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Inheritance of resistance to head bugs and its interaction with grain molds in *Sorghum bicolor*

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Summary

Sorghum head bug, *Calocoris angustatus* Lethiery is one of the most important pests of grain sorghum in India. Head bug damage increases the severity of grain molds, which renders the grain unfit for human consumption. Therefore, we studied the gene action for resistance to head bugs and grain molds in a diverse array of male-sterile lines and testers in a line × tester mating design under natural infestation. Mean squares for parents, parents vs crosses, lines, testers, and lines × testers were significant for head bug damage and grain mold severity. General combining ability (GCA) effects were significant and negative for ICSA 88019 for head bug damage, and ICSA 88019 and ICSA 88020 for grain molds (except for ICSA 88020 in 1993). General combining ability effects were positive for ICSA 42 and 296 A. GCA effects of lines and testers for head bug damage and grain mold severity were in the same direction (+ve or -ve). Head bug damage in the grain was significantly correlated with grain mold severity. Testers IS 8891, IS 15107, and TAM 2566 (with colored grain and less susceptibility to molds) produced mold-resistant hybrids in combination with all the male-sterile lines, while the reverse was true in the case of Swarna and ICSV 112. Resistance to head bugs showed dominance to partial dominance type of gene action, while in the case of grain molds, it showed dominance to overdominance. Resistance to these pests is governed by both additive and nonadditive types of gene action. The implications of these results are discussed in relation to need for crop improvement in sorghum.

Introduction

Sorghum [*Sorghum bicolor* (L.)] Moench is one of the most important crops in the semi-arid tropics. It is damaged by over 150 species of insects, of which sorghum head bugs (*Calocoris angustatus* Lethiery in India and *Eurystylus oldi* Poppius in West Africa) are a major constraint to sorghum production (Sharma, 1993). Head bug nymphs and adults feed on the developing grains, which become tanned, shrivelled, and under severe infestation, become completely invisible outside the glumes. Head bug damage also increases the severity of grain molds caused by species belonging to the genera *Fusarium, Curvularia, Phoma,* and *Alternaria* (Sharma et al., 1992, 1994). This spoils the grain quality, results in poor seed germination, and renders the grain unfit for human consumption (Natarajan & Sundarababu, 1988; Sharma & Lopez, 1994; Sharma et al., 1995).

Host plant resistance is an effective means of controlling insects, and considerable genetic variability exists in sorghum for resistance to head bugs (Steck et al., 1989; Sharma & Lopez, 1992a, 1992b; Sharma et al., 1994). Recent efforts in breeding for resistance to insects in sorghum are largely focused on developing insect-resistant hybrids based on cytoplasmic male-sterility (CMS). There is no information on the inheritance of resistance to head bugs in sorghum. Since future breeding efforts in improving sorghum productivity will largely focus on high yielding pest-resistant hybrids, it is important to understand the mechanisms and inheritance of resistance to insect pests. The objective of this study was to determine gene action for resistance to head bugs and interaction of head bug damage with grain mold severity in crosses involving four CMS male-sterile lines with nine testers selected at random from the restorer collection maintained at the International Crops Research Institute for the Semi-Arid Tropics.

Materials and methods

The gene action for head bug resistance was studied on two midge-resistant [ICSA 88019 (PM 7061 A) and ICSA 88020 (PM 7068A)] (Agrawal et al., 1996) and two commercial CMS male-sterile lines (296 A and ICSA 42). Sterility of all the CMS male-sterile lines was based on milo-cytoplasm. In the first experiment, nine diverse lines (ICSV 745, PM 15908-3, PM 17422-3, PM 17592-1, CS 3541, MR 750, MR 836, MR 844, and MR 923) were used as testers. Four male-sterile lines were crossed with the nine testers in a line $\times$ tester mating design. Thirty-six F_1 hybrids and their parents were evaluated during the 1990 rainy season (June to October) at the International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India. In the second experiment, seven testers (IS 8891, IS 15107, TAM 2566, AF 28, DJ 6514, Swarna, and ICSV 112) were mated with the same four male-sterile lines to produce 28 F_1 hybrids. The F_1 hybrids and their parents were tested during the 1993 rainy season.

