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Review Article

The role of new plant protection technologies in pearl millet improvement -A Review

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Abstract

Pearl millet [*Pennisetum glaucum* (L.) R.Br.] is one of the oldest cultivated crops of Asian and African countries. This millet is one of the most important with greatest potential of all the millets which provide staple food for millions of people in semi-arid tropics (SAT) regions. Due to its wider cultivation, it is prone to various pathogenic diseases. In the present review article, an attempt has been made to study the various pathogens affecting Pearl millet and various methods of their control.

Key words: Pearl millet, pathogens, disease and crop management, agricultural technologies

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Pearl millet [*Pennisetum glaucum* (L.) R.Br. is among the oldest cultivated crops of Asian and African countries. This millet is one of the most important with greatest potential of all the millets which provide staple food for millions of people in semi-arid tropics (SAT) regions. It is an important crop in the semi arid and tropical parts of the world, grown annually on about 26 million ha, 42 per cent of which are in India. This coarse grain is considered as poor man's food especially for working class. Besides grain, the fodder of this crop is of excellent quality. Pearl millet is fourth important food crop after rice, wheat and sorghum, grown in varying ecological environment of low to high productivity levels. Because of its adaptability to drier and low fertile conditions, pearl millet has comparative advantage over other coarse cereals in these environments and thus is an important component of food security in country. The crop is nutritionally rich with a good balance of starch, protein, fat, rich in iron, phosphorus, B-complex vitamins and fibre content and hence provides 11–12 % of worlds' supply of protein [1]. Currently 65 % pearl millet area is under high yielding varieties. As a result of its importance, during last 25 years, 115 improved pearl millet cultivars have been released. Due to its adaptability under very wide range of agro-climatic conditions this crop is mostly grown in the states of Andhra Pradesh, Gujarat, Haryana, Karnataka, Madhya Pradesh, Rajasthan, Tamil Nadu, parts of Delhi, Punjab and Uttar Pradesh. In India, the total production of crop was 10.28 m ton with area of 8.78 m ha during 2011-2012 and the productivity at national level is 1171 Kg/ha.

Pearl millet is also one of major kharif crop of Haryana with area of 5.78 lakh ha and total grain production of 11.80 lakh ton during 2011-2012 with a productivity of 2034 Kg/ha. Plant pathological research in pearl millet did not receive adequate attention until the F1 hybrids, based on cytoplasmic genic male sterile line, released for commercial cultivation in India in the mid-1960s and became susceptible to downy mildew in early 1970s. The superiority of high yielding cultivars over open-pollinated varieties for grain yield, uniform growth and shorter duration resulted in substantial increase in area under hybrid cultivation and this favoured incidence of diseases. The crop yield is adversely affected by several biotic factors. More than 100 diseases caused by fungi, bacteria, viruses, nematodes have been reported and they cause substantial yield losses and also adversely affect the quality of the produce and thus reduce its market value.

Among various diseases of pearl millet, downy mildew *(Sclerospora graminicola* (Sacc.) Schroet), smut *(Tolyposporium penicillariae* Bref.) and ergot *(Claviceps fusiformis* Loveless) are of economic importance in major pearl-millet growing areas of the country. In the light of above, there is need to understand the symptoms and epidemiology of major diseases of pearl millet and their management practices particularly through (integrated disease management (IDM/IPM).

Downey Mildew

Downy mildew pathogen was first reported on pearl millet in India in 1907 by Butler. Disease remained sporadic until 1970s. The first pearl millet hybrid HB 1 (tift 23A x Bill 3B) was released in India in 1965 closely followed by HB-2 and HB-3. Due to these hybrids, there was a quantum jump in yield and India harvested a record grain yield of 8.2 million tonne in 1970-71. In the following years, a severe and wide spread epidemic of downy mildew occurred and reduced the grain yield to about 4.5 million tonne. Even the land races which normally were not damaged become seriously diseased due to the spread of inoculum by cultivation of susceptible F1 hybrids continuously in larger areas.

Yield losses ranging from 10-60 per cent have been reported due to downy mildew in India by many workers. The pathogen population rapidly adapts to the genetically uniform host, inoculum levels build up and epidemic then occurs when favourable weather conditions prevail.

Two types of symptoms, downy mildew and green year are produced. Downy mildew symptoms may appear on the first leaf and generally on 2nd and 3rd leaf in the form of chlorosis of leaf lamina beginning at the base of the leaf. It progresses to the subsequently higher leaves under high humidity (>85%) and moderate temperature (20-25°C). Chlorotic areas on leaves produce abundant asexual sporulation generally on lower leaf, giving them a downy appearance. Severely affected plants remain stunted and do not produce panicle. After leaf symptoms develop, all the subsequent leaves and the panicle have symptoms due to systemic nature of the disease except in case of recovery mechanisms.

