RESEARCH ARTICLE

SABRAO Journal
of Breeding and Genetics
48 (3) 240-246, 2016

COMBINING ABILITY FOR GRAIN MOLD RESISTANCE IN SORGHUM (*Sorghum bicolor* (L.) Moench)

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SUMMARY

In all sorghum (*Sorghum bicolor* (L.) Moench) production systems, grain molds can reduce the yield and quality of short duration cultivars if they mature in wet and humid weather. This investigation was taken up to find out combining ability for grain mold resistance under 4 environmental conditions by studying 168 hybrids and their parents along with checks. The pooled analysis of variance for combining ability revealed significant differences due to environments, parents, hybrids and various interactions indicating the existence of wide variability in the material under study. The ratios of additive to dominance variances revealed that additive gene action was predominant for inheritance of grain mold resistance (Panicle Grain Mold Rating - PGMR). Among the parents, two A-lines ICSA 369 and ICSA 370 and six testers *viz*., IS 41675, ICSR 91011, ICSR 89058, PVK 801, GD 65028, GD 65055 in all the 4 environments were identified as a good general combiners for grain mold resistance. These parents can be utilized for the development of grain mold resistant hybrids.

Key words: Combining ability, grain mold, PGMR, sorghum

Key findings: The present study indicated the predominance of additive gene action for grain mold measuring traits and pedigree breeding may useful for development of lines with grain mold resistance.

Manuscript received: April 12, 2015; Decision on manuscript: December 29, 2015; Manuscript accepted: June 27, 2016.

Communicating Editor: Bertrand Collard

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth important cereal after wheat, maize, rice and barley and is cultivated in wide geographic areas in the Americas, Africa, Asia and the Pacific. In Asia the crop is grown predominantly by subsistence farmers in the areas subjected to low rainfall and drought, where it is mostly used as food. Many of the improved sorghum varieties and hybrids mature earlier than local varieties, often before the end of the rainy season. This results in increased exposure of the developing and maturing grain to conditions of high humidity and wetness. Grain mold develops under these conditions and results in decreased filling and size of the grain and chalky endosperm, which disintegrates during harvest and threshing. Grain molds are estimated to cause losses worth US $130 million per annum globally (ICRISAT, 1992) in sorghum. A number of pathogenic and saprophytic fungi are involved in the sorghum grain mold complex. Fungi belonging to more than 40 genera are reported to be associated with sorghum grain mold (Navi *et al*., 1999). Of these, only a few fungi infect sorghum flower tissues during early stages of grain development. These include Fusarium monaliforme sheld; Curvularia lunata (Walker) Boedjin and Phoma sorghi (Sacc.) Boerama, Dorenbosch and Venkatesan (Caster and Frederiksen, 1981; Mathur and Naik, 1981; Williams and Rao, 1981; Bandyopadhyay, 1986; Singh *et al*., 1988; Singh and Agarwal, 1989; Bandyopadhyay *et al*., 2000; Thakur *et al*., 2003). Sorghum research workers identified grain mold as one of the most vexing problems in sorghum. In most cases, avoidance or chemical control in farmers field is impracticable and therefore major research efforts have been focused on development of resistant cultivars for which knowledge of combining ability is necessary in selection of appropriate parents for hybridization. The general combining ability (GCA) and specific combining ability (SCA) are suitable genetic components for unbiased estimation to develop an efficient breeding procedure. Hence, this study was undertaken to study the combining ability for grain mold resistance by using Line × Tester mating system to generate the information on combining ability of parents to select better parents and develop superior cross combinations.

MATERIALS AND METHODS

The basic material for the present investigation comprised of 8 A-lines, 21 testers and 6 checks which were procured from sorghum breeding unit ICRISAT, Patancheru, Hyderabad (Table 1). The 8 A-lines (5 lines were grain mold resistant) and 21 testers (9 testers were grain mold resistant) were crossed in Line × Tester mating design during 2003-2004 and 2004-2005 post-rainy (October to February), seasons at ICRISAT, Patancheru, Hyderabad. The F_1s obtained were screened for grain mold resistance along with parents and checks in a Randomized Complete Block Design (RCBD) with two replications at ICRISAT, Patancheru, India and College Farm, College of Agriculture, Rajendranagar, India during the 2004 and 2005 rainy (June to September) seasons (*kharif*, 2004, 2005) following standard field screening technique. Each genotype was raised in two rows of 2 m length with a spacing of 60 × 15 cm. Recommended agronomic practices were followed to raise a good crop.

