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INHERITANCE OF FIELD RESISTANCE TO SORGHUM CHARCOAL ROT AND SELECTION FOR MULTIPLE DISEASE RESISTANCE*

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ABSTRACT

Six segregating and nonsegregating generations of three R x S and two S × S crosses were studied for charcoal rot resistance under epiphytotic conditions. CSV-5 (148/168) was comparatively the most resistant parent. The F_1 showed partial dominance of resistance.

The resistance appears to be a polygenic threshold character governed by duplicate epistasis with low heritability (38%). The F_3 progenies transgress the parental limits. In absence of absolute resistance for charcoal rot, selection 2 S.D. below population mean (S.I. = 1%) results in selecting resistant transgressive segregates.

Charcoal rot, SDM and leaf rust inherit independently. It is possible to combine these characters through simultaneous selection by choosing rust resistant plants from the segregating F_3 progenies possessing $<1\%$ SDM and $<10\%$ charcoal rot susceptibility.

Sorghum charcoal rot [*Macrophomina phaseolina* (Tassi) Goid.] has shown signs of being a potential danger in India in rainy and postrainy seasons during the recent years. Though the disease was reported long back in India (Uppal, Kolhatkar and Patel, 1936), its role in causing economic loss has been appreciated only recently. The disease is favoured by moisture stress ($<25\%$ available soil moisture) and high soil temperatures (35°C) at the time of grain filling in the susceptible varieties (Edmunds, 1962). Plant senescence is associated with charcoal rot (Rosenow, Johnson, Fredeiksen and Miller, 1977). Any destruction in the actively photosynthesizing leaf tissue reducing the amount of carbohydrate availability to the plant for cell maintenance can also be instrumental for predisposition to stalk rot (Dodd, 1978).

Sorghum downy mildew (SDM) and leaf rust are major diseases which can destroy leaf area and stimulate stalk rot. The inheritance of stalk rot resistance and simultaneous selection for SDM and leaf rust resistance in conjugation with stalk rot resistance are discussed here.

MATERIALS AND METHODS

Five parents, 'CS 3541 (CSV 4)', '148 (CSV 5)', '296', '303' and '168' were selected for the present study. Five crosses among first four parents were attempted and subsequently advanced

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to F_2 and F_3. The '296 × 303' cross was dropped due to its susceptibility to SDM. F_1s were crossed to both the parents and designated as BC-1 and BC-2. Nine such BCs were developed. There were 12 to 40 F_3 progenies in each cross.

The experiment was grown in randomized complete block design with two replications at U.A.S. Regional Station, Dharwar during *kharif* 1976, in a SDM sick plot. A large F_2 population of 435-532 plants was studied in different crosses. Forty plants per parent, 42-135 plants per F_1, 28-79 plants per BC and 100-150 plants per F_3 progeny (about 14000 total F_3 plants) were studied. The drought leading to moisture stress during September which coincided with grain filling resulted in epiphytotic of charcoal rot. The affected plants were assessed on the basis of hollow stem due to disintegration of pith by the fungus. Leaf rust was also endemic.

The anguler transformed susceptibility % data were used for analysis. The gene effects were estimated according to Hayman (1958) Standard statistical procedures were adopted to fit the normal curve and to compute regression and correlation coefficients.

Results

Inheritance of resistance to Charcoal Rot

The susceptibility in parents varied from 15.6% to 40.3% (Tables 1 and 2). Among them '148' with 15.6% susceptibility was the relatively more resistant parent (LSD=12.9%). The range of variation among F_1 was from 13.7 to 35.8%. The resistant × susceptible (R × S) F_1's, i.e., '148 × 303', '148 × CS 3541' and '148 × 296' were relatively more resistant than S × S F_1s. The R × S F_1's were close to the resistant parent for resistance indicating the partial dominance of resistance. Susceptibility in F_2 varied from 22.3 to 34.9%. R × S F_2's were relatively more tolerant than S × S. In general, F_2 performance was quite close to mid-parent value with only 12.5% decrease in susceptibility. The F_2 showed 22.5% inbreeding depression for resistance.

The susceptibility decreased with an extra dose of resistant parent in (148 × 303) × 148 BC indicating clear cut dose effect of resistance genes. The dose effect in other BCs was inconsistent.

