Archives of Phytopathology and Plant Protection
February 2007; 40(1): 19–35

Taylor & Francis
Taylor & Francis Group

Prevalence of major foliar and panicle diseases of Sorghum (*Sorghum bicolor* [L.] Moench) in the Deccan plateau of India

S. S. NAVI[1], R. BANDYOPADHYAY[2], V. A. TONAPI[3], T. G. N. RAO[3], S. INDIRA[3], R. K. REDDY[4], P. W. TOOLEY[5], & D. THOMAS[6]

[1]*Department of Plant Pathology, Iowa State University, USA,* [2]*IITA, Ibadan, Nigeria,* [3]*NRC for Sorghum, Hyderabad, India,* [4]*ICRISAT, Patancheru, India,* [5]*USDA–ARS, Fort Detrick, Maryland, USA, and* [6]*Tropical Agricultural Systems, NRMD, NRI, Chatham Maritime, Kent, UK*

(Received 29 May 2005)

Abstract
Extensive on-farm disease surveys were conducted from August 1999 until March 2001 in four sorghum-growing states of the Indian Deccan plateau. A total of 965 fields were surveyed covering 228 fields in Andhra Pradesh (AP), 406 in Karnataka (KAR), 290 in Maharashtra (MH) and 41 in Tamil Nadu (TN). Among 14 foliar diseases observed, maize stripe virus (MStV), a *tenuivirus* transmitted by the delphacid plant hopper (*Peregrinus maidis*), and among five panicle diseases, ergot or sugary disease (*Claviceps sorghi* and *C. africana*) were the most destructive diseases. MStV was prevalent in 28.4% and ergot in 13.4% of the fields surveyed in two years across four states. Yet, the mean incidence of MStV in AP was 6% with 85% mean severity. The values in KAR were 12% incidence and 83% severity, in MH 5% and 67%, and in TN 12% and 76%, respectively. The mean incidence of ergot in AP was 34% with 67% mean severity. The values in KAR were 41% and 79%, in MH, 30% and 67%, and in TN 100% and 100%, respectively. Variation in frequency of occurrence of MStV was observed between 1999 and 2001. Variations in frequency could be due to weather factors, vector survival, cropping pattern, and host specificity. The frequency of ergot also was varying among years, locations, seasons and cultivars. An ergot epidemic was observed during the 1999 rainy season in Maachinenipalli village (16°35′N; 78°3′E), Andhra Pradesh. In September 2000, the disease had spread to 13 neighboring administrative zones damaging about 130,000 ha. This paper elucidates the distribution of diseases observed between 1999 and 2001 but does not imply that the diseases are restricted necessarily to a particular zone or location.

Keywords: Claviceps *spp., ergot, maize stripe virus, sorghum, plant hopper*

Introduction

The Deccan plateau region consists of the states of Andhra Pradesh, Karnataka, Maharashtra, Tamil Nadu and Kerala. The term ''Deccan'' comes from the Sanskrit word dakshina, meaning ''the south''. The term Deccan Plateau is sometimes used to indicate the region

Correspondence: V. A. Tonapi, NRC for Sorghum, Hyderabad 500 030, A.P., India. Tel: +91 40 24018651. Fax: +91 40 24016378. E-mail: tonapi@nrcsorghum.res.in

ISSN 0323-5408 print/ISSN 1477-2906 online © 2007 Taylor & Francis
DOI: 10.1080/03235400500320232

south of the Narmada River, and to include parts of Maharashtra and Madhya Pradesh states. On the Deccan Plateau, deep, alluvial black soils that retain moisture for a long time are the basis for much of the region's output of farm products. However, the region also has many farming areas that are covered by thin, light-textured soils that suffer quickly from drought. Whether a crop is made or lost is, therefore, often dependent on the availability of supplementary water from ponds and streams. Major food crops grown in Deccan regions include millet, sorghum, rice, wheat and peanuts.

Sorghum (*Sorghum bicolor* [L.] Moench) is extensively grown for human food, animal feed, fodder and other industrial uses. The major sorghum growing states in India are Maharashtra, Karnataka, Madhya Pradesh, Rajasthan, Tamil Nadu, Uttar Pradesh, Andhra Pradesh and Gujarat. During the growing season the crop is attacked by several plant diseases that affect the quality and nutritive value of the residues, as well as grain and Stover yield (Pande et al. 2003). Grain mold is the most important disease and not only affects the sorghum yield (reduction in grain size, weight) but also quality, nutritional value, grain quality, consumer preference, leading to production of several mycotoxins and secondary metabolites due to several mold fungi (Navi et al. 1999). Sales of crop residues by farmers to Peri-urban milk producers account for 50% of income from cropping in rural areas (Rama Devi et al. 2000). The impacts of diseases on sorghum crop residues results in reductions in milk production and also command lower prices in the fodder market (Rama Devi et al. 2000).

Although there were 14 foliar diseases observed during the surveys, the damage due to maize stripe virus (MStV) of sorghum was the most evident. Similar observations were made through experiments conducted at the International Crop Research Institute for Semi Arid Crops (ICRISAT) (Pande et al. 2003). Similarly, of the five panicle diseases, one of the major panicle diseases of sorghum observed during the surveys was ergot, or sugary disease (*Claviceps sorghi* and *C. africana*). Bandyopadhyay et al. (1996, 1998) said that ergot is a threat to sorghum not only in India but also in Americas and Australia. Ergot is a serious limiting factor in production of hybrid seeds, particularly if seed set in male sterile lines is delayed due to lack of viable pollen caused by no synchronous flowering of male sterile and restorers. Moreover, environmental conditions favorable for disease development are not congenial for rapid seed set, thus making spikelets more vulnerable to ergot attack (Bandyopadhyay 1992). Ergot can also cause widespread damage of male fertile cultivars in farmers' fields when environmental conditions favorable to the pathogen occur at flowering (Molefe 1975; Sangitrao & Bade 1979; Kukedia et al. 1982). Widespread damage by ergot was observed in the Andhra Pradesh state during October 1999 and further spread to 13 neighboring administrative zones in Mahbubnagar district during the 2000 rainy season (Navi et al. 2002a). The objectives of this paper is to inventory diseases of sorghum observed during surveys and re-evaluate the importance of emerging diseases of sorghum (ergot and MStV) through extensive surveys in four major sorghum-growing states in India.

