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ETIOLOGY OF STALK ROT AND LODGING IN GRAIN SORGHUM*

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ABSTRACT

The effects of fungi alone, drought-stress alone, and in combination on the development of stalk rot (% lodging) in a sorghum were studied in field experiments at ICRISAT Asia Center, Patancheru and at University of Agricultural Sciences, Dharwad in India. Stalk rot and lodging occurred in drought-stressed, non-fumigated plots with high populations of stalk-rot fungi. In the presence of fungal inoculum, drought-stress accentuated stalk rot by 6 to 100-fold, Fumigation prior to sowing drastically reduced soil fungi (≥ 95%) and also reduced stalk rot and lodging in the drought-stressed plots. In the fumigated and drought-stressed plots, lodging was 7 and 27% as compared to 100% in the non-fumigated and drought-stressed plots. In non-fumigated and drought-stressed plots grain yield was reduced by 20-39%. In the absence of drought-stress, the mean percentage of lodged plants ranged from 2.9 to 17.6%, Irrespective of fumigation. *Fusarium* spp. were isolated from roots and stalks at all plant growth stages, irrespective of drought-stress and fumigation.

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Macrophomina phaseolina was isolated from roots and stalks at and after the soft-dough growth stage, and its frequency increased as the crop aged. Senescence increased in the non-fumigated and drought-stressed plots. These studies partitioned the effects of fungi and drought-stress, and showed that drought-stress favored host colonization by *M. phaseolina* towards crop maturity, that lead to severe charcoal rot, lodging and grain yield loss.

INTRODUCTION

Stalk rots grain sorghum (*Sorghum bicolor* [L.] Moench) are among the most destructive diseases wherever sorghum is grown (Tarr, 1962). In most cases root and stalk rot are two successive phases of the same disease which commences in the roots. Plants weakened by root and stalk rot, lodge easily with loss of harvestable grain (Tullis 1951, Tarr 1962). Stalk rot, caused by *Macrophomina phaseolina* (Tassi) Goid, occurs when sorghum plants are continuously subjected to drought-stress during grain development (Edmunds 1964, Odvody and Dunkle 1979, Pande *et al.* 1990). Similarly, stalk rot, caused by *Fusarium moniliforme* Sheldon was reported by Tullis (1951) and the disease was reproduced in the greenhouse under severe drought-stress from anthesis to mid-dough growth stages (Trimboli and Burgess 1983).

Dodd (1980), hypothesized that stalk rot (lodging) was caused by the interaction of drought-stress and fungal pathogens. Chamberlin (1978) and Henzell and Gillieron (1973), on the other hand, considered plant lodging under drought-stress to be a purely physiological problem. They indicated that drought-stress reduces assimilate supply to the lower part of the sorghum stalk for maintenance respiration causing senescence, disintegration of pith cells and hence lodging. There is no published data to support these two hypotheses. The major problem in field experiments is to separate the individual effects of drought and fungal pathogens.

It is acknowledged that drought-stress alone can caused lodging without assistance from pathogens were inoculum is absent. However, where pathogens are present, drought-stressed plants are invariably invaded by them, and this leads to increased lodging. Low or intermediate levels of drought-stress may be tolerated by the plant except when combined with the pathogen(s) (Mughogho and Pande 1984). The objective of this study is to test the above hypothesis by separating the effects of drought-stress (by with holding irrigation) and the pathogen (by eliminating the pathogen using soil fumigants) in the development of stalk rot.

MATERIALS AND METHODS

Experimental locations, soils and season

Two field experiments were conducted in the postrainy season (Sept. to Mar.) at the experimental farm of the University of Agricultural Sciences, Dharwad (15° 28'N

and 25° 2'E) in 1984-85 and 1985-86, and at ICRISAT Asia Center, Patancheru (17° 30'N, 78° 18'E) in 1985-86 and 1986-87 on Vertisols with previous history of epidemics of stalk rot and lodging.

The sowing dates, plot sizes, soil moisture contents at the time of soil fumigation and total rainfall during crop growth period, were given in Table 1. In 1984-85, the crop was sown on 28 November 1984 at Dharwad and a total rainfall of 2.0mm was recorded during the entire period of the experiment. In 1985-86, sowing was done on 10 September 1985 at Dharwad and on 17 September 1985 at Patancheru, A well distributed rainfall of 75.8 mm was received in September soon after sowing and was followed by another 94.2 mm of rainfall in the first two weeks of Octover. Thereafter no precipitation occurred until grain maturity at Patancheru. At Dharwad only 18.8 mm of rainfall was recorded. In 1986-87, sowing was done on 19 September 1986 at Patancheru and a total rainfall of 99.2 mm was received during the entire period of the experiment. Of the total rainfall, 53.6 mm was received after the fumigation treatment when plots were still under polyethylene covers and remaining precipitation occurred during the 7-8 fully-expanded-leaf growth stage on the crop.