Seeds of the F_1s and parental lines were sown in a 7 $\times$ 7 triple lattice design with three replications during the 1990 rainy season. During the 1993 rainy season, the seeds of the F_1 hybrids and their parents were sown in a randomized complete block design with three replications. Each entry was sown in a two-row plot, 4 m long. The rows were spaced 75 cm apart, and the plants were spaced at 10 cm within a row. The seeds were drilled with carbofuran 3G (1.2 kg a.i. ha^{-1}) to protect the seedlings against the sorghum shoot fly, *Atherigona soccata* Rondani. No insecticide was applied during the reproductive phase of the crop. Four infester rows of the early flowering ($<$35 days to 50% flowering) line IS 802 were planted after every 16 rows of the test material to increase head bug severity (Sharma & Lopez, 1992a).

During the 1990 rainy season, head bug damage to the grain was evaluated at maturity on a 1 to 9 damage rating (DR) scale (1 = grain fully developed with a few feeding punctures, 2 = head bug feeding punctures on the grain surface with slight tanning/browning, 3 = grain showing bug feeding punctures all over with slight tanning/browning, and $<$10% shriveling of the grain, 4 = grain showing tanning/browning, and 10–20% shriveling, 5 = grain showing 20–30% shriveling, 6 = grain showing 30–40% shriveling, 7 = grain showing 40–50% shriveling, 8 = grain showing 50–60% shriveling, and slightly visible outside the glumes, and 9 = grain showing $>$60% shriveling, and invisible outside the glumes).

Heavy head bug damage and extended rains increased the incidence and severity of grain molds. Sorghum grains in the panicles were infected with grain mold fungi such as *Fusarium moniliforme, F. pallidosporium*, and *Cuvularia lunata*. Grain mold severity was recorded 20 days after physiological maturity on a 1 to 9 scale (1 = $<$10% grain showing mold infection, 2 = 11–20%, 3 = 21–30%, 4 = 31–40%, 5 = 41–50%, 6 = 51–60%, 7 = 61–70%, 8 = 71–80%, and 9 = $>$80% mold infected grain). During the 1993 rainy season, data were recorded only on grain mold severity.

The combining ability analysis was done following Kempthorne (1957). Simple correlations were computed for head bug damage and grain mold severity. The sums of squares (SS) due to F_1 hybrids were partitioned into sum of squares due to lines, testers, and their interaction components, and these were used to estimate additive and non-additive components of variation. The contribution of lines, testers, and their interactions were computed for assessing their relative importance towards total variability for each character. The main effects of lines and testers are equivalent to general combining ability (GCA), and the line interaction with a specific tester is equivalent to specific combining ability (SCA) (Hallauer & Miranda, 1981). Standard errors for GCA and effects (SE GCA m and SE GCA n) were calculated to test the significance of these effects. Heterosis in the F_1 hybrids for head bug and grain mold susceptibility/resistance was computed in relation to mid-parent value or the lower/higher parent (Sharma et al., 1996).

Results and discussion

Head bug damage was lower in ICSV 745, MR 750, MR 836, and MR 923 (DR 6 to 7) than in PM 17422-3 and PM 17592-1 (DR 9.0) (Table 1). ICSB 88020 showed moderate susceptibility to head bug damage (DR 6). Head bug damage in the F_1 hybrids ranged trom 6–9, and mean DR was 6.7 for the hybrids based on ICSA 88019, 7.7 for hybrids based on ICSA 88020,

Table 1. Head bug damage[1] ratings of nine testers and their hybrids based on four male-sterile lines during the 1990 rainy season, ICRISAT Center, Patancheru, India

Testers/B-lines	Testers	Hybrids based on				Mean
		ICSA 88019	ICSA 88020	ICSA 42	296 A	
ICSV 745	6.0	7.0	9.0	7.0	9.0	8.0
PM 15908-3	7.0	6.0	8.0	8.0	7.0	7.3
PM 17422-3	9.0	8.0	8.0	9.0	9.0	8.5
PM 17592-1	9.0	9.0	9.0	9.0	9.0	9.0
CS 3541	7.0	6.0	7.0	6.0	7.0	6.5
MR 750	6.0	6.0	8.0	7.0	8.0	7.3
MR 836	5.0	6.0	6.0	7.0	8.0	7.3
MR 844	7.0	6.0	8.0	7.0	8.0	7.3
MR 923	8.0	6.0	6.0	8.0	7.0	6.8
B-lines	–	6.0	7.0	7.0	7.0	6.8
Mean	7.1	6.7	7.7	7.6	8.0	7.5
SE = ± 0.44						
CV (%) = 10.2						

[1] Head bug damage rating (1 = grain fully developed with a few feeding punctures, and 9 = grain showing >60% shriveling due to head bug damage, tanned, and slightly visible outside the glumes).