Material and methods

Locations surveyed

Sorghum diseases were assessed on 228 farms in seven districts of Andhra Pradesh state, 406 farms in 17 districts of Karnataka state, 290 farms in 21 districts of Maharashtra state and 41 farms in 5 districts of Tamil Nadu state. Farms were selected to obtain a good representation of administrative zones within each district along the survey route. Latitude and longitude of

each of the fields surveyed were recorded using hand-held global positioning system (© 1993 Magellan System Corporation, San Dimas, California, USA) to map survey locations.

Disease incidence and severity

Incidence and severity of diseases in each field were recorded in three randomly selected areas each measuring approximately 12 m^2. Diseases were recognized by the identification keys of Williams et al. (1978) and Frederiksen and Odvody (2000). Maize mosaic virus (MMV), a rhabdovirus transmitted by the delphacid plant hopper *Peregrinus maidis* (Ashmead), and maize stripe virus (MStV), a tenuivirus transmitted by *P. maidis*, were identified using descriptions of Naidu et al. (1989) and Peterschmitt et al. (1991), respectively. The incidence (%) of each disease was calculated based on the number of plants infected by a disease out of the total plants counted in the area.

Severity of anthracnose (*Colletotrichum graminicola* [Cesati] Wilson), gray leaf spot (*Cercospora sorghi* Ell. & Ev.), leaf blight (*Exserohilum turcicum* Leo and Sug), oval leaf spot (*Ramulispora sorghicola* Harris), rough leaf spot (*Ascochyta sorghina* Saccardo), rust (*Puccinia purpurea* Cooke), sooty stripe (*Ramulispora sorghi* [Ellis and Everhart] Olive and Lefebvre), tar spot (*Phyllachora sorghi* v. Hohnel) and zonate leaf spot (*Gloeocercospora sorghi* Bain & Edgerton) was recorded on a 0 – 100 scale with 10% increments, where 0 = healthy foliar leaves and 100 = severe leaf area damaged. This scale was adopted from scales published in the second world review (de Milliano et al. 1992).

Severity of downy mildew (*Peronosclerospora sorghi* [Weston and Uppal]) was recorded on a 1 – 5 scale (Pande et al. 1997) and the data was converted to a percentage. Severity of MStV was recorded based on the extent of panicle exertion and plant stunting symptoms. The scale used to record the severity for MStV was on a 0 – 100% with 10% increments, where, 0% = normal panicle exertion and no plant stunting compared to healthy plants and 100% = no panicle exertion and severe stunting compared to healthy plant height. However, for panicle diseases (ergot, smuts and grain mold), severity was recorded based on percent damage in individual panicles (0% = healthy and 100% = entire panicle damaged by the disease and/or no grain formation due to diseases).

Results

General observations

Most of the fields surveyed varied in size from 2 – 25 ha. Conditions of the fields varied from well-maintained to poorly maintained and near abandoned depending on availability of resources, climatic conditions for field operations and farmers' priorities. The agronomic practices followed by the farmers were also varied. The majority of the farmers planted local cultivars during the post rainy season (October to November north-east monsoon) and hybrids and local cultivars during the rainy season (June to September south-west monsoon). The surveys were conducted at various crop growth stages from vegetative to post physiological maturity. This also has indicated variable planting dates from location to location, within and/or among the Indian states depending on weather, soil type and availability of seed. If there was no increase in the percent incidence and/or severity during subsequent survey visits, then previous readings were considered as final. In this paper, we have discussed mainly the MStV and ergot diseases of sorghum. The number of fields surveyed and prevalence of MStV and ergot during 1999 – 2000 and 2000 – 2001 surveys in major sorghum-growing states is given in Figures 1, 2a and 2b, respectively.

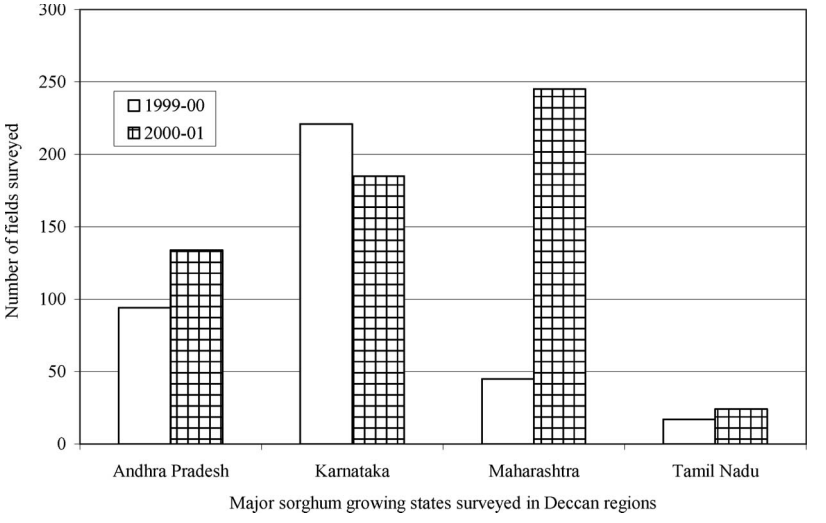

Figure 1. Number of fields surveyed for sorghum diseases from August 1999 to March 2001.

Cultivars

Most farmers in Andhra Pradesh had planted local yellow jowar, local white jowar and ICSV 745 as dual-purpose sorghum during the rainy seasons. Some of the forage sorghums, like SSG 777, SSG 878 and SSG 898, were grown exclusively for fodder purposes in dairy-intensive areas in the Kalwakurthy administrative zone all year. Whereas farmers in Karnataka had planted M 35-1 in the rainy seasons mainly for fodders and rarely for food, hybrids such as CSH 5, CSH 9, CSH 14, MSH 51, MSH 53, MSH 55 and MSH 65 were grown mainly for food either as an intercrop with pigeon pea or sorghum alone. During the post rainy season, M 35-1 was grown predominantly for dual purposes. In Maharashtra, unlike in Karnataka and Andhra Pradesh, during the rainy season local Jowar (Nilva, Motitura [popcorn type], Kaderu, Pandharpuri, Gulbhendi, Pandra piwala) and hybrids (CSH 9, CSH 14, and MSH 51) were observed. During post rainy season, M 35-1, Dagadi Maldandi, Ghat maldandi and other improved varieties were observed on the farmers' fields. In Tamil Nadu, most farmers had planted local Jowar (Namakal solam, Solam, Manjal jolam, Doddamanjal, and yellow jowar), improved Paiyur 1 and TNSH 39. Paiyur 1 was planted for fodder purposes while the rest of the cultivars were planted either for food, fodder or for both.