Green ear symptoms appear on panicles due to the transformation of floral parts into leafy structure. The host genotype, time of expression and ambient conditions may influence type of symptoms [2].

The infected leaves produce sexual spores (oospores) in the necrotic leaf tissue late in the season. Infection occurs at the seedling stage from the soil borne oospores and systemic symptoms as chlorosis generally appear on the second leaf and on all the subsequent leaves. Seedlings die under severe infection and panicle produced on the infected plant develop green ear. The oospores remain viable for up to 10 years [3, 4], secondary infection occurs by sporangia produced on the previously infected plants. The apical meristem is the most vulnerable site of infection for zoospores. Zoospores emerge through a pore produced by the release of an operculum. Zoospores swim for 30–60 min, encyst, and then germinate by forming a germ tube. Sometimes zoospores may germinate within the sporangium [5]. Zoospore release from the sporangia occurs at a wide temperature range (10–45 °C); liberation is optimum at 30 °C in about 2 h 40 min. Zoospores retain their infectivity for about 4 h at 30 °C and for a longer period at lower temperatures [6]. Low temperature, high relative humidity and well distributed rainfall are critical factors for infection by *S. graminicola* and for the development and spread of disease in the crop [7,8]. The pathogen reproduces both by sexual and asexual processes. Sporangia, the asexual spores produced on the infected leaves, germinate to release motile zoospores. Zoospores germinate and initiate infection. Oospores, the sexual spores are produced by two compatible mating type thalli in the infected leaf tissue. *Sclerospora graminicola* is also seed-borne, externally in the form of oospore contamination and internally as mycelial infection in embryo [9]. Oospores are produced in the infected necrotic tissue which fall in the soil and serve as source of primary inoculum for the next crop.

Integrated disease management methods for Downey Mildew pathogens

Host resistance

Use of downy mildew resistant cultivars has been most economical and effective means of managing this disease in farmers' field. Well planned intensive research during the past three decades has resulted in the development of highly effective field and lab screening technique, identification of several sources of resistance and development of several downy mildew resistant cvs like HHB-60, HHB-67, HHB-68, HHB-94, HHB-117, HHB 146, HHB 197, HHB 223, HHB 256, HC-4, HC-10 and HC-20 and many others at different places. Angarawai et al [10] reported that the inheritance of downy mildew in pearl millet is quantitative, highly heritable and would respond to selection. This could be further facilitated by modern biotechnological tools such as marker-assisted breeding techniques. Marker-assisted backcross breeding technique was employed to circumvent the breakdown of host resistance [11].

Plant disease resistance genes show significant similarity among their sequences with the presence of conserved motifs common to the nucleotide-binding site (NBS). Oligonucleotide degenerate primers designed from conserved NBS motifs encoded by different plant disease resistance genes can be used to amplify resistance gene analogues (RGAs) corresponding to the NBS sequences from the genomic DNA of various plant species. Using this approach 22 RGAs were cloned and sequenced from pearl millet [12,13]. Phylogenetic analysis of the predicted amino acid sequences grouped the RGAs into nine distinct classes. GenBank database searches with the consensus protein sequences of each of the nine classes revealed their conserved NBS domains and similarity to other known R genes of various crop species. One RGA 213 was mapped onto LG1 and LG7 in the pearl millet linkage map. Accumulation of the transcripts of this RGA during infection with *S. graminicola* in resistant pearl millet seedlings indicated its involvement in resistance mechanism against downy mildew [14].Further studies indicated that this RGA encodes a putative ser-thr protein kinase [15].

Cultural

These methods include sanitation, roguing, early sowing, transplanting, crop rotation etc. Use of disease (oospores) free seed, burning plant debris soon after harvesting and deep ploughing to expose oospores to high summer temperature can go to great extent in reducing initial infection. An early sown crop gets less downy mildew than late sown because prevalence of relatively high temperature (>30^{0}C) and low relative humidity of around 60%. Similarly, a transplanted crop has been shown to develop significantly less downy mildew. But this method is effective on small scale farming. Roguing and destruction of infected plants between 15-20 days after sowing has been recommended to reduce secondary infection. Field sanitation also reduces the amount of initial inoculum for the next crop. Use of clean disease free seed is one of the simplest methods of managing disease.

Chemical

Seed treatment with Metalaxyl @ 2g a.i. / Kg seed has been very effective in controlling downy mildew. The fungicide is systemic in nature and thus eliminates seed borne infection and protects from seedling infection from sporangial infection for about 25-30 days after sowing. Seed treatment (Apron SD 35@ 6g/Kg seed) followed by a foliar application of Ridomil MZ (2g a.i. / litre) has been recommended for complete control of this disease. Hot water treatment of seed at 55°C for 12 minutes following by drying in shade has also been found very effective.