Table 2. Grain mold severity[1] of nine testers , and their hybrids based on four male-sterile lines during the 1990 rainy season, ICRISAT Center, Patancheru, India

Testers/B-lines	Testers	Hybrids based on				Mean
		ICSA 88019	ICSA 88020	ICSA 42	296 A	
ICSV 745	9.0	8.0	9.0	9.0	9.0	8.8
PM 15908-3	9.0	6.0	5.0	9.0	9.0	7.3
PM 17427-3	9.0	9.0	9.0	9.0	9.0	9.0
PM 17592-1	9.0	9.0	9.0	9.0	9.0	9.0
CS 3541	8.0	6.0	5.0	9.0	9.0	7.3
MR 750	9.0	6.0	7.0	9.0	8.0	7.5
MR 836	9.0	5.0	4.0	8.0	9.0	6.3
MR 844	9.0	6.0	6.0	9.0	9.0	7.5
MR 923	9.0	6.0	6.0	9.0	9.0	7.5
B-lines	–	6.0	9.0	9.0	9.0	8.3
Mean	8.9	6.8	6.4	8.9	8.9	7.7
SE = ± 0.38						
CV (%) = 8.3						

[1] Grain mold score (1 = <10 and 9 = >80% mold infected grain).

7.6 for hybrids based on ICSA 42, and 8.0 for hybrids based on 296 A. Among the testers; CS 3541, MR 836, and MR 923 resulted in relatively less susceptible hybrids than PM 17592-1 and PM 17422-3.

Grain mold severity (MS) during the 1990 rainy season was quite high in all the testers (MS 8–9) (Table 2). ICSB 88019 was relatively less susceptible (MS 6.0) than ICSB 88020, ICSB 42, and 296 B (MS 9.0). PM 15908-3, CS 3541, MR 836, M 844, and MR 923 in combination with ICSA 88019 and ICSA 88020 resulted in F_1 hybrids with moderate susceptibility to grain molds.

During the 1993 rainy season, grain mold severity in the testers ranged from 1.0 in DJ 6514 to 8.5 in ICSV 112 (Table 3). Hybrids based on ICSA 88019, ICSA 88020, ICSA 42, and 296 A had mean mold severity ratings of 4.3, 5.4, 4.9 and 5.8, respectively. Male-sterile lines did not show a marked effect on the susceptibility of the hybrids. However, hybrids where IS 8891, IS 15107, and TAM 2566 were used as testers (having red colored grain), the mean grain mold severity was 2.3 to 3.8 compared with mold severity of 7.0 to 7.9 for hybrids produced with Swarna and ICSV 112 (both with white grain). In general, testers and the hybrids with red-brown grain were resistant to mold infection (except ICSA 88020 × TAM 2566 and 296 A × DJ 6514, which showed moderate susceptibility). In some cases where both the parents had white grain, but the F_1 hybrids had brown grain, the mold infection was low. Such an expression is known to occur in sorghum because of complementary B-genes (Esele et al., 1993).

Mean squares for the parents, lines, testers, and lines × testers were significant for head bug damage (Table 4). The proportional contribution of the lines (54%) was higher than for the lines × testers (24.6%). The general combining ability (GCA) effects were significant and negative for ICSA 88019, and positive for 296 A (Table 5). Amongst the testers; PM 17422-3 and PM 17592-1 showed significant and positive GCA effects for head bug damage, while the reverse was true for CS 3541, MR 836, and MR 844. The specific combining ability (SCA) effects for head bug susceptibility were significant and positive for ICSA 88019 × PM 15908-3 and 296 A × ICSV 745 (Table 6). Such effects were significant and negative for ICSA 88019 × PM 17422-3 and 296 A × PM 17422-3.

For head bug damage, ICSV 745 and PM 17592-1 showed partial dominance for susceptibility (positive values over the lower parent and mid-parent) in combination with all the four male-sterile lines. Hybrids based on ICSA 88019 (except with PM 17422-3 and PM 17592-1) showed a dominance type of gene ac-

Table 3. Grain mold severity of hybrids based on four male-sterile lines and seven testers in sorghum during the 1993 rainy season, ICRISAT Center, Patancheru, India