Experimental design, soil fumigation and drought-stress treatments

The experimental design at Dharwad in the 1984-85 season was a split-plot with six replications (Gomez and Gomez 1976). Plot size was 8 X 8 m and plots were separated from each other by a 5 m wide path. Soil fumigation and drought-stress treatments were allocated to main and sub-plots, respectively. Soil moisture content in the test plots at 0-15 cm depth before fumigation, as estimated by the gravimetic method, ranged from 16 to 19% which was optimum for fumigation. The aim of soil fumigation is to eliminate the soilborne fungi associated with sorghum stalk rot. The soil fumigant Dazomet Basamid-granular (R) (tetrahydro-3,5-dimethyl-2H-1, 3.5-Thiadiazine-2-thione, Manufacture by BASF, West Germany) was applied at the rate of 80 gm^{-2} by mixing it thoroughly with the well pulverized soil up to 30 cm depth in test plots. Treated plots were perfo-irrigated for 30 min. (equivalent to 4 cm rainfall) and covered for 18 days with opaque polyethylene sheets of 1000 gauge thickness. The polyethylene sheets were buried in the soil at the edges to 30 cm depth and sealed with soil. On the 19th day, the covers were removed, soil was loosened and left open for aeration for 4 days before sowing. Drought-stress was created by withholding irrigation at the boot leaf stage. In the no drought-stress treatment irrigation was continued up to physiological maturity.

Four-treatment combinations were obtained to compare stalk rot development:

1. Soil fumigation with basamid x drought-stress;
2. Soil fumigation with basamid x no drought-stress;
3. No soil fumigation x drought-stress;

3. No soil fumigation x no drought-stress;

In the 1985-86 experiment, at both locations, the crop developed under receding soil moisture. The experiment was laid out in a randomized complete block design with three replications. Plot size was 8 x 8 m and plots were separated from each other by a 5 m wide path. Soil in each plot was thoroughly rotavated after ploughing and the polyethylene tarp was buried in the soil at the plot margins before fumigation. Soil moisture content, estimated by the gravimetric method, was 17% at Patancheru and 23% at Dharwad. Three randomly selected plots wre fumigated with methyl bromide (Dowfume MC-2) at the rate of 500 g m^{-2}. The fumigant was released in the gaseous form under the raised polyethylene tarp through a plastic tube from pressurized cans with the help of an applicator. Polyethylene tarps were removed four days after fumigation and sowing was done 2 days later.

Stalk rot development was monitored in two treatment :
1. Fumigation with methyl bromide x drought-stress;
2. No fumigation x drought-stress.

In 1986-87 postrainy season at Patancheru, both soil fumigants (basamid and methyl bromide) were used. The design was a split-plot with three replications and 15 x 10 m sub-plot size with a 6 m wide gap. Soil fumigants were assigned to main plots and drought-stress to sub-plots. Drought-stress was created by withholding irrigation at the boot leaf stage. Soil fumigants were applied as in previous experiments and the soil moisture content before fumigation was 16%. An additional treatment in which plots were simply covered with polyethylene sheets for 18 days without fumigation was included. In all, eight treatment combinations of drought-stress and soil fumigation were obtained to study stalk rot development as follows :

1. Fumigation with basamid and drought-stressed
2. Fumigation with methyl bromide and drought-stress
3. Non fumigated but covered with polyethylene tarp and drought-stress
4. No fumigation and drought-stressed
5. Fumigation with basamid and no drought-stressed
6. Fumigation with methyl bromide and no drought-stressed
7. Non fumigated but covered with polyethylene tarp and no drought-stressed
8. No fumigation and no drought-stressed

Certified seeds of the stalk rot-susceptible hybrid cultivar CSH 6, procured from the National Seeds Corporation of India, were sown at the rate of 35 kg ha^{-1} in 12 rows per plot with 0.75 cm distance between rows. Plants population of 133,350 plants

was maintained. Crop maintenace, fertilization and plant protection measures were owed, as explaind in Pande *et al.*, (1990).

antitative estimation of fungi in field soil

Soil samples were collected from three depths (0-5, 5-10 and 10-15 cm) before igation and 4 days later. Samples were air-dried grounded sieved and soil from ee depths were mixed to make a composite sample. Soil samples were assayed for pulations of fungi on following three media:

1. Modified czapek-dox agar (MCDA) (Sharma and Singh 1973) a selective media for isolating *Fusarium* spp.
2. Chloroneb-mercuric chloride-rose bengal agar (CMRA) (Meyer *et al.*, 1973) for isolating *M. phaseolina*
3. Potato dextrose agar (PDA) modified by adding 0.2g dicrystisin-S to 1L of cool molten medium for isolating general fungi.

Fungal population per gram of soil was estimated using a 200 mg of composite il sample sprinkled uniformly over the solidified surface of 20 Petri plates for each f five replications and each medium.

eedborne fungi

Soilborne fungi on the seeds of CSH 6 were estimated by plating 300 seeds on ne above three media to determine their seedborne infection in the stalk rot etiology.

solation and identification of fungi from sorghum roots and stalks

Fungi colonizing roots and stalks were isolated by destructive sampling of plants 5 plants) from each treatment at seven plant growth stages described as follows:

1. 30 days after emergence (300DAE)
2. Boot leaf (BL)
3. Fifty percent (50%) stand in flower (DTF)
4. Milk (ML)
5. Soft dough (SD)
6. Hard dough (HD)
7. Physiological maturity (PM)

Root, crown and nodal portions were separated, washed in water, surface sterilized in mercuric chloride (1:1000) and plated on the three media (MCDA, PDA, and CMRA), at each plant growth stage. Plates were incubated at 30°C for 7 days and fungal colonies occurring in each media were counted and pooled. Identification of fungi was done

under light microscope using slide-culture method (Larsen and Covey, 1979).

The crown was considered as part of the root system, therefore, data on fungi isolated from crowns were combined with data from roots. Isolates from nodes were considered as isolates from stalks. The number of plated samples that yielded a fungal species was calculated as a percentage of the total samples from that growth stage and was defined as "isolation frequency". The percent isolation frequencies of all fungi were pooled into three groups : *Fusarium* spp., *M. phaseolina*, and other fungi which did not belong to these two genera (Table 1). The isolation frequencies of these three groups of fungi from roots and stalks in different treatment combinations were compared for each location and year.

