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ABSTRACT

The effects of sowing dates and plant densities on charcoal rot development in sorghum cultivars grown under receding soil moisture and natural infection conditions were studied during two postrainy seasons at four locations in India. In both the seasons, maximum charcoal rot infection (as measured by lodging) occurred in the first sowing. Significant ($P < 0.05$) differences were recorded in charcoal rot incidence among the test cultivars, and E 36-1 from Ethiopia was resistant at all locations. High incidence of lodging was recorded even in a population of 133,350 plants ha -1 and this plant density was found to be adquate to quantify genotypic differences in lodging. Lodging was significantly ($P < 0.05$) correlated with soft stalk, number of nodes crossed, root damage and plant senescence.

Introduction

Charcoal rot of sorghum (*Sorghum bicolor* (L.) Moench), caused by *Macrophomina phaseolina* (Tassi) Goid, is a major disease in the postrainy season (Anahosur and Patil, 1981). The disease occurs most often when plants are drought stressed during grain filling (Edmunds 1964, Odvody and Dunkle, 1979). Sorghum grown at close spacings had a higher incidence of charcoal rot than a widerspaced crop (Wadsworth and Sieglinger, 1950). Patil et al. (1982) observed cultivar differences in the incidence of charcoal rot at different plant densities. A higher incidence of charcoal rot was noted in sorghum cultivars sown in September than in October sowings (Anahosur and Patil, 1981). Data on the combined effects of these factors and their interactions on charcoal rot development are not available. In this paper we report the effect of sowing dates, plant densities, and a combination of factors that are most likely to favour charcoal rot development under natural infection conditions.

Materials and Methods

Experiments were conducted during the postrainy season at four sites (Patancheru, Nandyal and Madhira in Andhra Pradesh and Dharwad in Karnataka) in 1981-82, and at two sites (Patancheru, and Dharwad) in 1982-83 on fields (Vertisols and Alfisols) with previous histories of charcoal rot epidemics. The test genotypes included local landraces: E 36-1 (IS 30469), Annegeri-1 and M 35-1 (Maldandi), and improved cultivars: SPV 422, SPV 424, and CSH 6.

The experiments were conducted in split-split-plot design in 1981-82 and split-plot design in 1982-83 in a plot size of 4 X 4.5 m with three replications. The main plots were assigned to sowing dates and test cultivars

to sub-plots. In the 1981-82 season, the sub-sub plots had three plant population densities (D_1 = 66,675, D2 = 133,350 and D3 = 266,700 plants ha -1.

As equally severe charcoal rot developed in the 1981-82 season in both D_2 and D_3 planting densities (Table 2), therefore, in 1982-83 season experiment was raised only at 133,350 plants ha^{-1}. Sowings were done at the end of the rainy season, the first sowing coincided with the local farmers' sowing time. Successive sowings were done at intervals of 7-20 days, depending upon the rainfall distribution. In the absence of sufficient rainfall, experiements were irrigated (20 L 4 $rows^{-1}$ of 4 m length) initially after sowings, to get uniform emergence and crop stand. No supplementary irrigation was given after emergence and the crop was left to grow under natural conditions. All sowings received 40 kg N and P2O5 ha-1 as basal fertilizer and urea @ 40 kg ha-1 was applied as a top dressing 30 days after emergence and thinning. To protect the crop from shoot fly and stem borer damage, carbofuran granules were applied @ 15 g 4m-1 row length at sowing, followed by intensive sprays of endosulfan (0.35% a.i.) at 10-day intervals from 30 days after emergence to flowering.

Seven days after physiological maturity charcoal rot parameters (lodging, soft stalk, progress of infection up the stalk (calculated as number of nodes crossed), root infection, and plant senescence) were recorded on each plant in the four center rows in each plot. Total plants in each plot were counted before the initiation of loding. The number of lodged and soft-stalked plants were used to calculate percentage lodging and percentage soft stalks, respectively. Plants were uprooted and scored for percentage root infection on a 1-5 rating scale (1 = no infection, 2 = < 10 %, 3 = 11 to 25 % , 4 = 26 to 50% and 5 = > 50 % roots infected). Plant senescence was measured on 1-5 rating scale (1 = foliage completely green, 2 = < 10%, 3 = 11 to 25 %, 4 = 26 to 50 % and 5 = 50 % foliage brown and dry). Data were analyzed statistically and correlations were computed among different disease parameters to identify the most suitable parameters for estimating charcoal rot severity.

