THE CHANGING SCENARIO OF MAIZE, SORGHUM, AND PEARL MILLET DISEASES

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ABSTRACT

Maize, sorghum, and pearl millet are cultivated as grain, seed, and forage crops in both the rainy and the postrainy seasons in India. Until the 1950s, landraces were grown under traditional cultivation practices without a major threat from diseases. To increase yield, high-yielding and high-input responsive cultivars, particularly the F_1 hybrids, were released in early 1960s. A quantum leap in yield was achieved within a few years. Unfortunately, this change brought to the forefront several diseases that reduced the yield drastically, and became a major threat not only to the high-yielding cultivars but also to the traditional ones. These diseases were Pythium stalk rot (*Pythium aphanidermatum*), Erwinia stalk rot (*Erwinia carotovora*), downy mildews (*Peronosclerospora sorghi* and *Sclerophthora rayssiae var. zeae*), leaf blight (*Exserohilum turcicum*), and rust (*Puccinia polysora*) in maize; grain molds (unspecialized fungi), ergot (*Sphacelia sorghi*), and charcoal rot (*Macrophomina phaseolina*) in sorghum; and downy mildew (Sclerospora graminicola) and ergot (*Claviceps fusiformis*) in pearl millet. Considerable progress has been made for the control of some of these diseases with host-plant resistance and other control measures. While breeding for disease resistance and search for alternative disease control measures continues, constant monitoring of potentially important diseases is needed.

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench), maize (*Zea mays* L.), and pearl millet (*Pennisetum glaucum* (L.) R. Br.) are important cereal crops in India. These crops have been cultivated in India since times immemorial. Because of random selection and open pollination, the genetic constitution of cultivars has been in a state of constant change. As a result, such cultivars had a broad genetic base. This lead to a "buffering effect" against several biotic and abiotic stresses. The absence of any major outbreak of diseases or pests on any of these crops until the 1960s supports this phenomenon. Most of the diseases were present earlier but none reduced the yields significantly. The crops and the plant pathogens remained in a state of equilibrium in which both the hosts and the pathogens survived. Increased population growth in India, particularly after independence, necessitated increased food production. This paper describes the changing disease scenario in maize, sorghum, and pearl millet in India.

DISEASES OF MAIZE, SORGHUM, AND PEARL MILLET

These crops are grown as open-pollinated cultivars. Selection was made by the farmers, particularly to increase yield. Open pollination, as a rule, provided a broad genetic base. Due to this, the crops had high survival values even under severe stress conditions. This resulted in low but stable yields. A literature survey revealed that these crops are susceptible to a large number of diseases caused by various biotic factors (Table 1). Pearl millet, although considered to be comparatively less susceptible to diseases, is infected by a large number of diseases. Fungi are the most important pathogens on these crops. Amongst the other pathogens, a few bacterial and viral diseases are important on maize. Many nematodes have been reported but none is currently considered to be of any economic importance. However, only a few diseases are potentially important on each of these crops (Table 2).

Genetic diversity in landraces of these crops was the major reason for little or no disease problems. Due to this genetic diversity, the pathogens survived but never caused economically important crop losses. The other contributing factors were the traditional cultural practices and low inputs. Irrigation, for instance, was not available. Similarly, chemical fertilizers, which are now known to enhance development of several diseases, were also not available. Also, all these crops were grown in the main cropping seasons and over-lapping cropping was unknown. Thus, there was no carry-over of pathogens, particularly of viable asexual spores.

THE ESTABLISHMENT OF THE COORDINATED PROGRAMS

Population growth in India increased rapidly after independence. To meet the growing demand for food and to reduce dependency on imported food, the Indian Council of Agricultural Research conceived the idea of establishing "All India Coordinated Projects" for crop improvement. As a result, All India Coordinated Projects were established first for maize in 1957 and then for other crops including sorghum and millet (Singh, 1980). Intensive research was initiated by the establishment of these programs. The three major objectives of these programs were to produce crop cultivars that were short statured (particularly for sorghum and pearl millet), early maturing, and responsive to high inputs. The products of these programs were hybrids and varieties. These improved cultivars gave a quantum leap in yields of sorghum and pearl millet (Safeeulla, 1977; Singh et al., 1987). As a result, production increased substantially. However, these changes in cultivars were associated with a change in plant disease scenario. Disease epiphytotics occurred on the improved cultivars, and, due to increased inoculum levels, the traditional cultivars as well as the local landraces were threatened by these diseases. The diseases that were present but not important prior to the beginning of the crop improvement programs and those that became important later are presented in Table 3.