Diseases prevalence

The most commonly observed foliar fungal diseases in decreasing order of prevalence across states were leaf blight (*Exserohilum turcicum*), anthracnose (*Colletotrichum graminicola*), rust (*Puccinia purpurea*), downy mildew (*Peronosclerospora sorghi*), zonate leaf spot (*Gloeocercospora sorghi*), oval leaf spot (*Ramulispora sorghicola*), rough leaf spot (*Ascochyta sorghina*), sooty stripe (*Ramulispora sorghi*), gray leaf spot (*Cercospora sorghi*), and tar spot (*Phyllachora sorghi*) (Table I). Of the two foliar viral diseases observed MStV was more predominant compared with MMV. Bacterial leaf streak [*Xanthomonas compestris* pv. *holcicola* (Elliott) Starr & Burkholder] was observed both on local cultivars in the farmers' fields and in germplasm accessions at ICRISAT (Navi et al. 2002b).

Figure 2. (a). Prevalence of ergot and maize stripe virus of sorghum (MStV) in Deccan region's states of India surveyed from August 1999 to February 2000.

Similarly, the most commonly observed panicle diseases in decreasing order of prevalence across states were ergot (*Claviceps sorghi* Kulkarni, Seshadri and Hegde and *C. africana* Frederickson et al. 1991), grain mold caused by complex of fungi (Navi et al. 1999), head smut (*Sporisorium reilianum* [Kühn] Langdon & Fullerton, syn. *Sphacelotheca reiliana* [Kühn] G.P. Clinton), grain or covered kernel smut (*Sporisorium sorghi* Link in Wild. [syn. *Sphacelotheca sorghi* (Link) G.P. Clinton]) and long smut (*Sporisorium ehrenbergii* Vánky [syn. *Tolyposporium ehrenbergii* (Kühn) Patouillard]). There was one physiological disorder named as leaf sugary (Table I). In addition to the diseases were striga or witchweed (*Striga asiatica* [L.] Kuntze and *Striga hermonthica* [Del.] Benth).

Characteristic symptoms of MStV were chlorotic stripe and interveinal bands on leaves (Figures 3a and 3b), stunted plant growth, with or without normal panicle exertion

Figure 2. (b). Prevalence of ergot and maize stripe virus of sorghum (MStV) in Deccan region's states of India surveyed from August 2000 to March 2001.

(Figures 3c, 3d and 3e), and excessive tillering (Figure 3f). The MStV symptoms observed were similar to those described by Peterschmitt et al. (1991). The transmission of MStV is by the vector, viruliferous adults (Figure 3g) of the delphacid plant hopper (*P. maidis*).

The most obvious external symptom of ergot on sorghum panicle was the honeydew like exudation from the infected flowers in the inflorescence (Figure 4a). The name sugary disease for sorghum ergot originates from this sticky, sweet fluid. Also it is called honeydew that contains numerous conidia. Honeydew was either uniformly yellow-brown to pink (Figure 4a) or superficially white matt (Figure 4b). In few locations, sclerotial stage symptoms (Figure 4c) were observed. The ergot symptoms observed was either on panicles produced on nodal tillers or on the main panicle.

Table I. Prevalence of sorghum diseases[1] in decreasing order of prevalence across states observed in Deccan region states of India from August 1999 to March 2001.

Diseases	Percent fields[1] with sorghum diseases				
	Andhra Pradesh	Karnataka	Maharashtra	Tamil Nadu	Mean
Foliar fungal and physiological					
Leaf blight (*Exserohilum turcicum*)	5.00	14.30	11.00	26.8	14.3
Anthracnose (*Colletotrichum graminicola*)	15.30	5.20	2.40	–[d]	5.70
Rust (*Puccinia purpurea*)	0.20[a]	9.40	6.20	12.20[a]	7.50
Downy mildew (*Peronosclerospora sorghi*)	0.00	3.70	0.00	9.80	3.40
Zonate leaf spot (*Gloeocercospora sorghi*)	1.00	0.50[a]	6.90	4.90	3.30
Oval leaf spot (*Ramulispora sorghicola*)	9.90	0.20[a]	0.00	2.40[b]	3.10
Rough leaf spot (*Ascochyta sorghina*)	6.90	1.00	1.40	0.00	2.30
Sooty stripe (*Ramulispora sorghi*)	2.00[a]	3.90	1.40	0.00	1.80
Gray leaf spot (*Cercospora sorghi*)	0.00	0.50	0.00	4.90[a]	1.40
Leaf sugary (physiological disorder)	0.50[a]	0.70[b]	0.00	0.00	0.30
Tar spot (*Phyllachora sorghi*)	0.00	0.20[a]	0.00	0.00	0.10
Foliar viral					
MStV (a tenuivirus transmitted by The delphacid plant hopper [*P. maidis*])	8.90	28.30	44.50	31.70	28.40
MMV (a rhabdovirus transmitted by the delphacid plant hopper [*Peregrinus maidis*])	0.00	2.00	0.00	2.40[a]	1.10
Foliar bacterial					
Bacterial leaf streak (*Xanthomonas compestris* pv. *holcicola*)	–	1.70[b]	0.00	0.00	0.40
Panicle and parasitic					
Ergot (*Claviceps* spp.)	30.70	9.60	11.00	2.40[b]	13.40
Grain mold (complex of fungi)	1.00[a]	3.40	4.10	0.00	2.10
Head smut (*Sporisorium reilianum*) (syn. *Sphacelotheca reiliana*)	0.00	2.00	4.10[b]	0.00	1.50
Grain smut (*Sporisorium sorghi*) (syn. *Sphacelotheca sorghi*)	1.00	1.70	1.70[b]	0.00	1.10
Striga (*Striga asiatica* and *S. hermonthica*)	1.00	1.20	0.70[b]	0.00	0.70
Long smut (*Sporisorium ehrenbergii*) (syn. *Tolyposporium ehrenbergii*)	0.00	0.50[a]	0.30[b]	0.00	0.20
Free[c]	14.90	9.90	4.10	2.40	7.80

[1]Mean percent across two years; out of 228 farms in Andhra Pradesh, 406 in Karnataka, 290 in Maharashtra and 41 farms in Tamil Nadu; [a]observed only during August 1999 – February 2000; [b]observed only during August 2000 – March 2001; [c]Fields sown with improved cultivars including ICSV 745 and ICSV 112; –[d]Disease not observed.