Tester/B-lines	Tester		Hybrids based on CMS lines								Mean
			ICSA 88019		ICSA 88020		ICSA 42		296 A		
	MS	GC	MS	GC	MS	GC	MS	GC	MS	GC	
IS 8891	2.0	B	2.0	B	2.4	B	2.2	B	2.4	B	2.3
IS 15107	2.4	B	2.8	B	4.4	B	3.0	B	3.9	B	3.5
TAM 2566	3.1	RB	2.2	RB	5.9	B	3.1	B	4.0	RB	3.8
AF 28	7.1	CB	3.9	CB	8.0	CB	5.0	CB	7.1	B	6.0
DJ 6514	1.0	W	5.8	W	6.5	W	3.8	B	5.5	B	5.4
Swarna	7.7	W	7.1	W	7.0	W	8.4	W	9.0	W	7.9
ICSV 112	8.5	W	6.4	W	3.9	B	8.8	W	9.0	W	7.0
B-lines	–	–	5.4	W	5.4	W	9.0	W	9.0	W	
Mean	3.5		4.3		5.4		4.9		5.8		5.1
SE	± 0.93										

MS = Mold score (1 = <10% grain with mold infection, and 9 = >80% grain with mold infection). GC = Grain color (B = brown, RB = Red-brown, CB = Chalky-brown, and W = white).

Table 4. Mean squares (ms) for lines × testers for head bug damage and grain mold severity in sorghum during the 1990 rainy season, ICRISAT Center, Patancheru, lndia

Source of variation	df	Head bugs	Grain molds
Replications	2	1.353	1.43
Parents	12	4.026**	2.10**
Parents vs crosses	1	6.447	30.02**
Lines	3	8.012**	57.19**
Testers	8	7.583**	9.96**
Lines × testers	24	1.512**	3.57**
Error	96	0.569	0.392
Estimates of variance components			
gca		0.037	0.109
Sca		0.194	1.059
gca/sca		0.190	0.103
Proportional contribution (%) to total variance			
Lines		54.006	23.646
Testers		21.398	50.928
Lines × testers		24.596	25.247

** Variance components significant at $p < 0.01$.

Table 5. General combining ability (GCA) effects of lines and testers for head bug damage and grain mold severity during the 1990 rainy season, ICRISAT Center, Patancheru, India

Testers/lines	Head bugs	Grain molds
Testers		
ICSA 88019	–0.759*	–1.028*
ICSA 88020	0.129	–1.472*
ICSA 42	0.093	1.194*
296B	0.537*	1.306*
SE (gi)	0.145	0.121
SE (gi-gj)	0.205	0.171
Lines		
ICSV 745	0.417	1.056*
PM 15908-3	–0.167	–0.528*
PM 17422-3	0.917**	1.139**
PM 17592-1	1.417**	1.222**
CS 3541	–1.000	–0.528*
MR 750	–0.333	0.056
MR 836	–0.667**	–1.111**
MR 844	–0.667**	–0.861**
MR 923	0.083	–0.444*
SE (gi)	0.218	0.181
SE (gi-gj)	0.308	0.256

*,** = GCA effects significant at $p < 0.05$ and $p < 0.01$, respectively.

tion for susceptibility to head bugs. For grain molds, the resistance was largely governed by the dominant type of gene action in the case of ICSA 88019 (except in combination with ICSV 745, PM 174222-3, and PM 17592-1), dominance to overdominance in the case of ICSA 88020, and co-dominance in the case of ICSA 42 and 296A (except with CS 3541 and MR 750) during the 1990 rainy season. Genotypes IS 8891, IS 15107, TAM 2566, and AF 28, which have colored grain, showed dominance type of gene action (in relation to mid-parent value) for grain mold resist-

Table 6. Specific combining ability (SCA) effects for head bug damage and grain mold severity in sorghum during the 1990 rainy season, ICRISAT Center, Patancheru, India