Biological

Fusarium semitectum has been reported to severely parasitize oospores which become deformed and lost viability. This will reduce the source of primary infection. *F. equiseti* and *Dreschslera setariae* have found to colonize saprophytically and destroy infected areas. There are reports that many attempts have been made in which seed treatment with talc-based formulation of *Trichoderma* spp. (4 g/kg) and *P. fluorescens* (10 g/kg) and peat-based formulation of *Bacillus subtilis* (30 g/kg) were made and found that *P. fluorescens* treatment reduced the disease incidence to 9.50 % Integration of host plant resistance, cultural methods and seed treatment through systemic fungicides can provide an effective management of downy mildew.

Smut

It is an important disease in various parts of India and western Africa. Although present in almost all countries where crop is grown, no epidemic have been reported so far. It is more severe in CMS-based single cross hybrids than in open-pollinated varieties. The extent of losses caused by this disease is quite variable. The estimated grain yield loss due to smut is 5-20 per cent; although it can be higher under favourable conditions of susceptible host, environment and inoculum load [16].

Smut symptoms initially appear as green sori in the infected florets. These sori are generally larger than grains and appear as oval to conical bodies projecting beyond the glumes. The sori are bright green initially and later they turn brown to black. The sori are covered by a thin membrane which breaks at maturity to release spore mass. In panicle, having poor head exertion, the lower portion covered by the sheath of the flag leaf is frequently heavily infected with smut. Infection on a panicle may appear scattered or a bunch of florets get

infected at few places.
Smut infection begins from soil and seed borne inocula. Teleutospores from the previously infected florets are left in the soil and seeds get contaminated at the threshing floor. Under favourable conditions of soil moisture and temperature the teleutospores germinate in soil and produce numerous air borne sporadia. These sporadia land on the flowering panicles and initiate infection through young emerging stigma. Rapid pollination is known to reduce or even prevent smut infection. Dark green shining sori appear two weeks after infection and sori mature within next two weeks. Mature sori rupture to release masses of spore balls which germinate to produce second crop of sporodia. These sporodia play a major role in secondary spread of the disease. Infection and spread is most favoured by the prevalence of high relative humidity (>80%) and optimal temperature (25-30^{0}C) at the flowering stage of the crop. The spread of the disease from the early planted to the late planted crops through teleutospores has been observed.

Management methods for Smut infection

Host resistance

Like downy mildew of pearl millet, smut can also be best managed through genetic resistance. An effective field screening technique is available to identify resistance and breed resistance cultivars. A smut resistant open pollinated cv. ICMV-82132 named as 'Kaufela' has been released for cultivation in Zambia. Recently ICMA-88006 has been identified as the first smut resistant male sterile line and is also resistant to downy mildew and has high seed yield. Resistance to smut is dominant and simply inherited. Rai and Thakur [17] reported that the probability of producing resistant hybrids would be higher when both parents were resistant to smut. Thus, improvement in smut resistance of parental lines and fertility restoration ability of pollinators would provide the most effective genetic approach to smut disease management in hybrids.

Chemicals

Seed treatment with fungicides is not effective since the disease is not exclusively seed borne. Significant control of smut using vitavax + Plantvax (0.1 %) as foliar and panicle spray has been reported by many workers but these are neither economical nor feasible at the farmers' level. Meena et al [18] reported that hexaconazole 5SE @ 0.1 % and propiconazole 25 EC @ 0.1 % expressed their superiority giving 97.63 and 97.43 per cent disease control respectively over carboxin 75WP @ 0.2% controlling disease 86.54 per cent.

Ergot

Ergot. caused by *Claviceps fusiformis* Loveless, is a widespread and sometimes destructive disease of pearl millet [*Pennisetum glaucum* (L) R. Br.] in the semi-arid tropics (SAT). It is prevalent in large growing areas of Asia and Africa however the disease occurrence and spread is highly influenced by weather conditions prevailing during the flowering time of the crop [19]. Like downy mildew and smut it has become more important due to commercial cultivation of genetically