Percent fields with diseases

Among nine foliar diseases of sorghum observed in Andhra Pradesh, fields with anthracnose were 15.3% followed by oval leaf spot (9.9%), MStV (8.9%), and rough leaf spot (6.9%). Among these, the spectrum of damage caused by MStV was more significant in terms of reduced plant height and low or no panicle exertion. Similarly, among panicle diseases, fields with ergot were 30.7%. However, downy mildew, gray leaf spot, tar spot and MMV diseases were not observed. Among 202 fields surveyed in Andhra Pradesh, 14.9% of the fields were free from diseases (Table I).

Of the 406 farms surveyed in Karnataka, the disease scenario was different from that of Andhra Pradesh (Table I). There were 14 foliar diseases observed in the state. Mean number

Figure 3. Symptoms of maize stripe virus (MStV) of sorghum. a = Chlorotic stripes and interveinal bands on leaves. b = A farmer viewing chlorotic stripes of MStV. c = MStV infected plant with stunted growth and reduced panicle exertion. d = Comparison of MStV infected plant with stunted growth and reduced panicle exertion and healthy plants. e = Farmers holding stunted plants of MStV and healthy plants in the back. f = Excessive tillering in MStV infected plant. g = MStV transmitting agent the delphacid plant hopper.

of fields with MStV was 28.3%, followed by leaf blight (14.3%), rust (9.4%) and sooty stripe (3.9%). One of the important quarantine diseases observed in Karnataka was bacterial leaf streak (Navi et al. 2002b). MStV was observed most commonly on both local cultivars and hybrids grown either for food or fodder purposes. Near Bellary (15°08′N; 76°58′E) in Karnataka, the MStV incidence was from 30 – 50% with up to 70% severity in late infected plants and 100% in early-infected plants. A Bellary farmer, who continues to produce sorghum seed for the last seven years, said MStV reduced 0.75 t ha^{-1} yields in 2000. Members of seed producers association in the area said MStV damaged nearly 55 ha sorghum area where hybrid seeds were being produced for one of the leading seed companies. Another observation from a farmer of Dummi village [14°01′N; 76°04′E) in Chitradurga district considered MStV more dangerous than other diseases.

Among the states surveyed, the number of fields showed MStV infestation was highest in Maharashtra. Out of 290 fields surveyed, 44.5% were with MStV, followed by leaf blight (11%), zonate leaf spot (6.9%) and rust (6.2%). Similar to Andhra Pradesh, downy mildew, gray leaf spot, tar spot and MMV diseases were not observed in Maharashtra. However, fields with ergot infestation were 11% (Table I). Similar to Maharashtra, the MStV was more prevalent in TN than other diseases. Exceptionally, 26.8% of fields were infested with leaf blight disease in TN followed by rust and downy mildew.

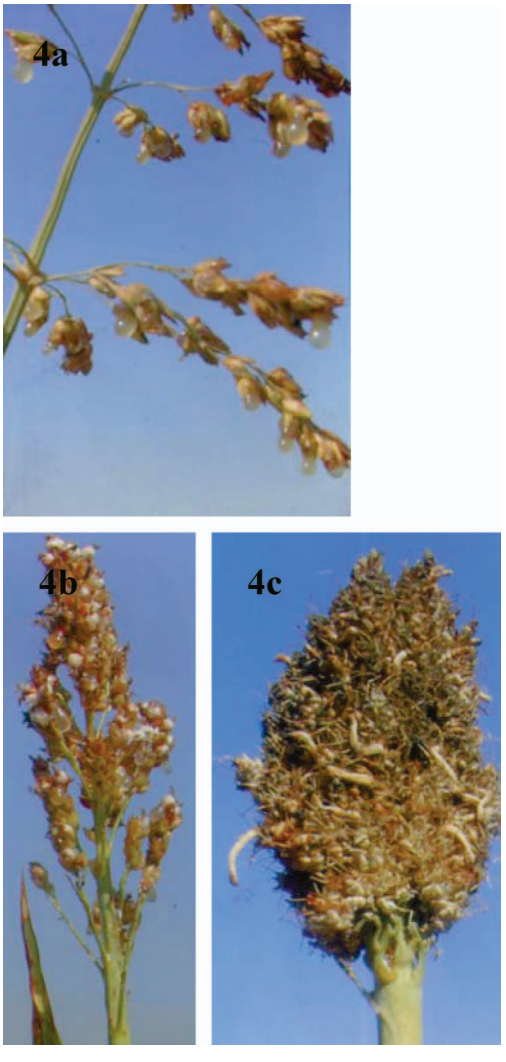

Figure 4. Symptoms of sorghum ergot. a = panicle with yellow brown to pink colored honeydew symptoms. b = panicle with superficial white mat. c = panicle with sclerotial symptoms.

Out of five panicle diseases observed, the percentage of fields with ergot was more predominant than smuts. However, less attention was paid towards grain mold because of its complex etiology and widespread damage during the rainy season. Of the 202 fields surveyed in Andhra Pradesh, 30.7% had ergot; similarly the values in Karnataka, Maharashtra and TN were 9.6%, 11% and 2.4%, respectively.

Prevalence of diseases and geographic regions

Prominent variation was observed in the prevalence of diseases depending on agro-climatic variation in fields surveyed in various administrative zones and districts in four sorghum-growing states in India (Table II). The number of fields with MStV was 129 in Maharashtra, 115 in Karnataka, 18 in Andhra Pradesh and 13 in TN. However, frequency of occurrence of

Table II. Number of fields, administrative zones (AZ) and districts (DIST) covered in Deccan region states of India to record prevalence of diseases from August 1999 to March 2001[a].

	Andhra Pradesh			Karnataka			Maharashtra			Tamil Nadu		
Disease(s)	Fields	AZ	DIST	Fields	AZ	DIST	Fields	AZ	DIST	Fields	AZ	DIST
Foliar fungal and physiological												
Anthracnose	31	7	2	21	17	13	7	5	5	–[b]	–	–
Downy mildew	–	–	–	15	11	9	–	–	–	4	4	4
Gray leaf spot	–	–	–	2	2	2	–	–	–	2	2	2
Leaf blight	10	5	2	58	36	19	32	27	21	11	9	6
Leaf sugary	1	1	1	3	3	2	–	–	–	–	–	–
Oval leaf spot	20	5	2	1	1	1	–	–	–	1	1	1
Rough leaf spot	14	3	1	4	3	3	4	4	4	–	–	–
Rust	4	7	4	38	27	17	18	15	9	5	4	3
Sooty stripe	4	3	2	16	10	5	4	4	4	–	–	–
Tar spot	–	–	–	1	1	1	–	–	–	–	–	–
Zonate leaf spot	2	2	2	2	2	2	20	18	17	2	2	1
Foliar viral												
MMV	–	–	–	8	7	6	–	–	–	1	1	1
MStV	18	14	7	115	45	20	129	55	19	13	8	6
Foliar bacterial												
Bacterial leaf streak	–	–	–	7	6	5	–	–	–	–	–	–
Panicle and parasitic												
Ergot	62	21	7	39	16	12	32	27	18	1	1	1
Grain mold	2	1	1	14	12	8	12	11	9	–	–	–
Grain smut	2	2	2	7	7	5	5	5	5	–	–	–
Head smut	–	–	–	8	6	5	12	8	3	–	–	–
Long smut	–	–	–	2	2	2	1	1	1	–	–	–
Striga	2	2	1	5	5	5	2	2	2	–	–	–
Free	30	2	1	40	26	17	12	10	6	1	1	1