Table 1. An inventory of maize, sorghum, and pearl millet diseases in India

	Number of diseases caused by					
Crop	Fungi	Bacteria	Virus	Nematode	Phanerogamic and non-parasitic	Total
Maize	48	4	3	6	-	61
Sorghum	66	2	6	22	5	101
Pearl millet	75	4	2	29	1	111

Source: Taar (1962), Ramakrishna (1963); Madan Mohan *et al.* (1978); and Payak and Sharma (1980).

Table 2. Important diseases of maize, sorghum, and pearl millet in India

Crop	Fungi	Bacteria	Virus	Nematode	Phanerogamic diseases	Total
Maize	9	1	1	-	-	9
Sorghum	12	-		-	1	13
Pearl millet	4	-			1	5

Source: Rangaswamy (1975)

Table 3. The relative prevalence (PR) and economic importance (EI) of maize, sorghum, and pearl millet diseases in India before and after the 1960s

Disease and causal organism	Prior to 1960s		Between 1960s and 1990		Remarks
	PR	EI	PR	EI	
Maize					
I. Seed Rot, Seedling Blight and Root Rot Diseases (Several unspecialized fungi such as *Sclerotium rolfsii* (Sacc.) Curzi, *Fusarium moniliforme* Sheld., *Cephalosporium acremonium* Cord. Gams, *Pythium aphanidermatum* (Eds.) Fitzp., etc.	-	-	+	3	Potentially reduces plant population especially in Himalayan region during Kharif, and in northern India during Rabi because of cold climate
II. Foliar Diseases					
Maydis leaf blight (*Helminthosporium maydis*) Nisikado	++	3	+++	3	Tolerant hybrids and composites available in different maturity groups for cultivation
Turcicum leaf blight (*Exserohilum turcicum*) (Pass.) Leonard & Suggs.	+	2	+++	4	A potential disease of concern and can become widespread in maize growing regions.
Carbonum leaf spot (*Helminthosporium carbonum*) Ulstrup	-		+	2	Sporadic but never became serious in maize production areas
Other Helminthosporium leaf spots (*Exserohilum rostratum* (Drechsl.) Leonard & Suggs emend Leonard, *H tetramera* McKinney, *Drechslera hawaiiensis* (Bugnicourt) Subram. & Jain ex. M.B. Ellis.	-	-	+	1	Occasionally present and can rarely cause significant loss
Banded leaf and sheath blight (*Rhizoctonia solani*) Kuhn	-	-	+++	3	Of increasing importance, causes significant loss in maize production in high rainfall areas during rainy season
Phaeosphaeria leaf spot (*Phaeosphaeria maydis* (P. Henn.) Rane, Payak & Renfro	-		++	2	Widespread in eastern and central Himalayan hills and foot hills.
Brown spot (*Physoderma maydis*) Miyake	+	3	+	2	Prevalent in Rajasthan, Himachal Pradesh, J & K and U.P. Resistant sources can be utilized to minimise the loss in case the disease becomes severe, in future
Anthracnose (*Colletotrichum graminicola* (Ces.) Wilson,			+	2	Sporadic, some of them are of increasing importance but have never caused significant loss in any maize growing region of the country
Cercospora leaf spot (*Cercospora sorghi* Ell. & Ev.)	-	-	++	2	