The actual F_3 mean (27.5%) was close to F_2 mean (27.9%). However, between and within F_3, differences were highly significant ($\sigma^2 F_3 = 1100.97$, $\sigma^2 e = 42.96$), '148 × 296' and '148 × CS 3541 F_3 being lowest in susceptibility (Table 2). There were 5% F_3 progenies with <10% susceptibility and 22% progenies with <20% susceptibility. None of the F_3 progeny was completely resistant. Frequency distribution of F_3 progeny means showed a close fit of observed frequencies to expected frequencies with mean=26.69 and S.D.=10.44 (Fig. 1). The alternative test to detect skewness as a supplement to χ^2 test confirmed the normality of distribution, β_1 being approximately zero. In the absence of absolute resistance, a selection pressure of 2 S.D. below population mean was considerably high resulting in 0.85% selection intensity. However, 11% progenies with $\leqslant$16.25% susceptibility could be selected when selection pressure was relaxed to 1 S.D. below the population mean.

TABLE 1

Generation means (angular values) for charcoal rot susceptibility % (LSD=12.90)

Generation	148×303		148×CS 3541		148×296		CS 3541×296		CS 3541×303	
	Actual	Ang. values	Actual	Ang. values	Actual	Ang. values	Actual	Ang. values	Actual	Ang. values
P_1 (R)	15.6	23.2	15.6	23.2	15.6	23.2	34.7	36.1	34.7	36.1
P_2 (S)	35.2	36.3	34.7	36.1	40.3	39.4	40.3	39.4	35.2	36.3
$\bar{P}$	25.4	29.7	25.2	29.6	27.9	31.2	37.5	37.7	34.9	36.2
F_1	18.6	25.5	13.7	21.7	17.7	24.7	35.8	36.7	—	—
F_2	28.3	32.1	22.3	28.1	22.7	28.4	34.9	36.2	30.3	33.4
BC-1 (R×S) R	12.3	20.5	57.1	49.8	28.8	32.3	40.5	39.5	50.8	45.4
BC-2 (R×S) S	55.8	48.3	30.4	33.1	16.7	24.1	30.0	33.1	40.6	39.6
F_3	28.5	32.3	23.9	29.3	21.7	27.8	30.0	33.2	35.6	36.6
Heterosis %	—26.8	—14.1	—45.6	—26.7	—36.6	—20.8	—4.5	—2.7	—	—
Inb. depression	52.2	25.9	62.7	29.5	28.2	15.0	—2.5	—1.4	—	—

TABLE 2

Charcoal rot susceptibility (%) in different generations.

Generation	Midclass values/frequencies						Total	Mean	Range	MS
	5	15	25	35	45	55				
Parents		1		3			4	31.90	15.59—40.33 (23.26—39.41)	*
F_1		2	1	1			4	22.78	13.70—35.84 (21.70—36.75)	*
BCs		2	2	1	2	2	9	35.99	12.30—57.05 (20.50—49.02)	**
F_2			3	2			5	27.90	22.81—34.91 (28.10—36.21)	
F_{3-1}		2	5	5	2		14	30.00	12.43—45.97 (20.62—42.65)	**
F_{3-2}	2	3	4	3			12	21.66	9.35—40.44 (17.76—39.47)	**
F_{3-3}	1		3	8	5	1	18	35.55	9.13—52.11 (17.46—46.20)	**
F_{3-4}		7	14	12	1		34	28.51	13.24—46.25 (21.22—42.90)	**
F_{3-5}	3	14	13	9	1		40	23.95	3.60—44.99 (10 94—42.13)	**

Angular transformed values are in parenthesis.

F_{3-1} CS 3541 × 296, F_{3-2} 148 × 296, F_{3-3} CS 3541 × 303, F_{3-4} 148 × 303, F_{3-5} 148 × CS 3541.

* Significant at 5%, ** Significant at 1%.