Number of district in Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu are 23, 27, 34 and 29 respectively; [a]based on 228 fields in A.P., 406 in KAR, 290 in MH and 41 fields surveyed in TN; –[b]Disease were not observed.

various other foliar diseases was varying in each state surveyed (Table II). The frequency of fields with ergot was higher in Andhra Pradesh (62), followed by Karnataka (39), Maharashtra (32) and TN (1). These readings are based on 206 fields in Andhra Pradesh, 406 in Karnataka, 290 in Maharashtra and 41 in TN. Perhaps the frequency of ergot in Rajasthan and Uttar Pradesh states was quite high because most of the fields surveyed had ergot infection. Additionally, objective of ergot survey in theses two states was to have representation from these areas to better understand the variability of the ergot pathogen.

Incidence and severities of diseases

In general, the percentage incidence and severity ranges of sorghum diseases observed during the survey were varying (Table III). Though the percentage incidence and severity range of MStV was relatively lower than anthracnose, rust, oval leaf spot and other diseases, the spectrum of damage by MStV (Figure 3a – f) was more significant, whereas the percentage incidence and severity ranges of ergot were very high in Andhra Pradesh than in other states (Table III). Similar to percentage incidence and severity ranges, the mean percentage incidence and severity of diseases provides proper assessment of the diseases across fields

Table III. Number of fields, percentage incidence (Inc) and severity (Sev) of sorghum diseases observed in the Deccan region states of India from August 1999 to March 2001.

	Percent incidence and severity ranges											
	Andhra Pradesh			Karnataka			Maharashtra			Tamil Nadu		
Disease(s)	Fields	Inc	Sev	Fields	Inc	Sev	Fields	Inc	Sev	Fields	Inc	Sev
Foliar fungal and physiological												
Anthracnose	31	<1–90 (20)[a]	1–30 (10)	21	1–100 (25)	2–45 (16)	7	50–100 (91)	5–60 (18)	0	0 (0)	0 (0)
Downy mildew	0	0 (0)	0 (0)	15	<1–80 (52)	10–100 (89)	0	0 (0)	0 (0)	4	<1–2 (1)	50–100 (75)
Gray leaf spot	0	0 (0)	0 (0)	2	<1–15 (8)	60–100 (80)	0	0 (0)	0 (0)	2[b]	100 (100)	10–20 (15)
Leaf blight	10	<1–10 (4)	20–20 (13)	58	<1–100 (24)	2–40 (12)	32	20–100 (32)	5–60 (17)	11	5–100 (47)	2–40 (20)
Leaf sugary	1[a]	10 (10)	* (*)	3[c]	50–90 (67)	* (*)	0	0 (0)	0 (0)	0	0 (0)	0 (0)
Oval leaf spot	20	2–100 (26)	2–40 (14)	1[b]	50 (50)	10 (10)	0	0 (0)	0 (0)	1[c]	100 (100)	20 (20)
Rough leaf spot	14	<1–50 (22)	<1–20 (12)	4	1–5 (3)	10–60 (24)	4	4–50 (24)	2–8 (6)	0	0 (0)	0 (0)
Rust	4[b]	2–80 (28)	5–15 (9)	38	1–100 (42)	5–100 (27)	18	5–100 (81)	5–100 (44)	5[b]	10–100 (64)	5–100 (32)
Sooty stripe	4[b]	<1–1 (1)	2–5 (4)	16	1–90 (14)	2–60 (13)	4	<1–100 (6)	2–5 (4)	0	0 (0)	0 (0)
Tar spot	0	0 (0)	0 (0)	1[b]	100 (100)	15 (15)	0	0 (0)	0 (0)	0	0 (0)	0 (0)
Zonate leaf spot	2	<1–30 (15)	1–10 (6)	2[b]	2–10 (6)	2–5 (4)	20	1–100 (54)	5–85 (21)	2[c]	10–90 (50)	15–40 (28)
Foliar viral												
MMV	0	0 (0)	0 (0)	8	<1–10 (8)	5–100 (82)	0	0 (0)	0 (0)	1[b]	30 (30)	60 (60)
MStV	18	<1–30 (6)	25–100 (85)	115	<1–50 (12)	20–100 (83)	129	Tr–100 (5)	Tr–100 (67)	13	1–30 (12)	50–100 (76)
Foliar bacterial												
Bacterial leaf streak	0	0 (0)	0 (0)	7[c]	<1–20 (6)	5–60 (28)	0	0 (0)	0 (0)	0	0 (0)	0 (0)
Panicle and parasitic												
Ergot	62	0–100 (34)	0–100 (67)	39	<1–100 (41)	2–100 (79)	32	0.5–100 (30)	Tr–100 (67)	1[c]	100 (100)	100 (100)
Grain mold	2[b]	6–10 (8)	25 (25)	14	2–100 (33)	5–100 (23)	12	Tr–100 (61)	Tr–50 (25)	0	0 (0)	0 (0)
Grain smut	2	1–5 (3)	100 (100)	7	<1–20 (4)	20–100 (90)	5[c]	1 (1)	100 (100)	0	0 (0)	0 (0)
Head smut	0	0 (0)	0 (0)	8	<1–15 (5)	100 (100)	12[c]	1 (1)	100 (100)	0	0 (0)	0 (0)
Long smut	0	0 (0)	0 (0)	2[b]	1–15 (8)	40–100 (70)	1[c]	1 (1)	100 (100)	0	0 (0)	0 (0)
Striga	2	2–20 (11)	* (*)	5	20–50 (29)	* (*)	2	12–13 (13)	* (*)	0	0 (0)	0 (0)
Free	30	0 (0)	0 (0)	40	0 (0)	0 (0)	12	0 (0)	0 (0)	1	0 (0)	0 (0)

MMV, Maize mosaic virus of sorghum; MStV, Maize stripe virus of sorghum; [a]data inside the parentheses are mean values; [b]observed only during August 1999–February 2000; [c]observed only during August 2000–March 2001; *Severity was not recorded.

surveyed in each state (Table III). It is also important to make proper assessment of the mean incidence based on the number of fields where a particular disease was observed. It was observed that the mean incidence of MStV in Andhra Pradesh was 6% with 85% mean severity. The values in Karnataka were 12% and 83%, in Maharashtra 5% and 67%, and in TN 12% and 76%, respectively (Table III). Similar to MStV, the mean percent incidence and severities of ergot was varying from state to state (Table III).