Pallescens leaf spot **(*Curvularia pallescens* Boedijn.)**	-	-	++	3	
Other leaf spot diseases **(*Curvularia clavata* Jain, *Pithomyces maydicus* (Sacc.) Ellis, *Phylosticta zeae-maydis* Saccas, *Gloeocercospora sorghi* Bain & Edgerton, *Aschochyta* species, *Dedymella exitiales*, (Mor.) Muller, *Diplodia macrospora* Earle.).**	-	-	+	2	
Rubrilineans Bacterial leaf stripe (*Pseudomonas* spp.) maize fields during rainy season.	-	-	+	2	Sporadic in occurrance. Sometimes can cause significant loss in occasional
Downy Mildew Diseases					
Brown stripe downy mildew (*Sclerophthora rayssiae* Kenneth var. Zeae, Payak and Renfro. maturity groups released for commercial cultivation. Chemical control by metalaxyl seed treatment.	-	-	+++	4	Important in high rainfall areas of northern India during rainy season. Resistant maize cultivars of different
Philippine downy mildew (*Peronoslcerospora philippinensis* (Weston) Shaw	+	2	++	2	Prevalent in sporadic form in north Indian states, except Rajasthan. Effectively controlled by metalaxyl seed treatment
Sugarcane downy mildew (*Perenosclerospora sacchari*) (T. Meyokw & Ito) Shaw	+	2	++	3	
Sorghum downy mildew (*Peronosclerospora sorghi*) Weston & Uppal	+	3	+++	4	Prevalent in South India and Rajasthan. Effectively controlled by metalaxyl seed treatment. Resistant sources are available
Stalk Rot Diseases					
Pythium stalk rot (*Pythium aphanidermatum*) (Eds.) Fitzp.			+	3	Restricted to high rainfall areas and comparatively more prevalent in heavy soils
Charcoal rot (*Macrophomina phaseolina*) (Tassi) Goid	+	1	+++	4	Reduces both quality and quantity of grains, and dry fodder in Kharif as well as Rabi crop seasons, especially if rainfall is scanty at post-flowering stage.
Fusarium wilt and stalk rot (*Fusarium moniliforme* Sheld.)			++	3	Potentially important diseases in light soils and can cause significant grain yield losses during Kharif season
Black bundle disease (*Cephalosporium acremonium* Cord. Gams	-	-	++	3	
Late wilt (*Cephalosporium maydis* Samra, Sabet & Hungorani			+	3	Of increasing importance and can cause significant grain yield losses, especially during Rabi cultivation
Other fungal stalk rot diseases (*Botryodiplodia theobromae* Pat., *Candida tropicalis* (Cast.) Berkhout.,		-	+	++	Sometime widespread. However, never became serious threat to maize cultivation

	Diplodia maydis (Berk.) Sacc.					
	Erwinia stalk rot (*Erwinia carotovora* (Jones) Holland f. sp. *zeae* Sabet	-	-	++	4	Prevalent under hot humid conditions during rainy season, causes significant loss and a threat to maize production
	Other bacterial stalk rots (*Erwinia dissolvens* Rosen) Burkh. *Pseudomonas lapsa* (Ark) Starr & Burkh.	-	-	+	2	Of occasional importance
V.	**Rusts and Smuts**					
	Common rust (*Puccinia sorghi* Schw.)	++	2	++	4	Prevalent in hilly tracts during Kharif and north-west plains of north India and peninsular India during Rabi
	Polysora rust (*Puccinia polysora* Underw)	-	-	+	2	Observed recently in Karnataka, occurring possibly in north-east region and Sikkim since 1965, of increasing importance
	False smut (*Ustilaginoidea virens* (Cke) Tak	+	2	+	2	Of occasional importance
	Common smut (*Ustilago maydis* (DC) Cda	+	2	+	2	
	Head smut (*Sphacelotheca reiliana* (Kuhn) Clinton	-		++	3	Widely spread in Himachal Pradesh and other hill regions, but never became serious threat to maize production
VI.	Ear, Cob and Kernel Rot Diseases (*Rhizoctonia zeae* Voorhees, *Gibberella fujikuroi* (Saw.) Wr., *Nigrospora oryzae* (Berk. & Br) Petch, *Fusarium graminearum* Schw , *Diplodia maydis* (Berk). Sacc. *Diplodia macrospora* Earle, *Aspergillus niger* Von Tieghen, *Macrophomina phaseolina* (Tassi.) Goid, *Botryodiplodia theobromae* Pat.		-	++	3	Prevalent during Kharif season, if rainfall coincides with ear development
VII.	**Virus Diseases**					
	Maize stripe or chlorotic stripe (Maize mosaic virus I)	-	-	+	2	Needs watch.
	Vein enation	-	-	+	2	Needs watch
	Mosaic (Sugarcane mosaic virus)		-	++	3	Is of increasing importance especially in spring maize cultivation
VIII.	**Nematode Diseases**					
	Maize cyst nematode (*Heterodera zeae*)Koshy, Swarup & Sethi	-		++	3	Restricted in maize growing areas of Rajasthan and other areas where soil is light.
	Other parasitic nematodes (*Pratylenchus zeae* Graham, *Tylenchorhynchus vulgaris* Upadhyay, *Helicotylenchus dihystera* (Cobb) Sher, *Hoplolaimus indicus* Sher, *Meloidogyne incognita* (Koford & White) Chit.	-		+	2	Needs watch

