downy mildew infected leaves have been shown to be infected by several fungi : *Fusarium semitectum* (Rao and Pavgi, 1976), *Dreschslera setariae* (Balasubramanian, 1980) and *Fusartum equiseti* (Singh and Navi, unpublished). These fungi colonize saprophytically and destroy infected areas. This results in reduction of sporangial production and spread of the disease. Rao and Pavgi (1976) reported that *F. semitectum* severely parasitized oospores which became deformed and lost viability. This will reduce the source of primary infection. However, further research is needed to assess the potential of these fungi as biocontrol agents for downy mildew.

Ergot: *Cerebella andropogonis* has been reported as hyperparasite which inhibit the formation of ergot sclerotia (Kulkarni and Moniz, 1974). Similarly, sclerotial germination was reduced when parasitized by *Fusarium sambucinum* and *Dactylium fusariodes*. The culture filtrate of *F. sambucinum* showed inhibitory effect on germination of ergot conidia (Tripathi *et al.*, 1981). Inhibition of the ergot pathogen *in vitro* and *in vivo* by *F. chlamydosporum* has also been demonstrated (Chahal *et al.*, 1987; Gill and Chahal, 1988). The culture filtrate of the parasite causes significant growth inhibition and browning of cultures of *C. fusiformis*, and reduces ergot severity when applied 24 h before, simultaneously or 24 h after inoculation of pearl millet panicles with ergot. Rao and Thakur (1988) have demonstrated *F. semitectum* var. *majus* as a potential biocontrol agent of ergot of pearl millet under field conditions.

More research efforts are needed to assess the potential of mycoparasites for their effective utilization in disease control and its integration with other control measures in pearl millet.

Chemical control

Use of chemicals becomes essential in a disease management program only when cultural practices, host resistances and alterations of environment are inadequate to suppress the pathogen sufficiently (Fry, 1977). Losses due to diseases might be lessened by greater use of chemicals, but the cost associated with chemical

use must be weighed against the potential benefits both in terms of quantity and quality, and against hazards to environment should also be considered. Chemicals are used to reduce the initial inoculum or to reduce the efficacy of inoculum (Van der Plank, 1963). Epidemiological characteristics of a disease including the initial inoculum and the infection rate are important determinants for the efficient use of chemicals in a disease manngement program. Control of pearl millet diseases with chemicals has been recently reviewed (Singh *et al.*, 1987; Thakur, 1987: Thakur and Chahal, 1987).

Downy mildew : Since downy mildew is both seed- and soilborne, both systemic and nonsystemic fungicides have been used. Most of nonsystemic fungicides applied as protectants to seed, soil or growing plants were not effective because of their inability to control systemic infection, to withstand frequent rains and to protect enlarging roots and plumules from infection by oospores (Singh *et al.*, 1987b).

With the advent of Ridomil 25 WP (metalaxyl), a systemic fungicide of acylalanine group (Urech *et al.*, 1977), control of downy mildew could become possible. Seed treatment with metalaxyl (1-2 g.a.i. kg^{-1} seed) provided excellent control of pearl millet downy mildew (Williams and Singh, 1981; Singh, 1983; Dang *et al.*, 1983). The fungicide is effective against soil and seed carried inoculum and is absorbed by the growing seedlings to protect them against airborne sporangial infection. In high tillering cultivars of pearl millet, the efficacy of seed treatment is reduced as the plants grow, and this necessitates for a foliar application of metalaxyl (Dang *et al.*, 1983; Shankara Rao *et al.*, 1987). Foliar application of metalaxyl has also been shown to have remissive effects on downy mildew (Singh *et al.*, 1987b).

Differential sensitivity of pearl millet cultivars to metalaxyl affecting seed germination and its narrow spectrum of activity, only against oomycete fungi, may be major limitations for prolonged use of this chemical (Singh, 1983; Singh *et al.*, 1987b).