Cross	Head bugs	Grain molds
ICSA 88019 × ICSV 745	0.18	0.61
ICSA 88019 × PM 15908-3	0.95*	1.39**
ICSA 88019 × PM 17422-3	–1.34**	–0.94*
ICSA 88019 × PM 17592-1	0.21	–1.06**
ICSA 88019 × CS 3541	–0.24	–0.47
ICSA 88019 × MR 750	0.20	–0.69
ICSA 88019 × MR 836	0.57	0.64
ICSA 88019 × MR 844	–0.53	0.53
ICSA 88019 × MR 923	0.34	1.19**
ICSA 88020 × ICSV 745	–0.55	1.31**
ICSA 88020 × PM 15908-3	–0.16	1.36**
iCSA 88020 × PM 17422-3	0.04	1.14**
ICSA 88020 × PM 17592-1	0.51	1.11**
ICSA 88020 × CS 3541	–0.05	1.22**
ICSA 88020 × MR 750	–0.01	1.11**
ICSA 88020 × MR 836	–0.45	1.22**
ICSA 88020 × MR 844	–0.07	–0.14
ICSA 88020 × MR 923	0.37	–0.69
ICSA 42 × ICSV 745	–0.26	0.31
ICSA 42 × PM 15108-3	–0.04	0.53
ICSA 42 × PM 77422-3	–0.07	–0.39
ICSA 42 × PM 17592-1	0.04	0.39
ICSA 42 × CS 3541	0.07	0.06
ICSA 42 × MR 750	–0.04	–0.06
ICSA 42 × MR 836	–0.07	0.89*
ICSA 42 × MR 844	–0.63	–1.44**
ICSA 42 × MR 923	–0.26	1.22**
296A × ICSV 745	0.96*	1.11**
296A × PM 15908-3	–0.07	–0.47
296A × PM 17422-3	–0.96*	–1.36**
296A × PM 17592-1	0.41	0.97*
296A × CS 3541	0.63	0.86*
296A × MR 750	–0.49	0.56
296A × MR 836	0.62	–0.11
296A × MR 844	0.66	0.22
296A × MR 923	–0.79	0.44
SE (gi)	0.43	0.36

*,** = SCA effects significant at $p < 0.05$ and $p < 0.01$, respectively.

ance in combination with ICSA 88019, ICSA 42 and 296 A, but behaved differently in combination with ICSA 88020.

Mean squares for parents, lines, testers, parents vs crosses, and lines × testers were significant for susceptibility to grain molds during the 1990 rainy season (Table 6). The proportional contribution of testers was greater (51 and 69% during the 1990 and 1993 rainy seasons, respectively) than those of the lines (24 and 6% during the 1990 and 1993 rainy seasons, respectively). The estimates of variance components for SCA were more than those of the GCA for both head bugs and grain molds. The GCA effects were significant and negative for ICSA 88019 and ICSA 88020, and positive for ICSA 42 and 296 A. ICSV 745, PM 17422-3 and PM 17592-1 showed significant and positive GCA effects, while PM 15908-3, CS 3541, MR 836, MR 844, and MR 923 showed negative GCA effects. The SCA effects were significant and positive for ICSA 88019 × PM 15908-3, ICSA 88019 × MR 923, ICSA 88020 × ICSV 745, ICSA 88020 × PM 17422-3, ICSA 88020 × CS 3541, ICSA 42 × MR 923, 296 A × ICSV 745, 296 A × PM 17592-1, and 296 A × CS 3541. The SCA effects were significant and negative for grain mold severity for ICSA 88019 × PM 17422-3, ICSA 88019 × PM 17592-1, ICSA 88020 × PM 15908-3, ICSA 88020 × PM 17422-3, ICSA 88020 × MR 750, ICSA 88020 × MR 836, ICSA 42 × MR 844, and 296 A × PM 17422-3.

During the 1993 rainy season, mean squares for parents (18.8, df 10), parents vs. crosses (2.3, df 1), lines (6.2, df 3), testers (32.8, df 6), and lines × testers (3.9, df 18) were significant. GCA effects were significant and negative for ICSA 88019, and significant and positive for 296 A (Table 7). For the testers, the GCA effects were significant and negative for IS 8891, IS 15107, and TAM 1566, while such effects were significant and positive for Swarna and ICSV 112. SCA effects were significant and negative for ICSA 88019 × AF 28, ICSA 42 × DJ 6514, and ICSA 88020 × Swarna. SCA effects were significant and positive for ICSA 88020 × TAM 2566, ICSA 88020 × AF 28, ICSA 88020 × ICSV 112, ICSA 42 × ICSV 112, and 296 A × ICSV 112.

Head bug damage and grain mold severity ratings were highly correlated (r = 0.83). The GCA effects for the lines and testers (that were significant) were in the same direction for head bug damage and grain mold severity. Gene action for resistance to head bugs seems to be governed by additive gene action, while in case of grain molds, it is governed by both additive and nonadditive gene action.