Percentage of fields with mean and ranges of disease incidence and severity

There was variation in the percentage of fields with incidence (%) from 377 fields surveyed during August 1999 until February 2000 and 588 during August 2000 to March 2001 (Table IV). The percentage of fields with MStV incidence in year 1 was 9.3% and 24% in year 2 on 1–5% range (Table IV). The percentages of fields with severity (%) from 377 fields sampled during August 1999 to February 2000 and 588 during August 2000 to March 2001 are given in Table V.

Prevalence of MStV and ergot

There was variation in the frequency of occurrence in sorghum diseases observed during the survey from August 1999 to March 2001. Prevalence maps for MStV and ergot in year 1 and year 2 are given in Figures 2a and 2b, respectively. Prevalence of sorghum diseases in Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu states in India has been discussed.

Table IV. Percentage of fields with disease incidence (%)[1] from 377 fields surveyed from August 1999 to February 2000 and 588 from August 2000 to March 2001 in the Deccan region states of India.

	August 1999–February 2000				August 2000–March 2001			
Diseases	1–5	6–10	11–25	>25	1–5	6–10	11–25	>25
Anthracnose	5.6	0.8	0.5	1.9	2.4	0.3	0.2	1.7
Bacterial leaf streak	0.0	0.0	0.0	0.0	0.7	0.3	0.2	0.0
Downy mildew	0.8	0.0	0.0	0.3	1.5	0.0	0.5	0.5
Ergot	8.0	5.0	1.3	4.8	2.4	1.7	1.4	5.4
Gray leaf spot	0.3	0.0	0.0	0.5	0.0	0.0	0.2	0.0
Leaf blight	6.9	3.4	1.9	3.2	2.7	1.2	1.5	2.0
Leaf sugary	0.0	0.3	0.0	0.8	0.0	0.0	0.0	0.0
MMV	1.6	0.3	0.0	0.3	0.0	0.2	0.0	0.0
Mold	1.3	0.8	0.8	4.0	1.2	0.0	0.2	0.5
MStV	9.3	1.9	1.9	2.7	24.0	5.1	4.1	3.7
Oval leaf spot	0.8	0.3	0.3	1.1	1.2	0.3	0.3	0.5
Rough leaf spot	3.2	0.5	0.3	0.5	0.3	0.0	0.3	0.2
Rust	2.7	1.1	1.1	6.1	0.7	0.5	0.2	2.9
Smut (grain)	1.1	0.0	0.3	0.0	1.7	0.0	0.0	0.0
Smut (head)	0.8	0.0	0.3	0.0	2.7	0.0	0.0	0.0
Smut (long)	0.3	0.0	0.3	0.0	0.2	0.0	0.0	0.0
Sooty stripe	2.7	1.9	0.0	0.8	0.5	0.0	0.2	0.0
Striga	0.3	0.0	0.5	0.3	0.0	0.0	0.7	0.2
Tar spot	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Zonate leaf spot	0.8	0.5	0.3	1.1	0.7	0.3	0.3	1.4

[1]Mean percent was from 94 farms in A.P., 221 in KAR, 45 in MH and 17 farms in TN from August 1999 to February 2000 and 134 farms in A.P., 185 in KAR, 245 in MH and 24 farms in TN from August 2000 to March 2001.

Table V. Percentage of fields with disease severity (%) from 377 fields surveyed from August 1999 to February 2000 and 588 from August 2000 to March 2001 in the Deccan region states of India.

	Percent fields with severity (%)[1]									
	August 1999 – February 2000					August 2000 – March 2001				
Diseases	1 – 5	6 – 10	11 – 25	26 – 50	> 50	1 – 5	6 – 10	11 – 25	26 – 50	> 50
Anthracnose	3.7	2.4	1.9	0.5	0.0	1.5	1.5	1	3.4	0.2
Bacterial leaf streak	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.5	0.0	0.3
Downy mildew	0.0	0.0	0.0	0.0	1.1	0.0	0.2	0.0	0.5	1.9
Ergot	2.4	2.9	2.1	2.1	9.5	0.5	0.0	0.3	0.3	8.8
Gray leaf spot	0.0	0.3	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.2
Leaf blight	5.3	5.8	4.0	0.3	0.0	1.7	3.1	2.4	0.3	0.0
Leaf sugary	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MMV	0.3	0.0	0.3	0.3	1.3	0.0	0.0	0.0	0.0	0.2
Mold	0.8	1.1	3.4	0.8	0.8	1.0	0.2	0.2	0.3	0.2
MStV	0.0	0.0	0.5	1.9	13.0	0.2	0.2	0.9	3.1	32.5
Oval leaf spot	0.5	1.1	0.8	0.0	0.0	0.3	0.7	1.0	0.2	0.0
Rust	2.7	1.9	1.9	1.6	2.9	0.5	0.7	0.7	0.5	1.7
Rough leaf spot	2.4	0.8	1.1	0.0	0.3	0.2	0.3	0.3	0.0	0.0
Smut (grain)	0.0	0.0	0.3	0.0	1.1	0.0	0.0	0.0	0.0	1.7
Smut (head)	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	2.7
Smut (long)	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.2
Sooty stripe	2.4	1.3	1.1	0.3	0.3	0.5	0.2	0.0	0.0	0.0
Striga	*	*	0.0	0.0	*	*	*	*	*	*
Tar spot	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zonate leaf spot	1.1	0.3	1.1	0.0	0.3	0.5	0.9	1.0	0.2	0.2

[1]Mean percent was from 94 farms in A.P., 221 in KAR, 45 in MH and 17 farms in TN from August 1999 to February 2000 and 134 farms in A.P., 185 in KAR, 245 in MH and 24 farms in TN from August 2000 to March 2001; *Severity was not recorded.