Ergot : A number of systemic and nonsystemic fungicides, tried as sprays at the flowering stage of pearl millet to control ergot, have met with limited success (Thakur, 1984). Sulaiman *et al* (1966) reported one spray of Aureofungin (5 ppm) at the flowering time to control ergot. Two to three applications of a mixture of coppor oxychloride and Zineb in the ratio of 1:2 at 500-600 g ha^{-1} at 5-7 day-intervals starting before panicle emergence was reported to reduce ergot significantly (Sundaram, 1975). Reddy *et al.* (1969) reported 50% control of ergot over the check with Cosan-80, a wettable sulfur when used as protective spray 24 h before ergot inoculation. Brar *et al.* (1976) reported Difolatan (2000 ppm) as the most effective

protective fungicide with *in vitro* and field studies to control ergot in pearl millet. Thakur (1984) reported two sprays of Cuman-L, first at boot and second at 50% flowering as effective against ergot. A significant control of ergot was reported by spraying a combination of fungicide and insecticide i.e. Bavistan, Benlate or Brestanol with Sevin or Thiodan, three times at weekly interval (Sharma *et al.*, 1984).

The major limitation of fungicidal control of ergot of pearl millet is the weather at the time of flowering. Ergot becomes severe when there are frequent rains at flowering as the spore concentration rises over fields with frequent rains (Chahal and Dhindsa, 1985; Tilak and Rao, 1987). Under such conditions fungicide spray is unlikely to be effective. High tillering characteristics of hybrid cultivars poses another problem of repeated fungicide application. With increasing cost of chemicals and spray equipments, and low market price of pearl millet, ergot control by application of chemical may not be an economical practice.

Smut : Significant control of smut, using Vitavax and Plantvax as foliar and panicle sprays in pearl millet, was reported by Wells (1967) Bhowmik and Sundaram (1971), and Chahal (1979). Pathak and Gaur (1975) used four sprays of Captafol (2 ppm) or Zineb (2 ppm), or heptaene antibiotic (1000 ppm) for successfully controlling smut under artificial inoculation. Seed treatment with Bavistin or Vitavax (2.5 g kg^{-1} seed) effectively reduced smut and increased grain yield (V.N. Pathak, Personal communication).

Like ergot, smut is also a soil- and airborne disease, and infection occurs at flowering through the emerging stigmas by the airborne sporidia produced by germinating teliospores in the soil. Seed treatment can only reduce the inoculum carried on or around the seed in the soil but in a field where soil inoculum load is heavy, seed treatment will not be effective. Spray fungicides, however, will not be economical.

Rust : Information concerning fungicidal control of rust in pearl millet is limited. Sinha and Dalela (1963) found decreased rust severity with 2, 4-D (10 ppm), Sulfadiazine (100 ppm) and Streptomycin (1000 ppm) applied as foliar spray 3-24 h after inoculation. Pre-inoculation sprays of pearl millet seedlings with Dithane M-22, Dithane S3, Cupramar and phenanthroline were reported effective in reducing rust severity (Kapooria, 1972). Spray application of 2-methyl benzoic acid anilide (75% WP), 2-iodine benzoic acid anilide (50% WP) and 2, 5-dimethyl furan-3-carboxylic acid (100 ppm) as pre-, post-, or simultaneously with inoculation, providing significant control of rust (Bahadur, *et al.*, 1975). Sharma and Sharma (1976) obtained control of rust by three sprays of a mixture of Mancozeb (70%) and Dinocap (60%) at 10-day-interval starting at panicle emergence.

Fungicidal control of rust of pearl millet is probably only economical in some instances of seed production; it is probably not economical in general cultivation for grain or fodder in farmers fields.

Host resistance

On all factors that can cause instability to crop yields, it is plant pathogens that can change genetically and increase inoculum of new forms rapidly with catastrophic results (Browning *et al.*, 1977). Manipulating host genes to overcome the effects of pathogen genes is the basis of controlling diseases through host resistance. Use of disease-resistant cultivars is the most economical and effective means of controlling plant diseases. As described by Thakur and Chahal (1987) development of resistant cultivars involves : development of an effective field-based screening technique; identification of resistance sources; determination of stability of resistance; understanding genetics and mechanism of resistance; and utilization of resistance to breed disease-resistant cultivars. Progress made in relation to the above steps for each of the four diseases has been discussed here.