Results and Discussion

As there was positive correlation between lodging and other disease parameters (Table1), percentage lodging was used to discuss the results.

Sowing Dates : Significant differences ($P < 0.05$) were recorded in charcoal rot incidence in different cultivars sown on different dates. Maximum lodging developed in the first sowing at all the locations in both the seasons (Tables 2 and 3). Thereafter, a gradual decrease was observed in charcoal rot incidence in all the test cultivars, irrespective of locations and seasons.

The difference in the disease incidence emphasized the importance of sowing time with respect to environmental factors prevailing at a particular test location. Maximum charcoal rot developed in cultivars sown by mid-September at Patancheru and Dharwad. Anahosur and Patil (1981) reported that CSH 8R sown during September had the highest incidence of charcoal rot at Dharwad and our results confirm their observation. However, >90 % CSH 6 plants developed charcoal rot in the early sowing (4 September 1981) at Madhira and Nandyal (12 October 1981) which was later than the normal postrainy-season sowing.

Table 1.Correlation coefficients among scores of sorghum charcoal rot parameters at four locations in the 1981-82 postrainy season

Disease Parameter	Percent soft stalk				Mean No. of nodes crossed				Mean score for root infection				Plant senescence			
	PAT	DH	ND	MD	PAT	DH	ND	MD	PAT	DH	ND	MD	PAT	DH	ND	MD
Percent lodging	0.99**	0.99**	0.98**	0.97**	0.91**	0.92**	0.84**	0.97**	0.43**	0.91**	0.94**	0.90**	0.75**	0.79**	0.88**	0.84**
Percent soft stalk					0.91**	0.92**	0.89**	0.98**	0.42**	0.91**	0.93**	0.83**	0.76**	0.80**	0.90**	0.87**
Mean No. of nodes Crossed									0.42**	0.85**	0.78**	0.88**	0.66**	0.75**	0.81**	0.83**
Mean score for root infection													0.48**	0.69**	0.83**	0.80**

** significant at P<0.01. a/ PAT = Patancheru, DH= Dharwad, ND= Nandyal, MD = Madhira

Table 2. Percentage lodging in two sorghum cultivars at three densities sown on different dates at four locations postrainy season sowing (1981-82)

Locations	Sowing date	Cultivar, plant destiny and % lodging: E 36-1 D1	E 36-1 D2	E 36-1 D3	E 36-1 Mean	CSH 6 D1	CSH 6 D2	CSH 6 D3	CSH 6 Mean	Grand mean
Patancheru	14 Oct	5.0	5.9	7.4	6.1	33.3	77.9	83.5	64.9	35.5
	23 Oct	0.8	2.5	3.4	2.2	52.5	50.4	68.9	57.3	29.8
	7 Nov	0.0	0.8	0.9	0.6	49.2	51.3	54.3	51.6	26.1
	16 Nov	2.5	2.5	3.8	2.9	29.6	51.3	52.1	44.3	23.6
	Mean	2.1	3.0	3.9	3.0	41.2	57.7	64.7	54.5	28.7
Dharwad	15 Sep	3.6	4.0	5.6	4.4	100.0	100.0	100.0	100.0	52.2
	25 Sep	2.7	4.4	5.6	4.2	89.8	97.6	96.1	94.5	49.4
	5 Oct	3.4	4.2	4.8	4.2	83.4	83.2	84.9	83.8	44.0
	15 Oct	4.9	5.8	6.4	5.7	75.0	86.4	88.4	83.3	44.5
	25 Oct	0.9	2.4	3.6	2.4	74.1	85.7	83.6	81.1	41.8
	Mean	3.1	4.2	5.2	4.2	84.5	90.6	90.6	88.5	46.4
Nandyal	12 Oct	1.7	4.7	4.2	3.5	99.2	100.0	99.2	99.4	51.5
	24 Oct	3.3	3.0	4.3	3.6	66.7	82.1	92.7	80.5	42.0
	4 Nov	0.5	1.0	3.9	1.8	64.3	76.7	82.5	74.5	38.3
	Mean	1.8	2.9	4.1	3.0	76.7	86.3	91.5	84.8	43.9
Madhira	4 Sep	0.3	0.3	0.7	0.4	98.3	98.3	100.0	98.9	49.7
	19 Oct	0.0	0.0	1.3	0.4	45.0	55.8	62.5	54.4	27.4
	Mean	0.2	0.2	1.0	0.4	71.7	77.7	81.3	76.7	38.6
	Grand mean	1.8	2.6	3.6	2.6	68.5	78.1	82.0	76.1	39;4