Discussion

Maize stripe virus

It was observed that the infection frequency of MStV was more predominant during the post-rainy season than in the rainy season. Transmission of MStV was also in a determined manner being higher towards the border than inside the fields. M 35-1 grown in a majority of the fields during the post rainy season was more susceptible to MStV than other varieties and hybrids. M 35-1 alone covers over 70% of the area under post – rainy sorghum in India. Narayana and Muniyappa (1995) and Narayana et al. (2002) have indicated MStV causes substantial losses in vegetative growth and grain yield of sorghum in India. Recently, Pande et al. (2003) and Navi et al. (2003) have shown loss in grain and stover yields with variability in digestibility (%) of healthy and MStV infected plants. It is estimated that an annual loss due to MStV will exceed £49 m in grain yields and £52 m in fodder yields. Therefore, reduction of losses due to the virus with appropriate management techniques will significantly enhance sorghum production, farm income and animal productivity.

Our observations indicated MStV occurs in different agro-ecological zones. It is currently not known if the virus occurs as distinct strains. Resistant sources for the virus or to the vector have not been identified, and also, the epidemiology of the disease has not been thoroughly investigated. As a result, control measures are currently not available. Therefore, hot spots for MStV need to be identified in major sorghum-growing areas of India and in other countries, thus facilitating large-scale screening of sorghum genotypes for MStV resistance. The MStV

can best be understood by making collections of isolates from different ecological zones, maintain, purify and develop diagnostic tools to distinguish different isolates, develop screening techniques, and identify broad based resistance.

Damages of MStV were drastic reduction in stover yield, grain yield and quality of the stover. This was not only the researchers' perception on MStV's multiple damages but also the perception of the farmers. The major damage by MStV could be because of the mono-cropping system in various states and survival of vector on ratoon crop, tillers and main crop. The observation of members of the seed producers association in Bellary (15°08′N;76°58′E) in Karnataka was that MStV damaged nearly 55 ha sorghum where hybrid seeds were being produced for one of the leading seed companies. Another important observation from a farmer of Dummi (14°01′N; 76°04′E) in Chitradurga district was comparative damages of MStV and ergot. According to several farmers in the village, MStV is more dangerous than ergot, because of the spectrum of damage by MStV. In the case of ergot, there is no reduction in stover yield but certainly in grain yield. Interestingly, farmers said animals desire to eat ergot-infested stover (honeydew fallen on foliar parts of plant) because of the sweet substance adhered on leaves and in panicles. However, the effects of consumption of ergot-infested panicles by animals are not known (Frederiksen RA. Personal communication).

On-farm surveys enlightened the fact that MStV plays a major role in reducing stover and grain yield. This was evident both from the type of symptoms observed and ranges of percentage incidence and severities. It is perceptive from our observations that if the infestation occurs at vegetative stage (15 days after emergence to flag leaf stage), the losses were higher than the infestation occurring from flowering to maturity stages (Pande et al. 2003).

Ergot

There was an observed occurrence of *C. sorghi*, *C. africana* during the surveys. In a group discussion with farmers in Vangoor administrative zone in Andhra Pradesh, it was learned farmers in the region were witnessing ergot in a severe form for the first time during the 1999 rainy season and later in 2000. Some farmers, who had harvested healthy and ergot-infected panicles, were pooled in a big heap; some separated out the infected panicles while most left the crop in the field for cattle. When asked, what happens to cattle if they eat the crop, few farmers said cattle suffer from stomach pain while others said nothing happens. On the contrary, in Bhootpur administrative zone (16°42′N; 78°02′E) about 40 – 50 km from Maachinenipalli in Andhra Pradesh, there was no ergot. Farmers in this village observed no trace of ergot except in 1996.

Our observations from a survey in 13 administrative zones in the Mahbubnagar district of Andhra Pradesh representing 22 farmers' fields in 15 villages revealed occurrences of an ergot epidemic in the district in September 2000 (Navi et al. 2002a). In 15 villages (nearly 75% of total villages surveyed), the ergot incidence was $\geq$50%. Most villages with high ergot incidence had extremely high disease severity (up to 100%) suggesting that farmers had little grain to harvest from sorghum fields (Navi et al. 2002a). The area under sorghum was nearly 130,000 ha (Source: Office of the Associate Director of Research, Regional Agricultural Research Station, Palem 509 215, Mahbubnagar district, Andhra Pradesh, India). We also discussed with farmers in Andhra Pradesh about sorghum ergot history, fodder storage system and loss due to ergot. With regard to ergot, farmers said they would take one or more of the following actions in an epidemic area: (i) select only healthy panicles for food and feed the ergot infected panicles and stover to animals (ii) allow plants to dry in the field due to difficulties in harvesting sticky panicles and leaves, and feed animals with the stover later in

the season since there is plenty of grass available on the farm, and (iii) allow cattle to graze on the farm without harvesting or drying the stover.

Sources of infection for an epidemic

Navi et al. (2002a) have indicated possible sources of infection for an epidemic in Andhra Pradesh during 1999. Farmers in Maachinenipalli village (Vangoor Administrative zone) had harvested plants with infected panicles and fed both green and dried stover to cattle; the uneaten stock was either stored or dumped in farmyard manure (FYM) pits. In 2000, the residues were distributed in the field as FYM. In addition, farmers had bartered infected fodder with farmers in near by villages. Based on this information it was assumed: (a) the fungus might have survived either in honeydew or sclerotial stage through FYM applied in the field, and (b) pathogen might have moved from an area of an ergot epidemic to other places in the district in 2000 through movement of fodder. In addition, pathogen spread was aided by exceptionally high rainfall during flowering time.

In Chitradurga district (Karnataka), a severe ergot was observed on MSH 51 continuously for three years since 1998 during both the rainy and post-rainy seasons. In another farm where MSH 51 was planted in Talaku village (14°27′N; 76°40′E) of the Challakere administrative zone (Chitradurga district, Karnataka), the crop was affected acutely by ergot with 80 – 90% incidence and 90 – 100% severity. Experience of the farmer on sorghum ergot in year 1 was appalling. The disease had damaged the crop more than ever expected. It is believed that from 1.6 ha irrigated land; he could harvest only 8 – 9 quintals compared to 25 – 30 quintals during the 1999 post-rainy season. He hired laborers to wash grains in water mainly to remove honey dew adhered to the grains and separate out black structures (sclerotial bodies, sclerotial bodies plus chaffy grains which normally float on the water) mainly to sell in the nearby market at Rs. 3000 t^{-1}.