Downy mildew

Screening techniques : A field screening technique that utilizes sporangia as the main source of inoculum (Williams *et al.*, 1981) involves infector rows (inoculum donor), a mixture of 2-3 susceptible genotypes planted in advance of test genotypes; test rows planted after about 50% plants in infector rows develop downy mildew, and indicator rows of a susceptible genotype planted in each bed to indicate the disease pressure. High humidity, essential for sporulation and infection, is operating perfo-mister system. The technique is simple, easily transferable and simulates natural epidemic conditions.

Laboratory or greenhouse screening technique, which is essential for precise information under controlled conditions, has also been developed. Recently, Singh and Gopinath (1985) described a technique which involves inoculation which microsyringe of seedlings in the coleoptile stage. The inoculum drop placed at the tip of the seedling flows down to the base covering most of the plant surface above soil. The inoculated seedlings are marked by placing toothpick beside it to differentiate from those emerging later. The technique can induce >90% incidence in a susceptible genotype.

A greenhouse technique for mass screening pearl millet seedlings for resistance to downy mildew has recently been developed (ICRISAT, 1987). Seedlings are spray-inoculated at the coleoptile to 1-leaf stage with a suspension of sporangia and incubated for 12-16 h at 20 C and >95% relative humidity. Plants are then moved to greenhouse benches and downy mildew incidence is assessed after 10-15 days.

This screening technique is faster and provides more flexibility for adjusting number of entries and plant population than other techniques, and the results are well correlated with the field screening.

Sources or resistance: A large number of downy mildew resistant selections have been identified by screening more than 3160 genetic resource accessions from 20 countries, at ICRISAT Center (Singh *et al.*, 1987b). Some of these resistant lines are in the form of inbreds and constitute the major resistant stocks for utilization in the breeding program in India. In downy mildew screening nursery at Punjab Agricultural University (PAU), Ludhiana, 534 lines with diverse genetic background have been identified as resistant by repeated testing and a number of them have shown resistance in multilocational testing as well (Chahal and Mohan, 1987).

Stability of resistance of some lines have been tested through a multilocational testing program at several locations in India and West Africa (Singh *et at.*, 1987b). Some of the entries have shown high levels of resistance across locations over several years of testing (Table 1). These genotypes seem to have durable resistance and should be utilized in resistance breeding program. Most of the downy mildew resistant accessions are from Nigeria and Mali supporting the theory of coevolution of host and the pathogen leading to natural selection for resistance in the center of diversity of the crop species (Singh *et al.*, 1987).

Table 1. Sources of stable resistance to downy mildew in pearl millet

Line	Origin	Mean[1] downy mildew incidence (%)
SDN 503	Nigeria	4
P 7	Mali	5
700251	Nigeria	4
760516	Nigeria	3
700651	Nigeria	4
7042 (Check	Chad	57

1 Based on 8-9 years of multilocational testing at 10-12 locations in India and West Africa
Source : Singh *et al.*, 1987

Distinct pathotypes exist in *S. graminicola* population in India, West Africa and Southern Africa (Singh *et al.*, 1987b; Singh and Singh, 1987). The most recent evidence of variation in the pathogen isolates from India (Table 2, S.B. Kang, personal communication) further suggests the occurrence of distinct pathotypes. This emphasizes the need for selecting genotypes with stable resistance for utilization in the breeding programs.

Table 2. Pathogenic variability in *Sclerospora graminicola* isolates from India

Genotype	Isolates		
	Patancheru	Mysore	Aurangabad
MBH 110	R	R	S
852 B	R	S	R
ICMH 451	R	R	R
7042	S	S	S

Source : S B. King, Personal Communication

Resistance utilization : In pearl millet, resistance can be utilized to breed hybrids and varieties. Open-pollinated varieties are known to have variability for downy mildew resistance and the levels of resistance can be enhanced by recurrent selection procedure in the downy mildew nursery. Two such varieties WC-C75 and ICMS 7703 have been improved for downy mildew resistance at ICRISAT Center (Singh *et al.*, 1987b) and released for cultivation in India.