	Patanchru	Dharwad	Nandyal	Madhira
SE(m) for density (D)	± 2.36***	±0.66 ***	± 2.89 ***	± 1.92
SE(m) for cultivar (C)	± 1.93***	±0.54***	± 2.36***	± 1.57***
SE (m) for sowin dates (SD)	± 2.71***	±0.85***	±2.89***	±1.57***
SE(m)for D xC xSD	± 6.68**	±2.09**	±7.07 NS	±3.84 NS

a D1 = 66, 675 plants ha-1 D2 = 133, 350 plants ha-1, D3 = 266, 700 plants ha-1.

* Significant at P< 0.05, and ** at P < 0.001, NS = not significant.

Table 3. Percentage lodging in six sorghum cultivars sown on different dates at two locations, postrainy season (1982-83)

Locations	Sowing date	Cultivars and % lodging						
		E 36-1	M 35-1	Annegeri-1	SPV 422	SPV 424	CSH 6	Mean
Patancheru	31 Aug	9.2	31.0	39.8	74.7	77.6	98.1	55
	10 Sept	7.3	20.4	34.4	56.2	58.0	95.7	45
	20 Sept	5.5	15.4	24.5	55.2	48.6	87.5	39
	30 Sept	2.0	6.3	15.5	1.9	21.3	79.9	21
	4 Oct	1.5	3.0	0.1	0.6	1.0	56.3	10
	Mean	5.1	15.2	22.9	37.7	41.3	83.5	34
Dharwad	30 Aug	4.2	41.2	25.0	60.0	80.0	99.2	51
	7 Sept	1.7	23.3	14.2	47.3	44.2	96.7	37
	22 Sept	0.8	10.8	10.2	35.0	28.7	85.0	28
	2 Oct	0.8	2.8	0.0	29.2	20.0	77.5	21
	22 Oct	0.0	1.7	0.0	8.3	8.3	72.3	154
	Mean	1.5	16.0	9.9	36.0	36.2	86.1	30
	Grand Mean	3.3	15.6	16.4	36.9	38.8	84.8	32

	Patancheru	Dharwad
SE (m) for cultivar (C)	± 1.87***	± 2.67***
SE (m) for sowing dates (SD)	± 3.29***	± 2.41***
SE (m) for C x SD	± 6.97***	±5.59***

*** Significant at P< 0.001.

Our studies confirm earlier reports (Edmunds, 1964; Odvody and Dunkle 1979) that drought stress and high soil temperatures at grain filling are important factors that predispose sorghum to charcoal rot infection and development. Rains ceased in all locations before flowering (Figs. 1 and 2). Consequently, grain filling took place under continuing moisture deficit stress as indicated by severe charcoal rot incidence in CSH 6. Percentage lodging in SPV 422, SPV 424, and Annegeri-1 were negligible in the crop sown on 4 October 1982 at Patancheru (Table 3), and panicle exertion and subsequent absent. These observations support the earlier findings of Edmunds and Voigt (1966) that in addition to drought stress and high temperature, normal seed production is essential to charcoal rot infection. Poor grain filling in these lines was attributed to their non adaptability to the late-sown environment.

Plant Population Densities : In 1981-82 season, overall significant differences ($P < 0.05$) were recorded in charcoal rot incidence in the three plant densities at all test locations. Highest percentage of lodged plants occurred at a plant density of 266, 700 plants ha-1 (Table 2). Location-specific differences in percentage lodging were observed for certain sowing dates at Dharwad, Madhira and Nandyal where the disease incidence was at similar for all the three plant densities of CSH 6. Similar observations were recorded in the first and second sowings at Dharwad and in the first sowing at Nandyal. Percentage lodging was significantly lower ($P < 0.05$) in E 36-1 than in CSH 6 at all locations. In the 1982-83 season, severe charcoal rot developed in all cultivars (except E 36-1) sown up to mid-September at two locations (Table 3). Thus, even a plant density of 133, 350 plants ha-1 (D2) was sufficient to identify charcoal rot resistance in a range of cultivars in the postrainy season in India.