Measurement of plant senescence

Available green leaf area (GLA) was used to measure the progess of senescence. Ten randomly selected plants were tagged at 30 DAE in each replication of a treatment and GLA was assessed at the same growth stages (30 DAE to PM) used for isolation of fungi from roots and stalks in 1984-85 and 1985-86 seasons. In 1986-87 season, of the two fumigated (methyl bromide and basamid) and the two non-fumigated (uncovered and covered with polyethylene sheets) treatments, GLA was assessed only from plots fumigated with methyl bromide and uncovered plots, respectively. Total leaf area and dry leaf area of all available leaves was determined by measuring the lenght (cm) and width (cm) of the individual leaves. Length was measured from base to the tip of a leaf, and width was measured at the center of a leaf blade. Total leaf area and senesced leaf area were separately averaged over replications of a treatment for each growth stage. Available GLA for each growth stage was expressed in percentage [GLA (%)= total leaf area (cm^2) - dry leaf are (Cm^2) divided by total leaf area x 100]. More than 50% yellow leaves were considered as senesced (dry).

Stalk rot evaluation

All plants in the center of each plot were tagged at 30 DAE. The tagged area was 4 X 3 m in 1984-85 and 1985-86 seasons and 9 X 3 m in 1986-87 season. Lodged plants were counted at seven plant growth stages (30 DAE, BL, DTF, ML, SD, HD, and PM) and expressed as % lodging. Seven days after PM other stalk rot disease parameters were recorded (Pande *et al.*, 1989, 1990) to confirm stalk rot infection in lodged and non-lodged plants in each treatment combination.

Grain yield

To determine the effect of stalk rot on grain yield, panicles both from lodged and standing plants of the tagged area in each treatment combination were harvested for the experiments conducted in 1985-86 and 1986-87 seasons. For each replication plot yield and 1000-grain weight were taken after sun drying using following formula :

Grain yield and 1000-grain weight = (a-b)/a

where a = Yield in fumigated and drought-stressed plots

b = Yield in non fumigated drought-stressed

tatistical analysis

Data for each location and season were analyzed separately for analysis of variance sing the GENSTAT statistical program for respective experimental designs used in iis study, and correlations were drawn among different disease parameters (Gomez nd Gomez 1976, Little and Hills 1978).

RESULTS

:nvironmental conditions

Air temperatures were similar at the two locations and ranged from 13 to 22°C min.) and 28 to 36°C (max.) during the three seasons. Soil temperatures were higher 19-28°C (min.) and 30-42°C (max.)] than air temperatures. Both air and soil emperatures increased continuously as the crop development and matured. The cultivar SH 6 flowered at 54-60 days and reached PM at 95-112 DAE.

Rainfall did not interfere with the irrigation schedule used for the induction of lrought-stress during 1984-85 and 1986-87 seasons. In 1985-86 rainfall occurred at oth locations but only during the initial stages of crop growth.

Soilborne fungi

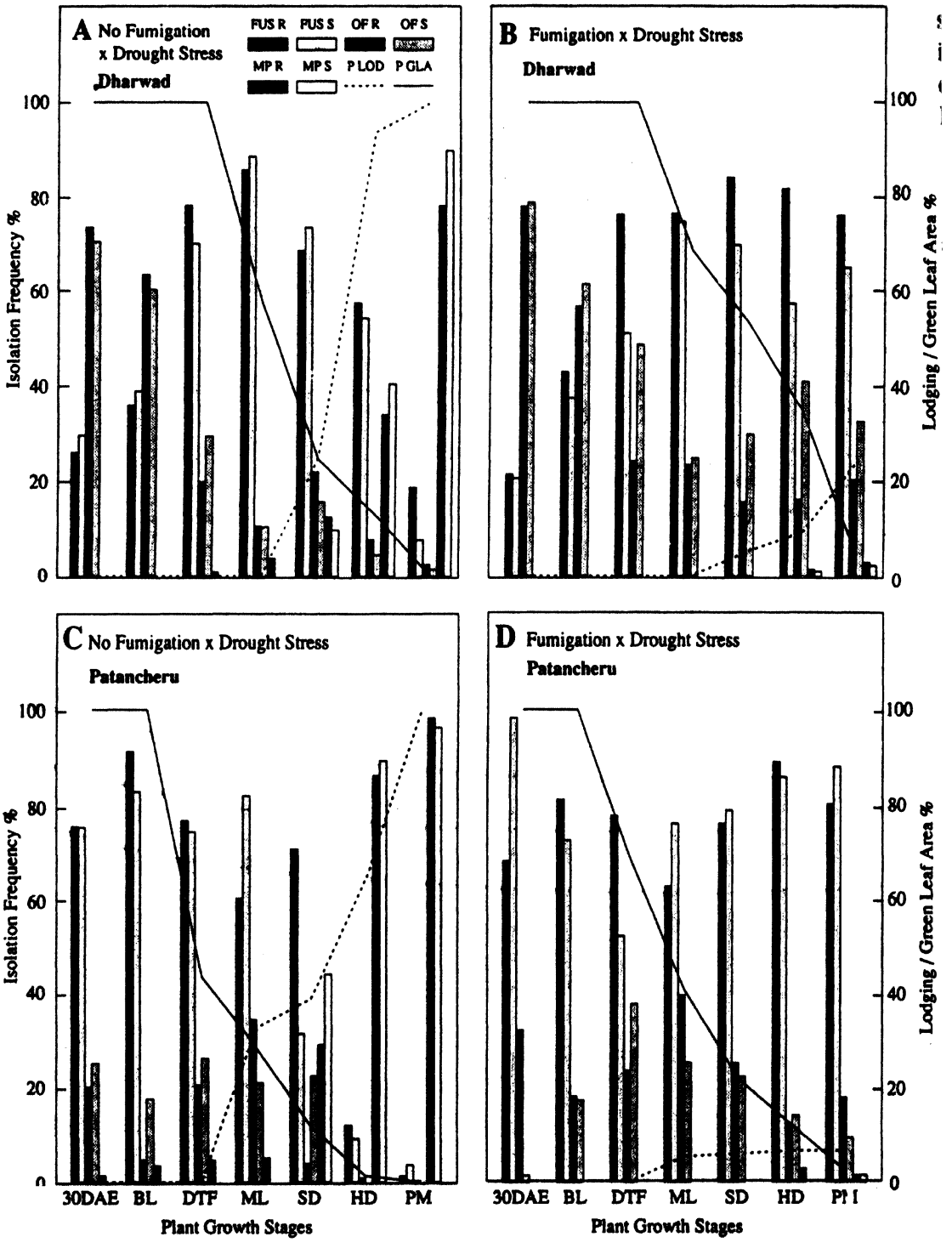
Initial soil populations of *Fusarium* spp., *M. phaseolina* and other fungi differed n each year and location. Drastic reductions (≤95%) in fungal populations were recorded ifter fumigation. Both fumigants were equally effective in reducing the soil fungal lora. Populations of *M. phaseolina* were lower than those of combined *Fusarium* spp. Table 1).