Direct utilization of resistance is done in hybrid parents were resistance can be transferred from the resistance donor to the established inbred lines. Resistance sources, SDN 503, P7, 700651, P 310 and 700516 that have shown stability of resistance, are being utilized in hybrid breeding program at ICRISAT Center (Singh *et al.*, 1937b).

At ICRISAT Center, two downy mildew resistant lines, 700651 and P7, have been crossed with a promising lined 843B and the resistant progenies are being utilized in the male-sterile breeding program (Rai and Singh, 1987). 700651 is also one of components of two millet varieties – ICMV 2 and ICMV 3, developed in Senegal.

The longevity of some of the promising high yielding hybrids based on male sterile lines Tift 23A, and 5141A was severely reduced because of their downy mildew susceptibility. However, it is now known that susceptibility to downy mildew is not related to the cytoplasm and nuclear gene resistance is more important (Kumar *et al.*, 1983; Rai and Singh, 1987). Transfer of resistance to the hybrid parent, will thus be an easy proposition.

Use of residual variability for downy mildew resistance in susceptible but otherwise promising genotypes has been suggested to prolong the useful life of commercial cultivars (Singh and King, 1988). This has been successfully demonstrated in a land race genotype, IP 2696 from Chad (Singh *et al* , 1988) and also for

parents of a hybrid, HB 104 (Singh, 1983). The selected parental lines (841A and ICMP 84814) of BJ 104 are phenotypically similar to the original parental lines. However, 841A differs from the original line 5141A in height, days to bloom, and panicle length (Singh *et al.*, 1987b). This line has now been released for the production of hybrids in India. Similarly Pb 204A and Pb 211A resistant versions of Tift 23A and 5141A, respectively have been developed (Gill *et al.*, 1981; Rai and Singh, 1987).

Recovery resistance : It is a form of resistance in which systemically infected plants outgrow the disease and produce healthy leaves and earheads. This trait has been detected in a wide range of genotypes (Singh and King, 1988; Singh, 1988). The levels of recovery resistance could be increased substantially through pedigree selection under high disease pressure in a downy mildew nursery. The genotypes showed considerable variation for the extent of sexual and asexual reproduction. The recovery resistance trait was stable at several locations in India. The phenomenon was also observed in Mali and Niger (Singh and King, 1988). A preliminary study has shown that the recovery trait is dominant over susceptibility (Singh, 1988). This form of resistance in which the pathogen does not affect the host adversely is likely to be more durable than the resistance based on nonrecovery traits.

Ergot

Screening technique : Thakur *et al.* (1982) developed an effective field-based screening technique which involves bagging the panicles at the boot stage, inoculating the protogynous panicles with aqueous suspension of conidia from honeydew, rebagging immediately after inoculation, and maintaining high humidity by operating overhead sprinkler. Bags are removed and panicle are scored for ergot severity 20 days after inoculation (Thakur and Williams, 1980; Thakur and King, 1988a). Seeds are harvested from the resistant panicles for further evaluation and utilization. The technique is precise and effective, and easily transferable. With provision of sprinkler irrigation, screening can be conducted even in the post rainy season.

Resistance source : In field at ICRISAT Centre a large number of genetic resource accessions from several countries and breeding lines were screened, but adequate level of resistance was not detected (Thakur *et al.*, 1982, 1985). Absence of detectable levels of resistance in genetic resource accessions can be attributed to inadequate selection pressure operating in nature for ergot resistance because of open-pollinated nature of the crop and pollination interference with ergot infection (Thakur and Williams, 1980). Ergot-resistant lines have been developed by intermating less susceptible plants and selecting resistant progenies under high disease pressure for several generations following pedigree (Thakur *et al.*, 1982) and recurrent selection (Gill *et al.*, 1981).

Stability of ergot-resistant lines has been tested (Thakur *et al.*, 1985; Thakur and King, 1988a, c) through a multilocational ergot nursery and several lines have shown high levels of ergot resistance across locations in India and west Africa over years (Table 3).