These observations confirm the reports of Wadsworth and Sieglinger (1950), and Patil et al. (1982). It appears that high plant densities increased the inter-plant competition for the available soil moisture that varied over locations, depending upon the soil type. Vertisols of Dharwad and Madhira are shallower and more gravelly than those of Nandyal. It is possible that the depletion of moisture in these soils was greater and faster than in the deep Vertisols of Nandyal, which have a higher clay content and better water-holding capacity. Hsi (1956) and Edmunds et al. (1964) reported high charcoal rot development in sorghum in lighter, sandy soils with low water-holding capacity.

Cultivars : Lodging started earlier in CSH 6 than in other cultivars, i.e., 15-30 days after flowering, when it was in the milk to soft-dough stage, irrespective of plant densities, sowing dates, locations, and seasons (Figs. 1 and 2). Lodging began at the hard-dough stage in other cultivars, with the exception of E 36-1 where it started at grain maturity. In both seasons significant differences ($p < 0.05$) were observed in charcoal rot incidence (lodging) among the test cultivars. Charcoal rot incidence in E 36-1 was < 10% in comparison to 100% lodged plants in CSH 6 (Tables 2 and 3). In the 1982-83 season overall lodging ranged from 3 to 80% in M 35-1, Annegeri-1, SPV 422, and SPV 424.

E 36-1 was resistant to lodging and charcoal rot due to its nonsenescence trait. Duncan (1984) and Rosenow (1984) utilized this nonsenescence trait in selection for charcoal rot resistance. The positive correlation (Table 1) between lodging and nonsenescence supports their findings, and suggests that

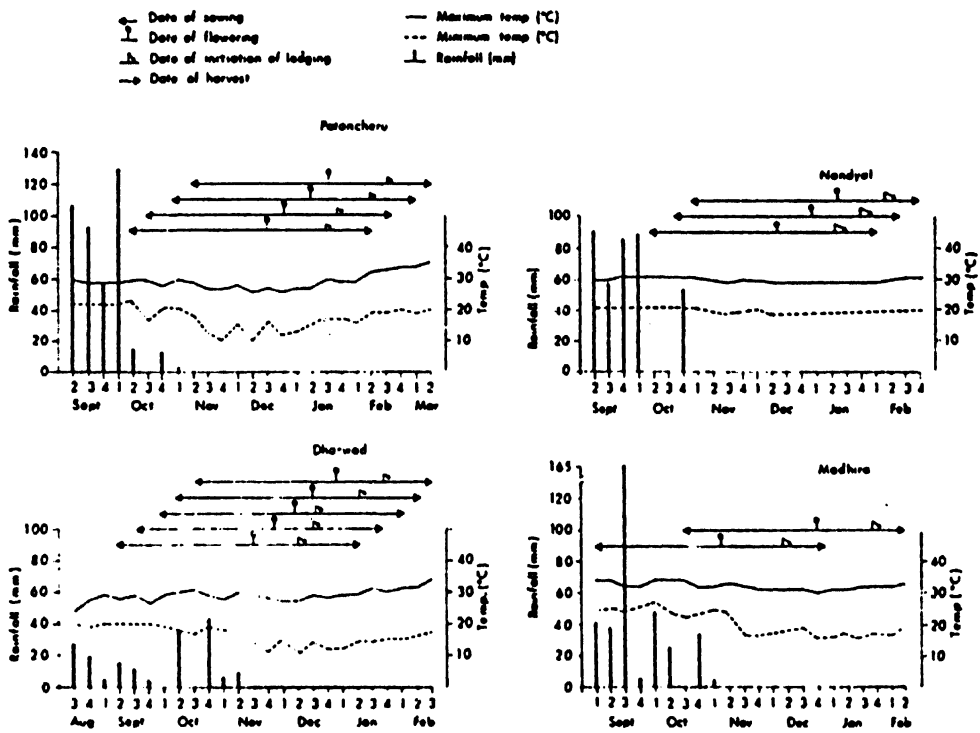

Figure 1. Weekly rainfall and temperature from sowing to harvest at Patancheru, Dharwad, Nandyal, and Madhira in the postrainy season (1981-82). Dates of flowering and onset of lodging are given for sorghum cultivar CSH 6.