Conclusions

Our observations during the surveys indicated MStV occurs in different agro-ecological zones. It is currently not known if the virus occurs as distinct strains. Resistant sources for the virus or to the vector have not been identified. Epidemiology of the MStV of sorghum has not been investigated thoroughly. As a result, control measures are currently not available. Therefore, hot spots for the disease need to be identified in major sorghum-growing areas of India and in other countries, thus facilitating large-scale screening of sorghum genotypes for disease resistance. The disease can best be understood by: (i) making collections of MStV isolates from different ecological zones, (ii) maintaining and purifying isolates, (iii) developing diagnostic tools to distinguish different isolates, (iv) developing screening techniques, and (v) identifying broad based resistance.

The surveys conducted in major sorghum-grown states in India during 1999 – 2001, and the recent investigation on diversity of sorghum ergot pathogen confirms the presence of *C. africana* and *C. sorghi* (Bandyopadhyay et al. 2002). Reproductive potential is an important determining factor which decides the relative predominance of one species over the other. The production of secondary conidia and their spontaneous wind dispersal are most likely the key characters of pathogenic fitness in sorghum ergot pathogen. The higher degree of secondary conidia production by *C. africana* than *C. sorghi*, in which secondary conidiation is negligible, when compared to the former, offers the pathogen a remarkable potential to spread rapidly over time and space. Thus, it could be possible for the *C. africana* to spread enough and dominate all the sorghum ergot positive regions throughout the world.

Acknowledgements

This study is an output from: (a) a research project supported by the United Kingdom Department for International Development (DFID), UK, for the benefit of developing countries, and (b) US Department of Agriculture, under special agreement No. 58–1920–9–F110. Any opinions, findings, conclusions or recommendations are those of authors and do not necessarily reflect the views of the US Department of Agriculture and DFID. Authors sincerely acknowledge the cooperation of farmers, non-government organizations (NGOs), staff of agricultural universities and the department of agriculture.

References

Bandyopadhyay R. 1992. Sorghum ergot. In: de Milliano WAJ, Frederickson RA, Bengston GD, editors. Sorghum and millets diseases: A second world review. International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India. pp 235–244.

Bandyopadhyay R, Frederickson DE, McLaren NW, Odvody GN. 1996. Ergot – a global threat to sorghum. Int Sorghum Millet Newsl 37:1–32.

Bandyopadhyay R, Frederickson DE, McLaren NW, Odvody GN, Ryley MJ. 1998. Ergot: A serious threat to sorghum in Americas and Australia. Plant Dis 82:356–367.

Bandyopadhyay R, Muthusubramanian V, Tooley PW, Chakraborty S, Pažoutová S, Navi SS. 2002. Distribution and diversity of the sorghum sugary disease pathogen in India. In: Leslie JF, editor. Sorghum and millet diseases. Ames, IA: Iowa State Press. pp 75–79.

de Milliano WAJ, Frederiksen RA, Bengston GD, editors. 1992. Sorghum and millets diseases: A second world review. Patancheru (A.P.), India: International Crop Research Institute for Semi Arid Tropics (ICRISAT).

Frederickson DE, Mantle PG, de Milliano WAJ. 1991. *Claviceps africana sp*. nov., the distinctive ergot pathogen of sorghum in Africa. Mycologic Res 95:1101–1107.

Frederiksen RA, Odvody GN, editors. 2000. Compendium of sorghum diseases. 2nd ed. APS Press, The American Phytopathological Society. p 77.

Kukedia MV, Desai KB, Desai MS, Patel RH, Raja KRV. 1982. Natural screening of advanced sorghum varieties to sugary disease. Sorghum Newsl 25:117.

Molefe TL. 1975. Occurrence of ergot on sorghum in Botswana. Plant Dis Reporter 59:751–753.

Naidu RA, Harikrishnan R, Manohar SK, Reddy DVR, Ratna AS, King SB, Bandyopadhyay R. 1989. Maize mosaic virus on sorghum. Ann Appl Biol 114:301–310.

Narayana YD, Muniyappa V. 1995. Effects of sorghum stripe virus on plant growth and grain yield of sorghum. Indian J Virol 11:53–58.

Narayana YD, Bandyopadhyay R, Navi SS, Muniyappa V. 2002. Sorghum viruses in Asia and Africa. In: Leslie JF, editor. Sorghum and millet diseases. Ames, IA: Iowa State Press. pp 431–439.

Navi SS, Bandyopadhyay R, Hall AJ, Paula Bramel-Cox. 1999. A pictorial guide for the identification of mold fungi on sorghum grain. In: Information Bulletin no. 59 [in English and French]. International Crops Research Institute for the Semi–Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.

Navi SS, Bandyopadhyay R, Nageswara Rao TG, Tooley PW. 2002a. An outbreak of sorghum ergot in parts of Andhra Pradesh, India. Int Sorghum Millets Newsl 43:68–70.

Navi SS, Bandyopadhyay R, Thirumala Devi K, Reddy DVR. 2002b. Bacterial leaf streak of sorghum – a new report from India. Int Sorghum Millets Newsl 43:61–63.

Navi SS, Bandyopadhyay R, Blümmel M, Reddy RK, Thomas D. 2003. Maize stripe virus: A disease of sorghum emerging in south India. Int Sorghum Millets Newsl 44:126–129.

Pande S, Bandyopadhyay R, Blümmel M, Narayana Rao J, Thomas D, Navi SS. 2003. Disease management factors influencing yield and quality of sorghum and groundnut crop residues. Field Crops Res 84:89–103.

Pande S, Bock C, Bandyapadhyay R, Narayana YD, Lenne J, Jegger M. 1997. Sorghum downy mildew. Information Bulletin No. 51. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Peterschmitt M, Ratna AS, Sacks WR, Reddy DVR, Mughogho LK. 1991. Occurrence of an isolate of maize stripe on sorghum in India. Ann Appl Biol 118:57–70.

Rama Devi K, Bandyopadhyay R, Hall J, Indira S, Pande S, Jaiswal P. 2000. Farmers' perceptions of the effects of plant diseases on the yield and nutritive value of crop residues used for peri–urban dairy production on the Deccan plateau: Findings from participatory rural appraisals. Information Bulletin no. 60 [In English, Abstract in English and French]. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Sangitrao CS, Bade GH. 1979. Meteorological factors associated with honeydew development and sclerotial stage in sorghum ergot. Sorghum Newsl 22:107–108.

Williams RJ, Frederiksen RA, Girard JC. 1978. Sorghum and pearl millet disease identification handbook. Information Bulletin No. 2. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.