Table 3. Sources of stable resistance to ergot in pearl millet

Line	Mean[1] ergot severity (%)
ICMPE 13-6-27	2
ICMPE 13-6-30	2
ICMPE 134-6-25	1
ICMPE 134-6-34	1
ICMPE 1	1
ICMPE 2	2
ICMPE 23	2
ICMPE 27	1
ICMPE 28	4
ICMPE 32	4
BJ 104 (Check)	67

1 Based on 2-4 years of multilocational testing at one location in Nigeria and six locations in India
Source : Thakur & Chahal, 1987

Ergot-resistant lines developed through pedigree selection showed undesirable agronomic attributes which created a problem for their utilization in resistance breeding program. Resistance to a disease is invariably linked with undesirable agronomic traits and it is often difficult to break this linkage. To overcome this problem, ergot resistant inbreds were sib-mated to produce sib-bulk populations with desirable agronomic traits and higher grain yield (Thakur and Chahal, 1987; Thakur and King 1988a, c).

There are indications of existence of pathogenic variation in *C. fusiformis* populations in India (ICRISAT, 1982; Chahal *et al.*, 1985). This suggests the need for a multilocational testing to select resistant lines with stable resistance for utilization in breeding programs.

Utilization of resistance : Resistance, in most ergot-resistant lines seems to operate through short protogyny, rapid anthesis and stigmatic constriction. Rapid development of constriction in the styler tissue following pollination of stigma aging prevents ergot infection (Willingale and Mantle 1985; Willingale *et al.*, 1986).

The genetics of ergot resistance is relatively complex, resistance is recessive and polygenically controlled (Thakur *et al.*, 1983c). Ergot resistant hybrids, therefore cannot be bred unless both hybrid parents possess resistance (Virk *et al.*, 1987). There is further evidence that the source of resistance in both hybrid parents should be as similar as possible to insure high levels of resistance in hybrid. Initial attempts to transfer ergot resistance into a male sterile line at ICRISAT Center have not shown much promise, because of undesirable agronomic attributes and narrow genetic base of ergot-resistant lines. From the new sources of ergot resistance, having desirable agronomic traits, efforts are being made to transfer resistance into a dwarf, early maturing, large seeded maintainer line with a high general combining ability (Rai and Singh, 1987).

To breed ergot-resistant varieties, a recurrent selection program has been continuing at PAU, Ludhiana, and an ergot-resistant composite has been formed at ICRISAT (Thakur and Chahal, 1987). Breeding ergot-resistant varieties is an easier approach than breeding an F_1 hybrid. But the major emphasis should be on breeding hybrids as hybrids are more susceptible than varieties (Thakur *et al.*, 1983b). However, population breeding should continue as source material to extract ergot-resistant inbreds that can be utilized in hybrid breeding program. Breeding for ergot resistance, however, is more resource and time consuming process with much less chances of getting success, particularly with hybrids.

Smut

Screening technique : An effective field screening technique (Tkakur *et al.*, 1983a) developed includes : inoculating the plants at the boot-leaf stage with an aqueous suspension of *T. penicillariae* sporidia, covering the boot with parchment paper selfing bags immediately after inoculating to eliminate the chances of pollination interference with smut infection (Thakur *et al.*, 1983b), and providing high humidity by overhead sprinkler irrigation. Bags are removed and panicles are scored for percentage smut severity 25-30 days after inoculation, using a smut severity rating scale (Thakur and King, 1988b). Seeds from resistant panicles are harvested for further evaluation and utilization. This technique is precise, effective and easily transferable and has been used every year in 2 ha at ICRISAT Center during the rainy season and on a smaller scale at other locations (Thakur and Chahal, 1987; Thakur *et al.*, 1986). Wells *et al.*, (1987) reported a screening technique which involves inoculating pearl millet panicles during the first 72 h after emergence with a sporidial suspension in the late afternoon and covering the panicles overnight with prewetting polyethylene bags. This technique has a major disadvantage for its use in field screening that the polythene bag has to be replaced by a paper bag after 16 h to eliminate pollination interference with smut infection (Thakur *et al*, 1983b; Wells *et al.*, 1987). If polythylene bag is not removed it will drastically reduce or even