Seedborne fungi

Fusarium spp. (≤2%) were isolated in the sorghum seeds. *M. phaseolina* was not isolated from the seeds. Other Fungi isolated were species of *Aspergillus, Rhizopus, Curvularia, Alternaria, Helminthosporium.*

Fungal colonization of roots and stalks

Sorghum roots and stalks were colonized by more than one *Fusarium* spp. and other fungal species except *M. Phaseolina,* at all the seven plant growth stages and treatment combinations of fumigation and drought-stress (Fig.1-3). In the 1984-85 season, stalk colonization by *Fusarium* spp. was not recorded up to the BL stage in non-fumigated treatments (Fig. 1A and C) and at 30 DAE in the fumigated treatments (Fig. 1B and D). Thereafter both roots and stalks were colonized by *Fusarium* spp. and other fungal species up to PM (Fig. 1A-D).


A No Fumigation x Drought Stress
Dharwad
FUS R
FUS S
OF R
OF S
MP R
MP S
P LOD
P GLA
B Fumigation x Drought Stress
Dharwad
C No Fumigation x Drought Stress
Patancheru
D Fumigation x Drought Stress
Patancheru
Isolation Frequency %
Lodging / Green Leaf Area %
0
20
40
60
80
100
30DAE
BL
DTF
ML
SD
HD
PM
Plant Growth Stages

In the 1985-86 season, *Fusarium* spp. colonized roots and stalks throughout the ıpling period in all treatments and at both locations (Fig. 2 A-D). A similar trend both root and stalk colonization was obtaind in the 1986-87 season at Patancheru, :ept that none of the fungal species, including *Fusarium* spp., were isolated at 30 ıE from no-drought-stress treatments (Fig. 3 C and D).

Fusarium spp. comprised >50% of the isolates from roots and stalks at DTF, ML] SD growth stages irrespective of treatment combinations, seasons and locations. ıong the Fusarium spp., *F. moniliforme* var. *subglutinans* Wollenw. & Reinking] *F. oxysporum* Schlecht. were predominant. Species of *Rhizoctonia, Exserohilum, 'ernaria, Acremonium,* and *Curvularia* were also isolated. the occurrence of these ıgi fluctuated at different plant growth stages in all treatments across seasons and :ations (Fig. 1-3).

In non-fumigated and drought-stressed plots, *M. phaseolina* was isolated from roots d stalks at or after SD. *M. phaseolina* was never isolated before BL except at ıtancheru in 1985-86 season, where it occurred in 2% of root samples even at 30 AE. Substantial reduction (20-95%) in the occurrence of *Fusarium* spp. and other ngi was recorded as the isolation frequencies to *M. phaseolina* increased predominantly roots and stalks (Fig. 1A, 2A, 2C and 3A).

lant senescence

Generally GLA decreased continuously as the crop progressed towards maturity respective of treatment combinations (Fig. 1-3). However, considerable differences the GLA were obtained between drought-stress and no-drought-stress treatments. In ıe no-drought-stress treatment GLA was higher (20-60%) at HD and PM growth stages ıan in the drought-stress treatments (Fig. 1 and 3). Fumigation delayed the progress f senescence in the drought-stress treatment.

ıcidence and development of stalk rot and lodging

In the non-fumigated and drought-stressed treatment, stalk rot development, as ıeasured by periodic lodging, was significantly (P=<0.05) higher across years and ıcations than in other treatments (Figs. 1-3). In this treatment, lodging started at SD ı the 1984-85 season, and in the other two seasons (1985-86 and 1986-87) lodging tarted at ML, and lodging increased continuously and at PM, 74-100% plants had ıdged.