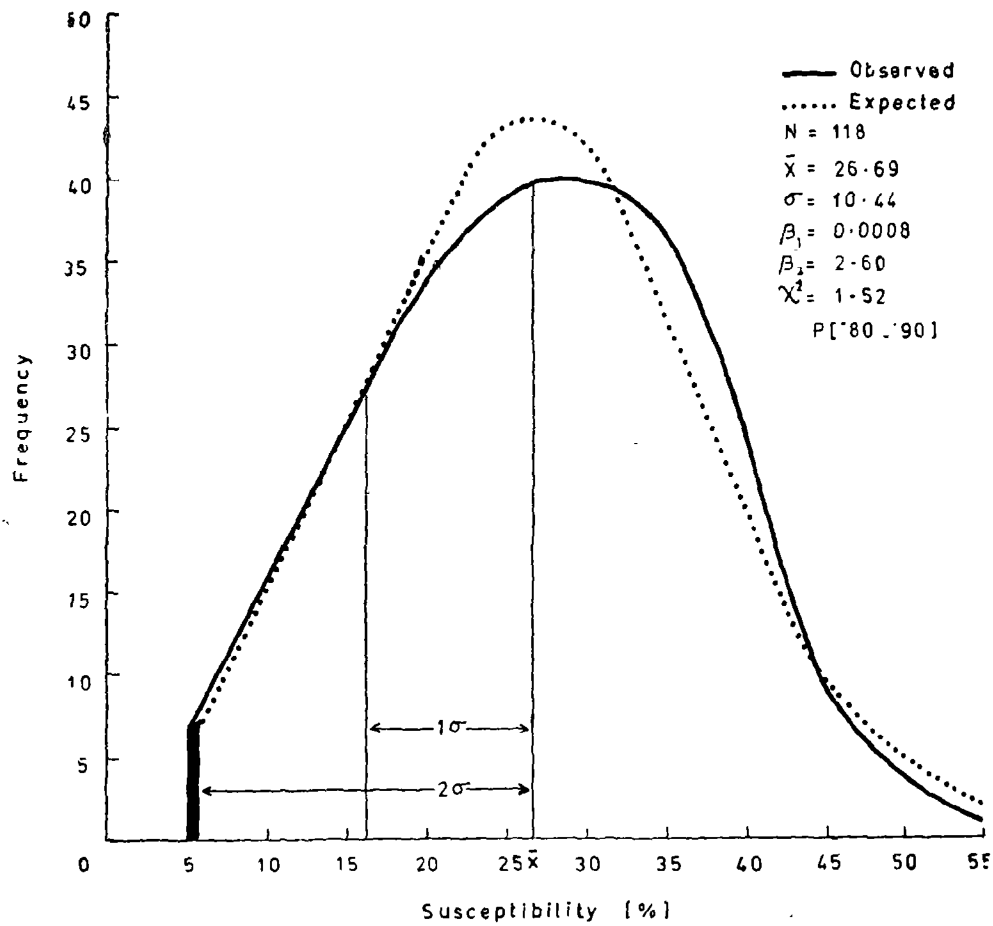

Fig. 1. Frequency distribution of F_8 progeny means.

The conclusion on gene effects was drawn on the basis of relative magnitude (Table 3). In '148 × 303', additive effect (d) was negative and responsible to reduce the susceptibility. Negative additive × dominance (j) and dominance × dominance (l) interaction effects were also quite pronounced in this cross. Additive × dominance effects were negative and largest in '148 × 296' and 'CS 3541 × 296' crosses. Heterotic (h) and dominance × dominance effects were opposite in direction. Epistasis governing resistance in all the crosses were, therefore, due to duplicate genes.

TABLE 3

Gene effects (based on angular values) for charcoal rot susceptibility (%).

Gene effect	148 × 303	148 × CS 3541	148 × 296	CS 3541 × 296
$\hat{m}$	32.10	28.15	28.45	36.20
$\hat{d}$	—27.85	16.70	8.20	6.45
$\hat{h}$	37.05	33.65	— 7.55	— 0.75
$\hat{i}$	41.30	53.20	— 1.00	0.30
$\hat{j}$	—115.20	—49.10	—46.20	—88.40
$\hat{l}$	— 68.50	—93.10	0.30	3.50
Epistasis type	Duplicate	Duplicate	Duplicate	Duplicate
$H=[(h-i)-(d-\frac{1}{2}j)]$	— 25.50	—21.70	—24.75	—36.70
Inbreeding depression (%)	25.88	29.72	14.95	— 1.36

The offspring-parent regression of F_2 on F_1 and F_3 on F_2 had low significance ($P < 0.10$). The correlation coefficients were 0.63* and 0.54* respectively (Table 4). The degree of determination of F_2 by F_1 was 40% and F_3 by F_2 30%. The heritability estimated by variance component method using estimates of between and within F_3 variance was 37.67%.

TABLE 4

Regression analysis for charcoal rot resistance

Source	F_2 on F_1		F_3 on F_2	
	DF	MSS	DF	MSS
Regression	1	89.63*	1	60.50*
Deviation	6	22.21	8	17.73
Correlation coefficient		0.6341*		0.5467*
R^2		0.4021		0.2989
Regression coefficient		0.527*±0.262		5.504*±0.272

* Significant at 1%; Heritability (σ^2 B.F_3/σ^2 B.F_3 + σ^2 W.F_3 + σ^2e)=37.67.