Sorghum

I.	Head and Seed Diseases, Grain Mold (several unspecialized fungi)	+	1	+++	4	Potentially reduces both quality and quantity of the short duration sorghums in rainy season.
	Ergot or sugary disease (*Spahacelia sorghi* (Mc Rae)	+	1	++	2	Specifically important and a threat to hybrid seed production.
II.	Foliar Diseases Anthracnose (*Colletotrichum graminicola* (Cesti.) Wilson,	+	1	++	3	Of increasing importance, causes significant loss along with zonate and other leaf spots to fodder sorghums.
	Zonate leaf spot (Gloeocercospora sorghi24 (Bains and Edgerton.	+	1	++	2	
	Leaf blight (*Helminthosporium turcicum* Pass.)	-	-	+	3	Of occasional importance.
	Rust (*Puccinia purpurea* Cooke)	+	1	+++	3	Of increasing importance in postrainy season sorghums.
III.	Downy Mildews Sorghum downy mildew (*Peronosclerospora sorghi* Weston and Uppal	+	1	++	2	Sporadic, effectively controlled by chemical seed dressings.
	Crazy top (*Sclerophthora macrospora* (Sacc.) Thirum; Shaw and Naras.	+	1	+	1	
IV.	Virus and Mycoplasm					Virus diseases are of growing importance.
	Maize dwarf mosaic	-	1	++	2	
	Maize stripe virus	-	-	++	2	
	Sugarcane mosaic	-	-	++	2	
	Potyvirus (?)	-	-	++	2	
V	Stalk Rots and Root Rots Charcoal rot (*Macrophomina phaseolina* (Tassi) Goid	+	2	+++	4	Hybrids and high yielding cultivars are supersusceptible.
	Acremonium wilt (*Acremonium strictum* Gams.)		-	+	2	Needs watch.
	Stalk and top rot (*Erwinia chrysanthemi* Burkh., McFadden & Dimoc	-	-	+	2	Restricted to high rainfall areas.
VI.	Smuts Head smut (*Sphacelotheca reiliana* (Kuhn) Clinton)	+	1	++	2	Smut, although widespread, never became a serious threat to sorghum production.
	Loose smut (*Sphacelotheca cruenta* (Kuhn) Potter)	+	1	++	2	
	Covered smut (*Sphacelotheca sorghi* (Link, Clinton)	+	1	+	1	

Long smut (*Tolyposporium ehrenbergii* (Kuhn) Potouillard)	+	1	++	2	
Pearl Millet					
Downy mildew (*Sclerospora graminicola* (Sacc.) Schoet.	+	1	+++	4	Continues to be the major constraint to production of F_1 hybrids
Ergot (*Claviceps fusiformis* Loveless,	+	2	+	2	Distribution is limited, but when occurs spoils grain quality, rendering the product unfit for consumption
Smut (*Tolyposporium penicillariae*) Bref.	+	2	+	2	Has limited occurrence
Rust (*Puccinia penniseti* Zimm	++	2	+++	2	Generally comes after grain filling. The losses may not be substantial. However, if comes in early stage, has potential to cause considerable damage
Blast (*Pyricularia setariae* Nisikado)	+	1	+	1	So far this is not considered a yield reducing factor on an overall basis

PR = prevalence
- \- not reported
- \+ occasionally present
- ++ commonly present
- +++ generally found on most plants in most fields.

EI = Economic importance:
- 1 causing no losses
- 2 minor importance
- 3 moderate importance
- 4 Represents a major deterrent at times to crop production

FACTORS AFFECTING SUSCEPTIBILITY TO DISEASES

A detailed analysis of the crop improvement programs in India clearly suggests that the programs were dominated by breeders. Because of this, the host was "over emphasized" and the pathogen was "under emphasized". To support this point, we cite the classical example of pearl millet improvement and the subsequent downy mildew epidemics in India. To improve yield several F_1 hybrids based on Tift 23A, male sterile line were released for commercial cultivation in India. Neither the male sterile line nor the hybrids were tested for their disease reaction. This resulted in severe downy mildew epidemics in 1971-72 to date (Singh *et al.*, 1987). Unfortunately, the potential of many diseases as yield reducing factors was not considered at that time.

Another important factor was the use of high input production practices. Since the improved cultivars were developed for high input conditions, farmers were encouraged to use fertilizers to increase production. Irrigation helped to increase yield but created a microclimate conducive to disease development. Several factors resulting in greater disease incidence are discussed below.

Genetic Uniformity

One of the most important products of crop improvement programs is F_1 hybrids. These have a narrow genetic bases. Therefore, the pathogen can easily adapt to these cultivars, and within a period of 3-4 years, a resistant hybrid may become susceptible. This has happened with downy mildew of pearl millet (Singh *et al.*, 1987) and brown stripe downy mildew of maize (Sangam Lal, Personal communication).

Ergot (*Claviceps fusiformis*) of pearl millet was not a serious disease in India prior to the advent of hybrids, except in certain areas. This was due to the cultivation of local cultivars in which flowering was spread over a long period. However, F_1 hybrids, which flower synchronously, if flowering occurs during a rainy period and ergot inoculum is available, severe ergot develops. Occasional but severe epidemics of ergot have occurred on F_1 hybrids in India.