There was a moderate variability among the parents for susceptibility to head bugs and grain molds during the 1990 rainy season. However, the variability among the parents and their hybrids for mold severity was considerably higher during the 1993 rainy season. The variance components for lines, testers,

Table 7. General combining ability (GCA) and specific combining ability (SCA) effects for four male-sterile lines and seven testers for grain mold severity in sorghum during the 1993 rainy season, ICRISAT Center, Patancheru, India

Tester/ line	GCA for lines	SCA for crosses with restores						
		IS 8891	IS 15107	TAM 2566	AF 28	DJ 6514	Swarna	ICSV 112
ICSA 88019	–0.81*	0.56	0.09	–0.79	–1.29*	1.21*	0.04	0.19
ICSA 88020	0.32	–0.17	0.56	1.78*	1.68*	0.78	1.19*	3.44*
ICSA 42	–0.23	0.18	–0.30	–0.48	–0.78	–1.38*	0.75	2.00*
296 A	0.72*	–0.57	–0.34	–0.52	0.38	–0.62	0.41	1.26*
GCA for testers		–2.88*	–1.60*	–1.33*	0.88	0.28	2.75*	1.90*
SE (gi) for GCA = 0.35.		SE (gi) for SCA = 0.47						
SE (gi-gj) for GCA = 0.50.		SE (gi-gj) for SCA = 0.67						

* GCA and SCA effects significant from zero at $p < 0.05$.

parents, parents vs crosses, and lines × testers were significant. GCA effects were significant and negative for head bug susceptibility for some lines and testers. Thus, both the parents contribute towards head bug resistance in F_1 hybrids. SCA effects for head bug and mold susceptibility were significant for some cross combinations. Thus, both additive and nonadditive gene effects seem to govern resistance to head bugs and grain molds in sorghum. Hybrids based on ICSA 88019 were less susceptible to both grain molds and head bugs. However, when IS 8891, IS 15107, and TAM 2566 were used as testers, the resulting hybrids were resistant to grain molds, while the reverse was true when Swarna and ICSV 112 were used as testers.

Resistance to head bugs in sorghum is due to nonpreference by the adults for feeding, low oviposition, and antibiosis (Sharma & Lopez, 1990). Long glumes, longer covering of the grain by the glumes (days to glume opening), quicker grain hardening, and grain hardness contribute to head bug resistance in sorghum (Toure et al., 1992; Sharma et al., 1994). Some of these traits are also associated with less susceptibility to grain molds. Patterns of resistance to head bugs may follow the same trends as the inheritance of glume and grain characteristics in sorghum (Sharma et al., 1996). Inheritance of pigmented testa (B1-B2 gene), a red pericarp (R-Y), a thin pericarp (Z-), and an intensifier gene (I-) is through dominant gene action (Esele et al., 1993). This is also supported by the production of colored grain hybrids when IS 8891, TAM 2566, and IS 15107 were used as restorers, and the resulting hybrids were less susceptible to grain molds. Pigmented testa is the most important trait conferring resistance to grain molds. The effect of red pericarp and red testa are additive. In the present studies, hybrids that showed pigmented grain color were less susceptible to both head bugs and grain molds. Dominance seems to be a component of resistance to grain molds, as reported earlier for inheritance of pigmented testa (Esele et al., 1993).

The additive type of gene action has been found to be predominant for resistance to grain molds caused by *Fusarium* spp. In a diallel study, both additive and nonadditive genetic components of variance determined the expression of resistance to *Curvularia lunata* (Dhabolkar & Baghel, 1983). Genes for susceptibility were recessive. Additive gene effects governed resistance to *Fusarium moniliforme* and *Curvularia lunata* in F_1, F_2 and backcross generations from three crosses involving two resistant and two susceptible lines (Kataria et al., 1990) (except in cross IS 402 × IS 10892). Additive effects in general are smaller in magnitude than the dominance effects. Duplicate type effects were also important for most crosses.

There is a considerable variability in sorghum for susceptibility to head bugs and grain molds. Some of the hybrids based on ICSA 88019 and ICSA 88020 were relatively less susceptible to both head bugs and grain molds. Cytoplasmic male-sterile lines and testers that combine to produce pigmented testa are relatively less susceptible to head bugs and grain molds. Both additive and nonadditive gene effects seem to govern the inheritance of resistance to both head bugs and grain molds in sorghum. Thus, there is a possibility of developing male-sterile lines that can be used to develop hybrids with resistance to grain molds and head bugs. Since head bug damage also increases the severity of grain molds, efforts should be made to develop cultivars with resistance to both factors. Genes conferring resistance to head bugs and grain molds should be transferred into male-sterile lines for development of hybrids with resistance. Efforts should also be made to identify restorer lines showing high specific combining ability for resistance to these traits to minimize the extent of losses, and to improve the quality of grain produced during the rainy season.

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