Field screening technique for grain molds

The screening nursery was sown in mid-June so that the crop experiences high probability of rains and high humidity during grain-filling and maturity stages in September. Adequate level of grain mold development for good screening was realized by providing sprinkler irrigation. Sprinklers were arranged in a sequence grid pattern, the shortest distance between any two sprinklers being 12 m. The nursery was sprinkled for one hour each at 10.00 A.M and 4.00 P.M. on rain free days to ensure high humidity from flowering to grain maturity (Bandyopadhyay and Mughogho, 1988). Grain mold damage was evaluated as a Panicle Grain Mold Rating (PGMR) at physiological maturity stage and Threshed Grain Mold Rating (TGMR) after harvest on 10 randomly selected plants of each genotype in each replication by using 1-9 scale, where 1 = no mold, 2 = 1-5% of grains colonized by grain mold fungi, 3 = 6-10% of grains colonized by grain mold fungi, 4 = 11-20% of grains colonized by grain mold fungi, 5 = 21-30% of grains colonized by grain mold fungi, 6 = 31-40% of grains colonized by grain mold fungi, 7 = 41-50% of grains colonized by grain mold fungi, 8 = 51-75% grains colonized by grain mold fungi, 9 = >75% of grains colonized by grain mold fungi (Bandyopadhyay and Mughogho, 1988).

Statistical analysis

The computed average values of PGMR and TGMR in both parents and hybrids from different environments were subjected to WINDOSTAT statistical analyses. Combining ability analysis performed according to Kempthorne (1957) separately for each year and season from hybrid trial.

RESULTS AND DISCUSSION

Combining ability analysis is a useful technique to estimate the nature of gene action controlling the traits and also to choose the parents and potential cross combinations based on general and specific combining ability effects. The combining ability studies made in the single environment may not provide precise information on gene action as the environmental effects play very important role in the expression of the genotype and hence the estimates of general combining ability of 29 parents and specific combining ability effects of 168 hybrids for grain mold resistance at 4 environments were used. The parents and crosses studied were evaluated for both PGMR and TGMR scores. The results of PGMR are only presented and discussed as there is high correlation between PGMR and TGMR.

Table 1. Details of material utilized in the experiment.

No	Genotype	Pedigree	Source	Disease reaction
Lines				
1	ICSA 369	(ICSB 11 ×IS 2815)30-1-3-1-1	ICRISAT, Patancheru	Resistant
2	ICSA 370	(ICSB 11 × IS 2815)30-1-3-3-2	ICRISAT, Patancheru	Resistant
3	ICSA 371	(ICSB 11 × IS 2815)32-1-1-3-2-2	ICRISAT, Patancheru	Resistant
4	ICSA 400	[(ICSB 37 × IS 2501)×ICSB 11]5-1-2-2-1	ICRISAT, Patancheru	Resistant
5	ICSA 384	(ICSB 17 × IS 2815)1-2-1-2-1	ICRISAT, Patancheru	Resistant
6	ICSA 382	(ICSB 11 × IS 2815)62-4-3-1	ICRISAT, Patancheru	Susceptible
7	ICSA 52	Ind. Syn. 422-1	ICRISAT, Patancheru	Susceptible
8	ICSA 101	(Ind. Syn. 89-1 × Rs/R 20-682)-5-1-3	ICRISAT, Patancheru	Susceptible
Testers				
1	IS 41720	IS 41720	ICRISAT, Patancheru	Susceptible
2	IS 41397	IS 41397	ICRISAT, Patancheru	Susceptible
3	IS 41675	IS 41675	ICRISAT, Patancheru	Susceptible
4	IS 18758C-618-2	IS 18758C-618-2	ICRISAT, Patancheru	Resistant
5	IS 18758C-618-3	IS 18758C-618-3	ICRISAT, Patancheru	Resistant
6	IS 30469C-140-2	IS 30469C-140-2	ICRISAT, Patancheru	Resistant
7	IS 30469C-1508-2	IS 30469C-1508-2	ICRISAT, Patancheru	Resistant
8	ICSV 96105	(IS 25017 × ICSV 233)-16-2-2-2-3-1	ICRISAT, Patancheru	Resistant
9	ICSV 96094	(IS 20844 × ICSV 88002)-4-2-1-2-1-1	ICRISAT, Patancheru	Resistant
10	IS 84	IS 84	ICRISAT, Patancheru	Susceptible
11	SPV 462	SPV 462	ICRISAT, Patancheru	Susceptible
12	ICSR 89013	[(C 89 × SPV 351) × MR 934]-6-2	ICRISAT, Patancheru	Susceptible
13	ICSR 91011	[(SPV 475 × (20-67 × SB 1067)-4-1)]-4-3	ICRISAT, Patancheru	Susceptible
14	ICSR 89018	[(C 89 × SPV 351) × MR 934]-6-6	ICRISAT, Patancheru	Susceptible
15	ICSR 89058	(PS 21143 × E 35-1)-2-2-2-3-1-1-1	ICRISAT, Patancheru	Susceptible
16	PVK 801	[(IS 23528 × SPV 475) ×(PS 29154)]-4-2-2-4	ICRISAT, Patancheru	Resistant
17	GD 65028	GD 65028	ICRISAT, Patancheru	Resistant
18	GD 65055	GD 65055	ICRISAT, Patancheru	Resistant
19	ICSR 92001	[(IS 2350 × MB 9) × SPV 351)]-6-1-1-5	ICRISAT, Patancheru	Susceptible
20	ICSR 91019	[(M 35-1 ×M 1009)-2-1 × F5-6)-5-3-2 ×SPV475)]-3-2	ICRISAT, Patancheru	Susceptible
21	ICSR 91029	(PM 11344 × SPV 351)-1-1-1-4	ICRISAT, Patancheru	Susceptible
Checks				
1	Bulk Y	Bulk Y	ICRISAT, Patancheru	Susceptible
2	IS 25017	IS 25017	ICRISAT, Patancheru	Resistant
3	IS 20	IS 20	ICRISAT, Patancheru	Susceptible
4	IS 14384	IS 14384	ICRISAT, Patancheru	Resistant
5	PVK 801	[(IS 23528 × SPV 475) ×(PS 29154)]-4-2-2-4	ICRISAT, Patancheru	Resistant
6	CSH 16	27A × C 43	ICRISAT, Patancheru	Susceptible