Selection for Multiple Disease Resistance

The correlations (r_{12}=0.07, r_{13}=0.13, r_{23}=—0.01) among SDM, charcoal rot and leaf rust in F_3 were not significant. Resistance to these three major diseases was therefore independent of each other.

These characters can be accumulated in single progeny by adopting a suitable simultaneous selection procedure. Data in Table 5 show than when SDM, charcoal rot and leaf rust segregate independently, it could be possible to select F_3 progeny No. 98 of '148 x 296' cross and progeny No. 106 of '148 x CS 3541' cross with 1% SDM and 10% charcoal rot incidence. Similarly, other progenies such as 42 and 97 could be selected with 2% SDM and 10% charcoal rot incidence. All these progenies segregated into rust resistant and susceptible plants. It is, therefore, possible to select rust resistant plants from the progenies showing a reasonably high level of resistance to SDM and charcoal rot.

Table 5

Simultaneous selection for resistance to SDM, charcoal rot and rust.

	No. of rust resistant plants			
	SDM % 0 — 1		1.1 — 2	
	P. No.	R : S	P. No.	R : S
Charcoal rot %	98	39 : 50	42	12 : 53
0 — 10	106	12 : 38	97	12 : 69

P. No.—F_3 progeny number 42 — 148 × 296,
97, 98, 106 — 148 × CS 3541.

R—Resistant, S—Susceptible.

Discussion

Macrophomina phaseolina is not an aggressive pathogen capable of attacking vigorous plant tissue but can overcome senescing tissue at grain-filling stage under soil moisture stress and high temperature causing a serious damage to susceptible varieties. The incidence of sorghum charcoal rot is therefore governed by environment-host-pathogen interactions and mainly depends on photosynthetic stress—translocation balance (Dodd, 1978). Host plants show variability for resistance (Frederiksen and Rosenow, 1971; Rosenow, 1978; Rao *et al.*, 1978) but absolutely resistant variety is not known. However, multilocation testing in AICSIP has helped to identify stable sources of resistance. CSV 5 (148/168) is one such variety with 16% susceptibility and significantly high resistance as compared to other parents under disease epiphytotic conditions.

Study of different segregating and non-segregating generations elucidates continuous variation indicating the quantitative nature of resistance. The distinct gradation of parents and F_1s may be due to different thresholds since those polygenically determined genotypes which have values below the threshold show no expression of the character and the expression occurs only when the genotypes have values above this threshold (Strickberger, 1968). R x S hybrids tend towards resistant parent due to partial dominance of resistance. The use of at least one highly resistant parent in hybrid programme would thus confer advantage to hybrids. Rosenow (1978) also observed less charcoal rot incidence in some hybrids with one or more resistant parents and indicated excellent progress from selection.

The degree of determination of F_2 by F_1 (40%), F_3 by F_2 (30%) and low heritability (38%) is expected due to duplicate type of epistasis and high genotype x environmental interactions predisposing to charcoat rot. However, F_3 progenies show normal distribution (truncated towards zero) and surpass the parental limits enabling one to choose the transgressive resistant progenies. In the absence of absolute resistance, selection of F_3 progenies 2 S.D. below mean results in approximately 1% selection intensity (S.I.) and $<6\%$ susceptibility.

Leaf rust, SDM and charcoal rot resistance are inherited independently. It is possible to select rust resistant plants from $R \times S$ and $R \times R$ F_3 progenies with 1% SDM and 10% charcoal rot susceptibility. Rust resistance being a trigenic recessive character (Rana *et al.*, 1976; Indira *et al*, 1982), selected rust resistant plants will breed true in F_4 but segregate for SDM and charcoal rot resistance. Further selection for SDM resistance and transgressive charcoal rot resistant segregants under epiphytotic conditions will stabilize the resistant progenies. The progress from selection for SDM is expected to be fairly rapid due to possible involvement of few major genes (Rana *et. al.*, 1982) but slow for charcoal rot due to low heritability and higher genotype $\times$ environmental interactions. 'CSV 5', 'SPV 104', 'SPV 126', 'SPV 178', 'SPV 193' and 'SPV 488' are some of the recently developed varieties which incorporate multiple resistance to these diseases.

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