Early Maturing Cultivars

Prior to the beginning of crop improvement programs in India, grain molds were never a problem in sorghum. Cultivars were photoperiod sensitive, and of long duration in which the grains matured only after the rains ceased. These cultivars had low to modest yields, with limited adaptation outside their natural habitat, and often failed to produce grains if rains ceased early (Bandyopadhyay *et al.*, 1988). In order to increase yield, short- to-medium duration cultivars were developed. These cultivars are photoperiod insensitive and widely adapted, but mature during the rainy season. This favors development of grain molds, which is the most important problem in sorghum production at present. Several leaf diseases of maize also became important after the introduction of early maturing cultivars (Sangam Lal, personal communication).

Change in the Growing Season

Winter cultivation of maize in India is a relatively recent development. Initially, no serious diseases were observed on winter maize. However, turcicum leaf blight (*Helminthosporium turcicum*) is now an important disease in Bihar and also in the Tibetan colony in the Mysore area. Similarly, rust on maize (*Puccinia sorghi*) in Punjab, Haryana, and eastern Uttar Pradesh, and post-flowering stalk rots, particularly charcoal rot (*Macrophomina phaseolina*) in Peninsular India, have become important (Sangam Lal, unpublished data).

Seed Production in Off-season

With the release of F_1 hybrids for commercial cultivation, the seed of these hybrids is produced during the off-seasons, and in areas where the crop was not cultivated previously. For the production of F_1 seed of sorghum, the crop is grown during the postrainy season when temperatures generally are lower. Frequent irrigation increases humidity in the crop canopy. High humidity and low temperature favor the development and spread of the ergot pathogen (*Sphacelia sorghi*) in sorghum. This is an important disease on the off-season seed crop. Likewise, pearl millet rust (*Puccinia penniseti*) has become a potential problem in seed crop in Gujarat from February to April.

RECENT ADVANCES IN DISEASES MANAGEMENT

The cereal crops discussed in this paper received major research thrust in the 1960s, and, all of them are the mandate crops of the International Agricultural Research Centers (IARCs). Therefore, considerable research efforts have been made by the IARCs and the Indian National programs. Some examples of successful disease control are given here.

Downy mildew was a devastating disease of pearl millet hybrids in India during 1970s (Singh *et al.*, 1987). Because of the availability of reliable screening techniques, resistant sources were identified and several disease-resistant cultivars were released. The resistant cultivars are now used by the farmers. Although epidemics of this disease continued to occur in the 1980s, these were less frequent and over smaller geographical areas. This has reduced the crop losses caused by downy mildew. Brown stripe downy mildew of maize was also a severe problem, particularly in northern India. However, the disease is now controlled by using resistant cultivars. The same is true for *Peronosclerospora sorghi* on maize.

One of the major developments of the last two decades has been the availability of a systemic fungicide - metalaxyl. This fungicide effectively controls downy mildews when used as a seed treatment at 2 gm (a.i.) kg^{1} of seed (Singh, 1983; Singh and Shetty, 1991). The fungicide can also control the disease after it has become established (as a systemic infection) if applied at the right stage (Singh *et al.*, 1984).

Turcicum leaf blight of maize is now under control with the use of resistant cultivars. Leaf and sheath blight of maize are now successfully controlled by cultural practices. Seed rots can be effectively controlled by seed treatment with fungicides. Sufficient data are now available to show that stalk rot (*Macrophomina phaseolina*) in maize can be controlled by reducing water stress at flowering time (Sangam Lal, personal communication).

FAILURE OF DISEASE CONTROL

There are several cases where we have failed to control diseases. Disease control measures have not been developed for grain molds and charcoal rot in sorghum, ergot in pearl millet, and stalk rots (several) in maize. Unfortunately, all of these destructive diseases are highly important and have global significance.

Our failure to control these diseases has been due to several reasons. Resistance, which is the most economical method of disease control, has either not been found or is only present in low frequencies, and is not easy to utilize. Also, use of fungicides is not recommended because this may interfere with the process of pollination in the case of floral diseases. However, the most important reason has been the lack of continued active research programs.

Grain molds and charcoal rot of sorghum, ergot of pearl millet, and several stalk rots of maize are still difficult to control. It is unlikely that these diseases will be controlled by fungicides or by other cultural control methods. Genetic resistance is the only answer. Therefore, it is necessary that these diseases are considered a high priority for future research programs.

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