uniform single cross F1 hybrids based on CMS system in India.
Disease is not as severe and widespread as downy mildew but causes substantial loss both for grain yield and quality under favourable weather conditions. The estimated grain yield loss is reported to be 58-70% in F1 hybrids. Ergot sclerotia which replace grains contain neuro-toxic alkaloids that affect the health of human beings and animals and in extreme cases can result in death. The first epidemic of ergot occurred in 1958 in Satara district of Maharashtra. Ergot disease can be easily identified when cream to pinkish droplets called honey dew ooze out of the infected florets on pearl millet penicles. These droplets contain numerous asexual spores called conidia. Within 10-15 days these droplets dry out and hard dark brown to black structure larger than seed develop in place of normal grains. If the infection is severe then honey dew falls on leaves and some time on the soil giving them a white appearance. During harvesting and threshing these sclerotia get mixed with grain or fall to the ground and serve as primary source of inoculum for the next crop. Following rains these sclerotia· germinate and release numerous ascospores that are carried by air current to flowering pearl millet panicle. These ascopsores germinate and infect the florets through stigma. Under relative humidity (80- 85%) and moderate temperature (20-30^{o}C) with cool night honey dew symptoms appear within 4-6 days and sclerotia become visible within 10-15 days after inoculation. It also survives on wild grasses *(Cenchrus ciliaris, Panicum antidotale* and *Seteria verticillata).* Secondary spread through conidia by insects, wind, rain etc. [20].

Management methods for Ergot infection

Host resistance

Ergot management through genetic means is most effective and economical. Ergot resistance is controlled by polygenic recessive genes, implying that to breed ergot-resistant hybrids, resistance should be incorporated in both male-sterile lines and pollen parents [21, 22]. Resistant lines may be developed by intermating less susceptible plants and selecting resistant progenies under high disease pressure for several generations following pedigree and recurrent selection procedure. Ergot resistant has been incorporated by both the parent and pollinator using back cross breeding.

Male sterile

Male sterile lines such as ICMA-91113, ICMA-91114, ICMA-91115 have produced hybrids with good yield potential and resistant to ergot.

Pollen management

Ergot infection can also be prevented during the time required for germination of pollen and spores of pathogen. Thus, if pollen is lodged on stigma simultaneously with the spores or several hours after, pollen germinate and pollen germ tube reaches the ovary much faster than the germ tube of ergot spore. When ovary is fertilized it becomes resistant to infection by ergot pathogen. It is more feasible in open pollinated varieties and land races where flowering continues for a longer time and pollen is available throughout flowering. In contrast in F1 hybrid where flowering is more uniform and synchronous, ergot control is not much effective. It has been demonstrated that if a hybrid is sown as seed mixture or in alternate rows with an ergot resistant, earlier flowering pollen donor line, ergot incidence can be significantly reduced in hybrid [23].

Cultural

One of the best method of controlling Ergot is make use of sclerotia free seed. If the sclerotia are mixed with seed then the sclerotia can be removed by soaking seed in 10% salt solution. In this way sclerotia being light in weight will float on top and then the seeds are washed thoroughly with clean water twice-thrice to remove excess salt. Thus washed seeds are dried in shade which are free from Ergot. The collateral host mentioned above which harbour the pathogen should be removed from the surroundings of the field. Intercropping pearl millet with moong bean has been found to reduce ergot incidence. The crop canopy of mungbean probably intercepts ascospores from reaching penicles and this prevent infective.

Chemical

Two sprays of Cuman L, @0.2% *i.e.* 400 ml in 200 litre of water, first at boot and second at 50% flowering has been found effective but with increasing cost of chemicals and spray equipments and low market price of pearl millet ergot control by application of chemicals may not be economical practice in routine [24].

Biological control

Two spp. of *Fusarium i.e. F. sumbucinum* and *F. semitectum* var. *majus* and *Cerebella andropogonis* parasitize honey dew and sclerotia and significant control has been achieved. Integration of HPR, pollen management, biocontrol and cultural methods can provide an effective management of ergot.

Conclusion

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 disease management system based on sound knowledge of hosts, pathogen and environment and their interaction in a given agro-ecosystem should provide the best control strategies. For the major diseases of pearl millet which are seed, soil and airborne, cultural practices, host resistance, bio-control and chemical control can be applied either singly or in combination. Recovery mechanism with top cross hybrids would be ideal strategies for long terms control of downy mildew in hybrids under farmers' field conditions. Host plant resistance combined with fungicides seed treatment to control downy mildew and other seedling diseases could be most profitable. Information on management currently is adequate, and there is a need to educate farmers on growing varieties / hybrids recommended for a particular regions and disease control methods of crop management system. Other diseases which are of minor importance but may have the potential to become serious such as rust and blast are being monitored regularly to realize their potential threat to cultivars.

Research efforts needed in future

Apart from these, various research initiations such as utilization of tissue culture techniques and MAS (marker assisted selection) for downy mildew, identification of sources of multiple disease resistance and their utilization, identification of source of different type of resistance (Stable, complete and recovery mechanism), development of effective biocontrol methods, utilization of biocultural control like pollen management for floral diseases and understanding the mechanism of breakdown of resistance against downy mildew may also prove to be useful.

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