SORGHUM DOWNY MILDEW OF MAIZE IN KARNATAKA, INDIA

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Introduction

In 1975 maize *(Zea mays* L.*)* was cultivated on more than 5.6 million hectares in India and grain production was about 6.2 million tons, for an average of 10.3 quintals/ha. This is a significant increase over 7 years earlier when the area was about 4.6 million hectares. The state of Karnataka is making rapid progress in maize production. The average yield is 300% above the national level. In 1966-67 about 17,000 ha. of maize was grown in the state; in 1971-72 more than 96,000 ha; and, in 1974-75 it increased to about 120,000 ha. On account of the moderate climate maize is cultivated throughout the year where irrigation is available. The districts where maize is popular are Bangalore, Belgaum, Dharwar, Kolar, Mysore, Tumkur and Bijapur. The hybrids and composites commonly grown in these areas are Deccan, Ganga 5, Ganga Safed 2 and Vijay. Recently, the two experimental hybrids 4207 and 3047 were introduced to the area.

The appearance of downy mildew (DM) *(Sclerospora sorghi* Weston and Uppal*)* and leaf blight *(Helminthosporium turcicum* Pass.*)* have become limiting factors to maize cultivation, not only in Karnataka, but also in the neighboring areas of Tamilnadu. Most of the hybrids and composites introduced for commercial production are susceptible to both of these diseases. It is imperative, therefore, to find sources of resistance to these economically important diseases, which cause enormous damage to this important cereal crop, and know the biology of the causal pathogens.

During the past few years efforts were made at this laboratory, in collaboration with Indian Coordinated Maize Research Program and international agencies, to find resistance to DM and leaf blight. The screening of hybrids and inbreds is going on systematically at this center and several lines developed in and imported from Thailand, Philippines, United States and India have been tested (Tables 1, 2). In addition, basic research on several aspects like disease cycle,

Table 1. Reaction of maize hybrids and composites to *Sclerospora sorghi*.

Hybrids	Percent infected plants*		Composites	Percent infected plants*	
	Laboratory (conidia)	Field (oospores)		Laboratory (conidia)	Field (oospores)
Deccan	80	20	Amber	25	10
Ganga 101	39	10	Jawahar	20	5
Ganga 5	25	20	Kisan	30	40
Ganga 3	82	25	Sona	10	2
Ganga Safed 2	40	10	Vijay	20	10
Popcorn**	78	58	Vikram	40	5

* Average of three replications with 50 plants each.
** Susceptible check.

Table 2. Reaction of 10 entries of maize recomended for International Downy Mildew *(Sclerospora sorghi)* Maize Nursery*.

Pedigree	Country submitting	Percent infected plants	
		Laboratory (conidia)	Field (oospores)
Tainan DMR Comp. 1	Taiwan	29	15
Tainan DMR Comp. 2	Taiwan	33	12
Tainan DMR Comp. 3	Taiwan	48	18
College White × Tuxpeno	Philippines	43	2
MIT × Cuba Gr. 1	Philippines	55	4
MIT × Flint Comp. Amar.	Philippines	50	20
Chain DMR Syn.	Philippines	32	3
Bogor Syn. I	Indonesia	25	1
Bogor Syn. II	Indonesia	25	1
Penjalinan	Indonesia	45	4
Popcorn**		66	45
DMS 652 (Sorghum)**		68	56

* Average of three replications with 50 plants each.
** Susceptible checks.

epidemiology, oospore germination, seed pathology, host-parasite relationships, cultural practices, chemical control, histopathology and taxonomy of the fungi involved is being carried out.

Taxonomy

Kenneth (3) is of the opinion that *Sclerospora maydis* (Racib.) Butler and *S. sorghi* are the same species existing as two different physiological races; one tending to infect sorghum but capable of attacking maize at times and the other either exclusively related to maize or maize-teosinte hybrids. This observation clearly indicates the need for the study of the morphological and physiological characters between the two species including pathogenicity tests. Ullstrup (7) rightly suggested the re-examination of all the species of *Sclerospora* recorded on maize, as he expects more similarity among them than was originally described. Safeeulla and Shaw (6) not only observed a clear cut difference in the morphology of the oospores of *Sclerophthora* and *Sclerospora*, but also indicated distinct morphological features in the oospores of *S. sorghi* and *S. graminicola*. They stressed the significance of vestigious oogonial wall on the oospores. Safeeulla (5) further suggested the greater stability and uniformity in the oospore morphology of *Sclerospora* spp. compared to their asexual phase which is ephemeral and subject to environmental changes.