In fumigated and drought-stressed treatment, lodging was low (5-27%) except in he 1986-87 season at Patancheru, where up to 50% lodged plants were recorded at 'M in basamid-treated plots. Number of lodged plants showing soft stalks were at ower percentage (6-19%) in the fumigated plots, than in the non-fumigated plants in he drought-stressed treatment (Table 2-3).

The visible incidence of *M. phaseolina* in roots and stalks was also significantly P<0.05) higher (< 80%) in the non-fumigated x drought-stress than in the fumigated

ıle 1. Locations, dates of sowing, soil moisture at the time of sowing, plot size, and total rainfall ıng crop season.

ar & cation	Date of sowing	Soil moisture content at the time of fumigation	Total rainfall during the crop season	Plot size
84-85 arwad	28.11.84	17.5%	2.0	8 x 8
85-86 arwad	10.09.85	23.0%	18.8	8 x 8
85-86 C	17.09.85	17.0%	169.4	8 x 8
86-87 C	19.09.86	16.0%	99.2	15 x 10

Soil moisture content in the soil before fumigation was estimated using Gravimetric method.

Total rainfall during the entire crop season

A gap of 6 m was given between any two plots

Table 2. Colonies of fungal species isolated from soil before and after fumigation at Patancheru and Dharwad in postrainy seasons 1984-85, 1985-86 and 1986-87.

Season	Location	Fungal species	Colonies-soil g^{-1}		Reduction in colonies after fumigation (%)
			Before fumigation	After fumigation	
1984-85	Dharwad	*Fusarium* spp.[a]	12405	222	98.2
		M. phaseolina	5865	7	99.2
		Other fungi[b]	3120	55	98.2
1985-86	Patancheru	*Fusarium* spp.	11330	270	97.6
		M. phaseolina	8825	0	100.0
		Other fungi	4685	90	95.2
1985-86	Dharwad	*Fusarium* spp.	13985	225	98.4
		M. phaseolina	6125	0	100.0
		Other fungi	4785	90	98.1
1986-87	Patancheru	*Fusarium* spp.	15135	180	98.8
		M. phaseolina	5075	1	99.9
		Other fungi	1820	20	98.9

a *F. moniliforme* var. *subglutinans* and *F. oxysporum* were predominant among the seven *Fusarium* spp. isolated.

b *Rhizoctonia solani, Trichoderma harzianum, Curvularia lunata, Exserohilum rostratum* and species of *Alternaria, Acremonium*, and *Phoma*.

able 3 Mean lodging, soft stalk, and visible *Macrophomina phaseolina* incidence in stalks of the orgnum hybrid CSH 6 under different treatment combinations of soil fumigation with basamid and ioisture stress at Dharwad in postrainy season 1984-85

	Treatments and disease parameters					
	Lodging (%)		Soft stalk (%)		Visible M. phaseolina incidence (%)	
	DS	NDS	DS	NDS	DS	NDS
umigation	27.4 (30.8)[b]	3.4 (9.6)	6.4 (12.8)	0.0[a]	10.2 (16.7)	0.0
o fumigation	71.9 (59.4)	3.6 (10.7)	63.6 (53.5)	0.0	81.9 (66.6)	0.0
SD P=0.05						
rought-stress	(9.60)		(14.90)		(15.9)	
umigation	(7.53)					
rought-stress x umigation	(11.20)					

ro values were not used in LSD calculations.

gures in parenthesis are values using angular transformation.

= Drought stressed

)S = Non-drought stressed

x drought-stress treatments (Tables 2-4). This fungus was not observed in split roots and stalks in the no-drought-stress treatment in the 1984-85 season (Table 2). However, in 1986-87 seasons, *M. phaseolina* was observed in a few roots and stalks in this treatment (Table 4).

Across seasons and locations lodging was positively correlated with soft stalk (r=0.86 to 0.96; P<0.01), mean number of nodes crossed (r=0.86 to 0.98; P<0.01), root infection (r=0.70 to 0.75; P<0.01), and visible incidence of *M. phaseolina* (r=0.95 to 0.97; P<0.01). Lodging correlated negatively with plant senescence (r= -0.59 to 0.73; P <0.01) plot yield (r=-0.52 to 0.73; P<0.01) and grain mass (r=0.60 to 0.76; P<0.01).

Relationship between plant senescence, fungal colonization and disease development at different plant growth stages

No statistical test was used to establish a relationship between these components of the experiment. However, Fig. 1, 2 and 3 present the possible relationships between these components at different growth stages. Colonization of roots and stalks by *Fusarium* spp. was not affected by plant senescence, or by drought-stress and soil fumigation treatments. Isolation frequencies of *Fusarium* spp. were higher than other fungi, except *M. phaseolina,* in all treatments, and at all plant growth stages. In the no-fumigation x drought-stress treatments, *M. phaseolina* colonized both roots and stalks beginning at the SD plant growth stage and its isolation frequencies continued to increase at later growth stages. The increase in the frequency of *M. phaseolina* coincided with the decrease in GLA and increased lodging (Fig. 1A, 2A, 2C and 3A). This occured in all three seasons at the two locations.

Grain yield loss

In the 1985-86 and 1986-87 seasons, 18-22% less grain mass (1000 grains), and 20-39% less yield were observed in the non-fumigated x drought-stress treatment than in the fumigated x drought-stress treatment. Reduction in yield in the former treatment related to increased stalk rot and lodging. (Tables 3 and 4).