Table 4· Sources of stable resistance to smut in pearl millet

Line	Mean[1] smut severity (%)
SSC FS 252-S-4	<1
ICI 7517-S-4	1
EBS 46-1-2-S-2	1
EB 112-1-S-1-1	<1
P 489-S-3	1
ICMPS 100-5-1	0
ICMPS 200-5-5-5	<1
ICMPS 700-1-5-4	<1
ICMPS 900-3-1	<1
ICMPS 1300-2-1-2	<1
ICMPS 1400-1-6-2	1
ICMPS 1500-7-3-2	1
BJ 104 (Check)	45

1 Based on multilocational testing for six years across three locatons in India and location in Senegal

Source : Thakur & Chahal, 1987

inhibit seed sets due to high moisture and raised temperature in the bagged panicles, and selection for resistant plants will be difficult.

Resistant sources : Efforts to identify resistance to smut have been very limited prior to 1976, although several pearl millet lines resistant to smut have been reported (Murthy *et al.*, 1967; Yadav, 1974; Pathak and Sharma, 1976). Since 1976, a systematic screening at ICRISAT Center has identified many smut resistant lines and stability of resistance of these lines has been determined through multilocational testing (Table 4) (Thakur *et al*, 1986; Thakur and King, 1988d).

Resistance utilization : Most smut-resistant lines possess desirable agronomic attributes and therefore can easily be utilized in a breeding program. Observations at ICRISAT Center (Thakur and Chahal, 1987) and earlier evidence (Yadav, 1974) indicate resistance to smut is dominant and simply inherited. Recent studies (Phookan, 1987; Chavan *et al*, 1988) indicate both dominant and additive gene action for smut resistance in some pearl millet lines. Experience at ICRISAT Centre has shown that hybrids produced on certain male sterile lines could be resistant of the male parent is resistant, and similar observation has been reported from Hisar (Khairwal *et al*, 1986).

At ICRISAT Center, smut resistance is being utilized to breed hybrids and varieties (Andrews *et al.*, 1985). In hybrids, resistance is being transferred to both parents using backcross breeding method. Several smut-resistant lines which were identified as maintainers are being converted into male-sterile lines (Rai and Singh, 1987).

Considerable progress has been made in breeding smut-resistant varieties through recurrent selection and synthetic-breeding. In multilocational trials two population varieties and two synthetic varieties have shown high levels of resistance to smut and downy mildew, and yielded either on par or more than the control variety (Thakur and Chahal, 1987).

At ICRISAT Center efforts are underway to increase the levels of smut resistance in the promising composites by screening the progenies in smut nursery, and selecting resistant plants for utilization in the next cycle of random mating.

Rust

Screening method : Screening for rust resistance has been done, so far, under natural disease pressure. Depending upon weather conditions rust severity can vary from location to location. At ICRISAT Center, maximum severity of rust was recorded during November-January (ICRISAT, 1987). High severity of natural occurrence of rust during the crop growing season is known at Ludhiana (Punjab). Mysore (Karnataka), Aurangabad and Pune (Maharashtra) and Bhavanisagar (Tamil Nadu). However, there is need to develop an artificial inoculation method for precise and effective screening.

Resistance source : A systematic screening of genetic resource accessions for rust resistance was initiated at ICRISAT in 1975 and a large number of accessions have been screened so far. A number of rust-resistant lines have been identified by screening at ICRISAT Center, Aurangabad and Bhavanisagar (Singh and Williams, 1979). Resistance sources with single dominant genes have been identified (Hanna *et al.*, 1985; Singh *et al.*, 1987a).

Stability of resistance of these lines has been tested through multilocational testing and several lines with high levels of rust resistance are available (ICRISAT, 1987) for utilization.

Resistant utilizatiou : Resistance to rust in pearl millet line ICML 11 (IC 2696-1-4) is reported to be governed by a single dominant gene (Andrews *et al.*, 1985; Singh *et al.*, 1987a). Resistance to rust in a wild species, *P. americanum* sub sp. *monodii* has also been reported to be governed by a single dominant gene (Hanna,

1987; Hanna *et al.*, 1985). Rust resistance is being utilized at ICRISAT Center in hybrid breeding program by transferring resistance into the hybrid parents (Rai and Singh, 1987).