A close examination of the sorghum DM occurring on maize in Karnataka, Rajasthan and Tamilnadu has indicated that the pathogen infecting maize in some parts of Karnataka and Tamilnadu is different from the one reported from Rajasthan. This conclusion is based on morphological and host range studies. The conidiophores of the fungus occurring on maize in Rajasthan are shorter and stouter and the pathogen can infect *Heteropogon contortus*, whereas the pathogen which occurs on maize in Karnataka does not infect *H. contortus*.

Morphology

In *S. sorghi*, the conidiophores are erect, spreading, comprising a basal cell, main axis more or less complex, usually dichotomously

branched, with an expanded top. The basal cell is knobbed or bulbous at the bottom, of fairly uniform diameter (7.9μ) after a length of approximately 100 to 150 μ until delimited usually by a complete septum or more rarely by a partial ring-like thickening. The main axis expands above to a diameter of 15 to 25 μ, and is usually less than or equal to the basal cell in length; i.e. extending about 80-150 μ from the septum of the basal cell to the beginning of the branch system. The branch system is comprised of a rapid succession of short, stout dichotomies usually involving primary, secondary and tertiary branches terminating in tapering sterigmata usually about 13 μ long. The branches are so arranged that the conidia borne on their tips lie approximately in a hemispherical plane. Conidia are suborbicular, varying from 15 to 28.9 μ × 15 to 26.9 μ, most frequently 21 to 24.9 μ × 19 to 22.9 μ, under natural conditions. Conidia are hyaline, with a thin wall, continuous at the apex, unmodified and without any papilla of dehiscence, hence germinating is invariably by hyphae.

The oogonial stage resembles *S. graminicola* in general structural characteristics, such as the thick, irregularly polygonally-angled oogonial wall closely enveloping the single, hyaline, spherical oospore within; but, differing slightly from *S. graminicola* on *Pennisetum* in effect on the host in that oospores, which develop chiefly within elongate reddish discoloured areas in the mesophyll between the fibrovascular bundles, cause marked disintegration of the leaf tissue into tangled fibres. Oospores are spherical, the majority being 31 to 36.9 μ in diameter, the mode being 35 to 36.9 μ, extremes ranging from 25 to 42.9 μ; wall a light shade of Mars Yellow (of Ridgway's 'Color Standard's) most frequently from 1.1 to 2.7 μ thick, extremes ranging from 0.3 to 4.4 μ; content finely granular with masses of oil globules, central or eccentric in position; germination by means of unseptate, usually branched, hyaline germ tube, averaging 4.4 μ in width, extremes ranging from 2.5 to 8.3 μ Weston and Uppal (9). The measurements of the reproductive structures of the fungus are indicated below:

Author and Year	Host and Locality	Measurement in microns
Kenneth, 1966	*Zea mays* L. Israel	Conidiophores:400-600 × 18-30
Cosper (cf. Frederiksen *et al.*, 1970)	*Sorghum bicolor* (L.) Moench	
	Sorghum almum Parodi	Conidiophores:140-200
	Sorghum halepense	Conidia:20-25 × 16-18
	Zea mays Texas (USA)	Oospores:30-50
Govindu *et al.*, 1970	*Zea mays*, Bangalore (India)	Conidiophores:91-120 × 17.5-24
		Conidia:17.5-21.75 × 12.0-19.25

Symptoms and identity of sorghum DM on maize. In the field, infected maize plants were mostly short and slender with overall leaf chlorosis. In some of the upper leaves clear-cut chlorotic streaks appeared with the intervening green area. On certain dewy mornings, followed by intermittent rains, heavy sporulation took place from the chlorotic area of the leaf. Sporulation was intense on the upper unfolding leaves. The "down" of germinated conidia was heavy and equal on both the upper and lower surface of the leaves. The infected leaves turned yellow and later were invaded by *H. turcicum*. The affected plants produced smaller ears which formed fewer kernels. Local lesions were absent on the leaves. We have observed malformation of the floral parts in most of the maize entries screened in sick plots.

When the infected leaf bits or entire plants were uprooted and incubated in the laboratory under high humidity, only mycelioid structures emerged through the stoma of the leaves and spread over the leaf surface. When the infected plants were watered heavily in the field and the

leaves were covered with polythene bags at 4 PM, the conidiophores emerged through the stoma at about 10 PM and fully developed by mid-night. The conidiophores contained rotund conidia at the tips of the sterigmata. Conidia germinated *in situ* or after getting released from the conidiophores. The morphology of the conidiophores was identical with the description of *S. sorghi* given by Weston and Uppal (9); viz., the presence of a basal cell delimited by a septum, short but stout branches with conidia of unmodified wall substance borne on the sharp sterigmata and germination by germ tubes. Besides these important features, the measurements of the conidia and conidiophores were more or less similar to the measurements given by the above authors and also with the fungus *S. sorghi* occurring on sorghum in this locality.