DISCUSSION

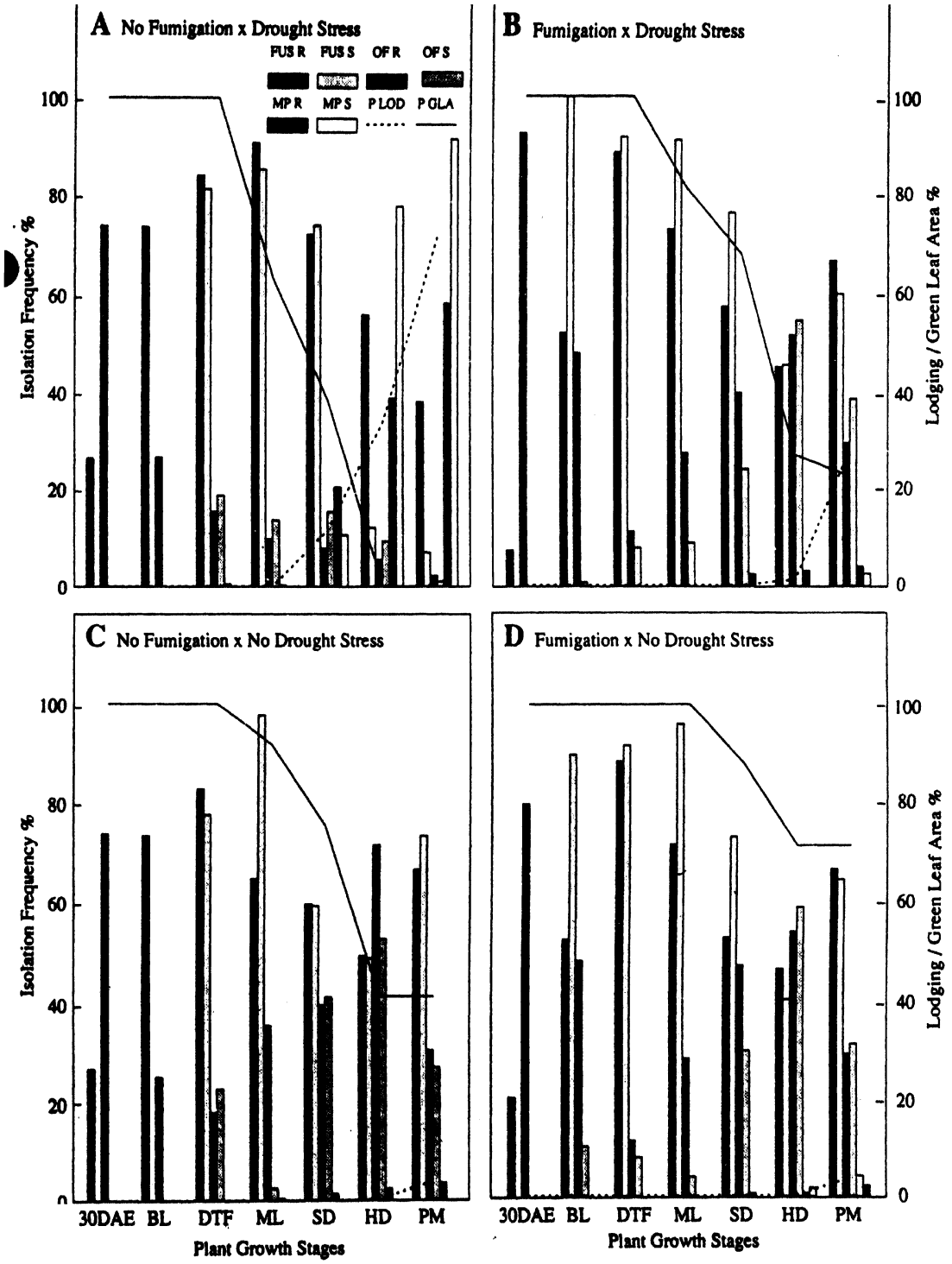
These studies demonstrated the individual and combined effects of fungi and drought-stress on the development of charcoal stalk rot and lodging. Our results showed that the combined effect of drought-stress and presence of fungi has caused extensive stalk rot and lodging than in the absence of fungi, as effected by soil fumigation. Colonization of roots and stalks by fungi alone in the absence of drought-stress, did not lead to the development of stalk rot. Soil moisture stress condition has greatly influenced the parasitic ability of *M. phaseolina* which colonized nearly mature drought-stressed plants much more vigorously than did any other fungi but was a poor colonizer under the no-moisture stress conditions regardless of growth stage (Figs. 1-3). This