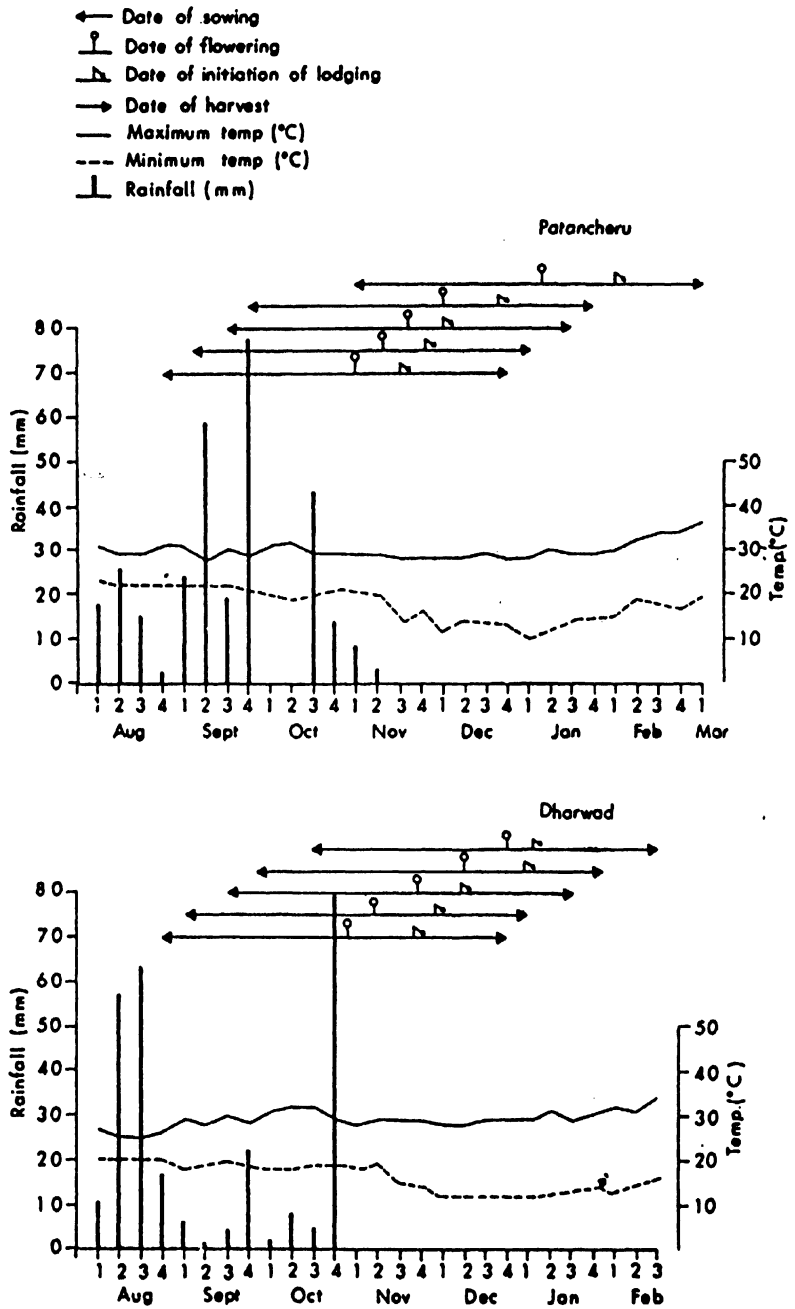

Figure 2. Weekly rainfall and temperature from sowing to harvest at Patancheru and Dharwad in the postrainy season (1982-83). Dates of flowering and onset of lodging are given for sorghum cultivar CSH 6.

drought stress enhanced plant senescence and was directly correlated with charcoal rot incidence.

Sowing Dates, Cultivars, and Plant Densities : The effect of interaction among these three factors on charcoal rot incidence in different cultivars was significant ($P > 0.05$) in the 1981-82 season at Patancheru and Dharwad, but not at Nandyal and Madhira (Table 2 and 3). Effect of cultivars x sowing dates in disease incidence was highly significant ($P < 0.05$) at Patancheru and Dharwad during the 1982-83 season.

These results indicate that effective field screening under natural infection conditions to identify charcoal rot resistance in grain sorghum is possible in postrainy season sowings in India, and possibly else where if environmental conditions are similar. However, the selection of a sowing date for charcoal rot resistance screening would depend on the rainfall pattern, soil type and water-holding capacity, and location.

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