Conidiophores: basal cell - 125-173 × 6.5-7 μ
main axis - 120-175 × 12-22.5 μ
sterigmata - 12-14 μ
conidia - 18.5-26.2 × 16-23 μ

Cross inoculation studies. — Cross-inoculation tests were conducted to confirm the field and laboratory identity of the DM on maize. Two-day-old sorghum seedlings were brought in contact with the sporulating maize leaves for 24-48 hours in the field. The seedlings were then transferred to pots in the glass-house and watered daily until symptoms appeared, which were visible on a majority of the inoculated plants 3-4 days after transplanting. These symptoms were similar to the symptoms of *S. sorghi* infected sorghum plants. Sporulation was normal and the size and shape of conidiophores and conidia agreed fully with *S. sorghi* occurring on sorghum. Characteristic shredding of the leaves also occurred in a few plants.

When the seedlings (3-4 day-old seedlings of 'Deccan' hybrid) were inoculated with the conidia from sorghum plants, chlorosis appeared at the first or second leaf stage, 5-6 days after transplanting. The first leaf of the seedling was half chlorotic. The successively formed leaves were completely chlorotic. Sometimes the disease symptoms appeared at the maturity stage. Infected maize plants sporulated abundantly only when the intact plants were kept under high humidity. Although oospores were observed in the mesophyll there was no leaf shredding. The oospores produced on these artificially inoculated maize plants measured 30-39 μ in diameter. These measurements coincided with the measurements of oospores of *S. sorghi*.

Studies on oospore production in maize. — In order to observe the maize varietal reaction with regard to oospore production, 11 entries were inoculated with conidia of *S. sorghi* obtained from infected sorghum plants. A few of the inoculated seedlings of each variety were transferred to pots containing garden soil. Some of the pots were kept in the glasshouse, others placed in the open field, while some were transplanted in experimental plots and the seedlings examined critically for oospore production. The experiment was repeated once.

As indicated below, oospores were observed in all the entries inoculated with conidia and maintained in the glasshouse. No oospores were formed in entries which were inoculated in a similar manner but transplanted in the field. Among the entries inoculated but transferred to pots and kept in the open field, two entries; viz,. Tainan DMR Composites 1 and 3, produced oospores in one of the trials although oospore production was inconsistent and sparse. During the experiment, a temperature range of 28-32°C and 70-85% RH were recorded in the glasshouse, and in the field, 19-27°C and 70-94% RH, respectively.

Attraction of *S. sorghi* conidia to maize roots. There are a few maize lines resistant to oospore inoculum of *S. sorghi* but susceptible when conidia are used as the inoculum source. This phenomenon prompted a study as to whether the roots of living maize seedlings actively attract the conidia or not, and whether any difference in chemotaxis could be correlated with susceptibility and resistance.

Pedigree	Glasshouse pot culture	Field	
		Pot culture	Transplanted
Tainan DMR Comp. 1	XX	X	-
Tainan DMR Comp. 2	XX	-	-
Tainan DMR Comp. 3	XX	X	-
College White × Tuxpeno	XX	-	-
MIT × Cuba Gr. 1	XX	-	-
Chain DMR Syn.	XX	-	-
Bogor Syn. I	XX	-	-
Bogor Syn. II	XX	-	-
Pendjalinan	XX	-	-

XX Oospores observed in two trials
X Oospores in one of the trials
- Oospores absent in both the trials

Systemically infected maize leaves were collected in the evening, cut into 2-3 cms pieces, cleaned and dried to remove the previously produced conidia and conidiophores and floated in distilled water in a petri plate lined with moist filter paper. Thus, the conidial suspension was obtained in which several excised root segments of CM 500, Ganga 5, Phil. DMR 1 and Phil. DMR 5 were submerged in a conidial suspension. The killed root repelled conidia and the roots of living species attracted the conidia of *S. sorghi* within a few minutes.

The first indication of chemotaxis occurred in the region of elongation immediately behind the oldest portion of the root cap. This is the area where the pathogen actually penetrates. The reason for the strongest chemotaxis at the region of elongation, or immediately behind the root cap, may be due to the exudation of the metabolic products from the young cells at the region of elongation that differ in structure and concentration from the exudates of mature cells in other root areas. The conidial response of *S. sorghi* to susceptible and resistant host and non-host roots were:

Test plant	Degree of chemotaxis	Susceptibility to infection
Sorghum:		
DMR 652	S	H
Swarna	S	H
CSV - 5 (148)	S	H
I.S. 184	S	H
Maize:		
CM 500	S	H
Ganga 5	S	H
Phil. DMR-1	S	R
Phil. DMR-5	S	R
Setaria italica	S	I
Pennisetum typhoides (K.K)	M	I
Eleusine coracana	S	I
Phaseolus mungo	M	I
Phaseolus radiatus	M	I

S = strongly attractive; M = moderately attractive; H = highly susceptible; R = resistant; I = immune.