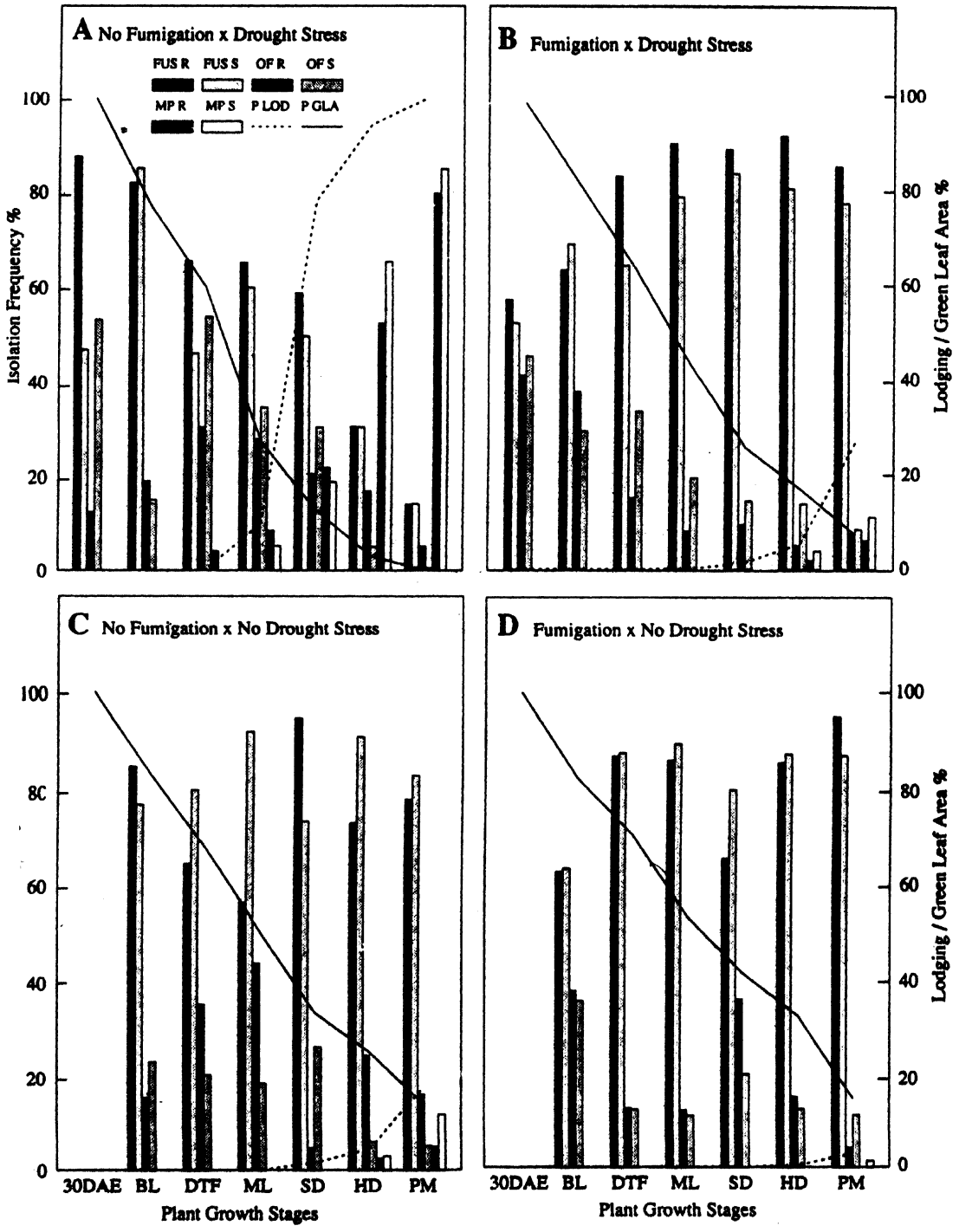
under different combinations of soil fumigation and drought-stress [illegible]

Treatments, disease parameters and locations	Lodging (%)		Soft stalk (%)		9 x 3 m plot yield (kg)		1000 grain weight (g)		Visible *M. phaseolina* incidence (%)	
	DS	NDS	DS	NDS	DS	NDS	DS	NDS	NS	NDS
Soil fumigation with methyl bromide	27.4 (31.4)	2.9 (5.7)	11.3 (18.9)	0.8 (3.0)	11.6	14.2	19.4	23.8	11.0 (16.8)	1.2 (3.6)
Soil fumigation with basamid	50.1 (45.0)	12.2 (20.4)	19.1 (25.9)	3.8 (10.1)	13.0	15.6	21.1	22.9	35.0 (36.2)	1.9 (5.5)
No soil fumigation but covered with polyethylene sheets	99.5 (86.9)	16.4 (23.6)	96.6 (80.8)	9.3 (17.3)	7.2	14.2	15.3	22.3	96.7 (80.5)	30.9 (33.3)
No soil fumigation and uncovered (control)	100.0 (90.0)	17.6 (24.5)	99.6 (88.0)	3.7 (9.9)	7.8	14.1	16.5	22.4	96.9 (84.1)	12.2 (17.6)
LSD (P=0.05)										
Drought-stress	(6.56)		(6.99)		1.21		2.52		(10.57)	
Fumigation	(8.15)		(4.02)		3.10		1.18		(18.38)	
Drought-stress x fumigation	(9.15)		(8.82)		2.17		1.92		(15.96)	
Percent loss in yield due to stalk rot causing pathogens[b]					39.1		21.5			

a DS = Drought-stress; NDS = no drought-stress.
b Figures in parenthesis are values using angular transformation
c Yield of fumigated and drought-stressed - yield of non-fumigated and drought-stressed

$$\frac{\text{Yield of soil fumigated and drought-stressed}}{\text{Yield of soil fumigated and drought-stressed}} \times 100$$


A No Fumigation x Drought Stress
FUS R
FUS S
OF R
OF S
MP R
MP S
PLOD
PGLA
B Fumigation x Drought Stress
C No Fumigation x No Drought Stress
D Fumigation x No Drought Stress
Isolation Frequency %
Lodging / Green Leaf Area %
0
20
40
60
80
100
30DAE
BL
DTF
ML
SD
HD
PM
Plant Growth Stages


A No Fumigation x Drought Stress
FUS R
FUS S
OF R
OF S
MP R
MP S
P LOD
P GLA
B Fumigation x Drought Stress
C No Fumigation x No Drought Stress
D Fumigation x No Drought Stress
Isolation Frequency %
Lodging / Green Leaf Area %
0
20
40
60
80
100
30DAE
BL
DTF
ML
SD
HD
PM
Plant Growth Stages