Resistance selection through tissue-culture technique

Tissue culture technique has tremendous potential for selection and development of novel disease-resistant plants. Attempts have been made to select ergot resistant lines of pearl millet, using sclerotial extract and culture filtrate of *C. fusiformis* as selective agent (Bajaj *et al.*, 1980; Sharma and Chahal, 1988). Regenerants have successfully been isolated from the surviving callus masses of susceptible pearl millet lines repeatedly exposed to the culture filtrate. The regenerated plants showed improved resistance to levels of 15 to 92 per cent higher than the original susceptible line (Chahal and Sharma, 1988). Downy mildew resistant plants have also been generated from infected tissue-callus (Prasad *et al.*, 1984). Further work is needed to refine the technique to obtain disease resistant genotypes in pearl millet.

Multiple disease resistance

Growing cultivars with multiple disease resistance is the most effective means of reducing the yield losses due to diseases. Several sources of resistance for two or more diseases are available (Thakur *et al.*, 1988), which can be utilized in a breeding program to evolve multiple disease resistant varieties (Table 5). Transferring

Table 5. Sources of multiple disease resistance in pearl millet

Line	Ergot severity (%)	Smut severity (%)	Downy mildew incidence (%)
ICMPE 13-6-30	1	1	11
ICMPE 34-1-10	6	1	1
ICMPE 134-6-25	1	0	1
ICMPE 134-6-34	1	0	1
ICMPES 2	1	0	2
ICMPES 9	7	1	8
ICMPES 15	1	0	3
ICMPES 16	2	0	3
ICMPES 23	1	0	2
ICMPES 28	4	0	2
ICMPES 32	7	0	2
ICMPES 34	1	1	1
ICMPES 37	1	1	1
BJ 104 (Check)	67	54	48

Source : Thakur & Chahal, 1987

multiple resistance in individual parents could be a difficult proposition, but can effectively be done in a population program, through recurrent selection (Thakur, 1987).

Concluding Remarks

Integration of disease management practices with the crop management system is an ideal way of reducing losses due to diseases, and increasing crop yield. Development of a disease management system based on sound knowledge of host, pathogen and environment, and their interactions in a given agroecosystem should provide the best control strategies. For fungal diseases of pearl millet which are seed-, soil- and airborne cultural practices, chemical control and host resistance can be applied either singly or in combination.

Diversity creates stability in both natural- and agroecosystem. From the perspective of plant disease management, the most important type of diversity in the egroecosystem is genetic diversity in the crop species, both temporal and spatial. It is well knvwn that monocultures have reduced the spatial genetic diversity in the top species. Fortunately, pearl millet is very rich in genetic diversity both from ecological and reproduction points of view. Open-pollinated varieties provide tremendous genetic buffering against hosts of pests and diseases. However, single-cross hybrids take off that genetic advantage and make the cultivars susceptible to pests and diseases.

Disease management strategies must utilize the concept of introducing diversity selectively to maximize the role of biological and physical factors in stabilizing pathogen population at levels below thresholds.

Host-plant resistance combined with fungicidal seed treatment to control downy mildew and other seedling diseases could be most profitable. Research information currently available on pearl millet disease control in India appears to be adequate, but the communication of this information to the farmers is inadequate. Agriculture extension specialists need to educate farmers on growing varieties recommended for a particular region in the country, disease and pest control methods, crop management system and post-harvest problems and their remedies.

Other diseases which are of minor importance, but have the potential to become serious, such as leaf blast (*Pyricularia penniseti*), Cercospora leaf spot (*Cercospora penniseti*), Curvularia leaf spot (*Curvularia penniseti*), should be monitored regularly at the experiment stations and farmers' field to realize their potential threat to cultivars. No information is currently available on the economic importance of any virus, bacterial and nematode diseases, and these also need to be monitored.

Further research efforts are needed on application of various genetic engineering methods to isolate and incorporate resistance genes; biocultural control, like pollen management for ergot; and biological control through mycoparasitism. Several new methods available to identify pathotypes and races should be explored. Interdisciplinary research efforts can be useful to develop effective disease control methods that would be a part of a crop management program.

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