Systemic infection of maize (CM 500) sown in plots infested with *S. sorghi* oospores. — Systemic infection in maize seedlings is characterized by chlorotic symptoms which appear 2 weeks after sowing in the DM sick plots. The first leaf is invariably free from infection. However, by using conidial inoculum in the laboratory, it is possible to induce systemic infection on the first leaf itself. This difference may be due to the fact that the first leaf overgrows the pathogen which takes time to penetrate the root and invade the stem tissues under natural conditions. Data in Table 3 indicates a close correlation between leaf age and symptom appearance. If no infection is observed within 2 weeks, the second and third leaves escape infection while the younger leaves may develop symptoms subsequently. Like-wise, if the 4th, 9th and 11th leaves do not show infection after 4, 6 and 8 weeks respectively, symptom expression does not take place and the leaves below this region escape infection.

Host variety reaction. — Breeding for disease resistance basically requires identification of sources of resistance to the prevailing pathotypes and a knowledge of the mode of inheritance. Considerable data on the identification of sources of resistance to *S. sorghi* has been accumulated by the International Downy Mildew Nursery conducted during 1969-1973 (4). During the present investigations, a portion of the germplasm of maize have been screened against *S. sorghi* using oosporic inoculum in sick plots at this location.

Conclusions

1) There is a great potential for maize cultivation in Karnataka as the yields are more than 300% of the national average.

2) Downy mildew caused by *S. sorghi*, and leaf blight, caused by *H. turcicum*, are two major diseases of this crop and have become the limiting factors to maize production in this area. The commercial hybrids Deccan and Ganga 5, which are grown extensively in this part, are highly susceptible to these pathogens. However, some

Table 3. Systemic infection on maize (CM 500) sown in sick plots infested with *S. sorghi* oospores.

Row No.	Total plants	Plant age and the No. of plants showing systemic infection				Total plants with systemic infection At maturity
		15 days	28 days	40 days	56 days	
1	98	3(2-3)*	12(4-5)	0	0	15
2	93	6(2-3)	6(4-5)	1(9-10)	1(11-12)	14
3	107	7(2-3)	5(4-5)	3(9-10)	0	15
4	138	10(2-3)	6(4-5)	7(9-10)	0	23
5	100	6(2-3)	16(4-5)	4(10-11)	0	26
6	89	6(2-3)	8(4-5)	0	0	14
7	100	11(2-3)	6(4-5)	1(9-10)	1(12-13)	19
8	115	11(2-3)	1(4-5)	2(10-11)	0	14
9	130	9(2-3)	5(4-5)	2(9-10)	1(15-16)	17
10	94	5(2-3)	4(4-5)	3(9-10)	0	12
11	99	9(2-3)	6(4-5)	3(9-10)	0	18
12	102	4(2-3)	5(4-5)	5(9-10)	0	14
13	100	3(2-3)	6(4-5)	2(9-10)	1(13-14)	12
14	89	7(2-3)	3(4-5)	6(9-10)	1(12-13)	17
15	120	4(2-3)	5(5-6)	2(9-10)	1(12-15)	12

*Numbers within the parenthesis represent the leaves on which chlorosis first appeared.

of the new hybrids involving Phil. DMR 1, Phil. DMR 5, CM 202, CM 111 and Thai Op. 2 Comp. are more resistant than the previously introduced commercial hybrids.

3) Many of the commercial hybrids which have shown susceptibility to DM and leaf blight can be grown in the Rabi (winter) season when the disease incidence is practically nil. This conclusion is drawn on the basis of our field observations and the experiments conducted for the last 2 years. The search for better resistance to *S. sorghi* should continue in Mysore area on account of the large area under maize production. Increased production over the existing levels would be a good indication of progress in this direction. Therefore, most of the research material and hybrids to be introduced should be tested at this location on a large scale.

4) Variations in the symptomatology caused by DM infection should be investigated. Some systemically infected plants sporulate and others do not; some show malformation and others do not; some express symptoms in the seedling stage and others at maturity.

5) The role of conidia should be determined. Although there is a difference in the morphology of the DM which affects maize in Udaipur and at Mysore, this aspect should be studied in great detail to find out whether these are different.

6) The role of DM mycelium present in seeds must be determined specially in view of the rapid spread of this pathogen over a large area of Karnataka and Tamilnadu.

7) Epidemiology needs investigation as little work has been done. Basic work of a fundamental nature should be started so that a better understanding of the pathogens involved may emerge.

8) Tissue culture studies, including axenic culture, of the DMs involved would be helpful in studying the physiology of the pathogens.

9) Our DM research laboratory is geared towards undertaking all these facets of research. A semester course on DMs will be initiated from December 1976 in view of the importance of these diseases to Indian agriculture and the course is open to all.

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