Soil fumigation had almost eliminated the *M. phaseolina*, *Fusarium* spp. and other soil fungi propagules. However, eventually a high rate of recolonization by *Fusarium* spp. was obtained even in the fumigated plots, which was perhaps due to airborne fusaria and contamination through irrigation. We have not estimated the fungal population from air and water, however, the experimental evidence on the recolonization of the fumigated or sterile soils by *Fusarium* spp. provided by several workers (Watanabe *et al.*, 1970, Ferrant and Corroll 1981) supports this view. The eventual recolonization of fumigated plots resulted in equally high isolation frequency of *Fusarium* spp. in roots and stalks from this treatment. The population of seedborne *Fusarium* spp. were negligible, and therefore unlikely to contribute much to the soilborne inoculum and sorghum stalk rot syndrome. Similarly, The seedborne *F. moniliforme* was negatively correlated with root and stalk colonization and corn stalk rot disease (El-Meleigi *et al.*, 1983).

Average air and soil temperatures were similar and favorable throughout the season for root and stalk colonization by *Fusarium* spp., *M. phaseolina* and possibly other fungi as indicated by isolation data. Rainfall if any, restricted either during the early growth stages of the crop or coincided with pre-flowering irrigation and did not interfere with moisture stress schedule in these experiments. In general, these environmental conditions were within the range that favors root and stalk colonization by *Fusarium* spp. particularly *F. moniliforme* (Tullis 1951, Trimboli and Burgess 1983) and *M. phaseolina* infection and root and stalk rot development in grain sorghum (Pande *et al.*, 1989, 1990).

The lodging and stalk rot development in the non-fumigated and drought-stress plots support the hypothesis that charcoal stalk rot and lodging in grain sorghum is an interaction of moisture stress and the fungal pathogen. These findings strongly support the data on *Fusarium* stalk rot in grain sorghum (Henzell *et al.*, 1984) where *F. moniliforme* remained dominant throughout whereas in the present investigation *M. phaseolina* became dominant towards grain-maturity, though *Fusarium* spp. were always isolated from roots and stalks. Similar to our results, significant reduction in the soil population of *M. phaseolina* and less disease development in fumigated plots were reported in soybean (Gray 1978, Pearson, *et al.*, 1984) and forest nurseries (Watanabe *et al.*, 1970, Rowan 1971).

The results of the present investigations separae the effect of the pathogen and drought-stress on yield components and demonstrated the importance of fungi in directly causing charcoal stalk rot and lodging and also reducing yields. These results contradict with the findings of Henzell and Gullieron (1973); Chambers (1978); and Henzell *et al.*, 1984, who proposed that stalk rot and lodging occur only due to physiological stress (drought-stress) caused by low source/sink ratio at the grain-filling stage and that the Dodd's hypothesis (1980), that the interaction between host, pathogen and drought-stress can alone cause stalk rot and lodging.

Highly significant correlations between senescence, lodging and stalk rot confirm

our earlier results (Pande *et al.*, 1989, 1990) and further suggest that lodging is the most useful parameter to measure stalk rot resistance.

The data presented in this paper provide the evidence that fungi (*M. phaseolina*) and drought-stress are the two essential components in the etiology of stalk rot (Charcoal rot) and lodging of grain sorghum.

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Isolation frequencies of fungal species [occurrence of *Fusarium* spp. collectively in roots (FUS R) and stalks (FUS S); other fungal spp. collectively in roots (OF R) and stalks (OF S); and *Macrophomina phaseolina* individually in roots (MP R) and stalks (MP S)], lodging (P LOD) and green leaf area (P GLA) at 30 days after emergence (30 DAE), boot leaf (BL), 50% stand in flowering (DTF), milk (ML), soft dough (SD), hard dough (HD), and physiological maturity (PM) growth stages of the sorghum hybrid CSH 6 grown under different combinations of soil fumigation with basamid and drought-stress at Dharwad in 1984- 85 postrainy season.

Isolation frequencies of fungal species [occurrence of *Fusarium* spp. collectively in roots (FUS R) and stalks (FUS S); other fungal spp. collectively in roots (OF R) and stalks (OF S); and *Macrophomina phaseolina* individually in roots (MP R) and stalks (MP S)], lodging (P LOD) and green leaf area (P GLA) at 30 days after emergence (30 DAE), boot leaf (BL), 50% stand in flowering (DTF), milk (ML), soft dough (SD), hard dough (HD) and physiological maturity (PM) growth stages of sorghum hybrid CSH 6 grown under soil fumigation with methyl bromide and receding stored soil moisture (drought-stress) at Patancheru in 1985-86 postrainy season.

Isolation frequencies of fungal species [occurrence of *Fusarium* spp. collectively in roots (FUS R) and stalks (FUS S); other fungal spp. collectively in roots (OF R) and stalks (OF S); and *Macrophomina phaseolina* individually in roots (MP R) and stalks (MP S)], lodging (P LOD) and green leaf area (P GLA) at 30 days after emergence (30 DAE), boot leaf (BL), 50% stand in flowering (DTF), milk (ML), soft dough (SD), hard dough (HD) and physiological maturity (PM) growth stages of sorghum hybrid CSH 6 grown under different combinations of soil fumigation with methyl bromide and drought-stress treatments at Patancheru in 1986-87 postrainy season.