Analysis of variance

The pooled analysis of variance revealed significant differences due to environments for grain mold resistance indicating sufficient diversity among the environments. The significant mean squares due to parents and crosses for grain mold resistance indicated diversity among the parents and the hybrids. Variances due to females and males and interaction of females × males were significant for all the traits indicating the significant contribution of females and males towards GCA variance and female × male interaction towards SCA variance (Table 2).

Table 2. Pooled analysis of variance for combining ability for grain mold resistance components in sorghum.

Source of variation	d.f.	PGMR	Source of variation	d.f.	PGMR
Replicates	1	2.879**	Females ×Males	140	2.45 **
Environments	3	14.80**	Parents × Environments	84	1.19**
Rep × Environments	3	2.33 **	(Parents vs Crosses) × Environments	3	2.28**
Parents	28	28.08**	Crosses × Environments	501	1.06 **
Parents vs Crosses	1	309.43**	Females × Environments	21	3.97 **
Crosses	167	15.07 **	Males × Environments	60	2.37 **
Females	7	63.08 **	Females × Males × Environments	420	0.72 **
Males	20	86.62 **	Error	668	0.38

* Significant at 5% level, ** significant at 1% level

Estimation of genetic components of variances

Information on nature of gene action is required to facilitate breeding of resistant cultivars. Murty and House (1984) and Kataria *et al*. (1990) reported large dominance effects besides significant additive and additive × additive interaction for grain mold resistance. Both additive and non-additive components of variances determined the expression of grain mold reaction (Dabholkar and Baghel, 1980). In this study the additive variances were higher than the dominance variances in all the environments. The ratios of additive variance to dominance variance were 9.77, 1.67, 6.61 and 3.78 at Patancheru *kharif* 2004, Rajendranagar *kharif* 2004, Patancheru *kharif* 2005 and Rajendranagar *kharif* 2005 respectively. Due to additive gene action for these mold reacting trait, selection procedures such as pedigree breeding may be followed to isolate lines with grain mold resistance. Similarly, Narayana and Prasad (1983), Ghorade *et al*. (1998), Rodríguez-Herrera *et al*. (2000) and Audilakshmi *et al*. (2000) reported that the additive gene action was predominant in the inheritance of resistance to grain mold.

GCA and SCA effects

Among the parents, two A-lines ICSA 369 and ICSA 370 in all the 4 environments, ICSA 101at Patancheru *kharif* 2004, ICSA 371at Rajendranagar *kharif* 2004, Patancheru *kharif* 2005 and Rajendranagar *kharif* 2005 and nine testers *viz*., IS 41675, IS 30469C-140-2, IS 30469C-1508-2, ICSR 91011, ICSR 89058, PVK 801, GD 65028, GD 65055, ICSR 92001 at Patancheru *kharif* 2004, nine testers *viz*., IS 41675, IS 30469C-140-2, IS 30469C-1508-2, ICSV 96105, ICSR 91011, ICSR 89058, PVK 801, GD 65028, GD 65055 Rajendranagar *kharif* 2004, seven testers at IS 41675, ICSV 96105, ICSR 91011, ICSR 89058, PVK 801, GD 65028, GD 65055, Patancheru *kharif* 2005 and eleven testers *viz*., IS 41720, IS 41675, IS 30469C-140-2, ICSV 96105, SPV 462, , ICSR 91011, ICSR 89058, PVK 801, GD 65028, GD 65055, ICSR 92001 at Rajendranagar *kharif* 2005 were identified as a good general combiners for grain mold resistance. These parents can be utilized for the development of grain mold resistant hybrids (Table 3). Since high general combining ability effects correspond with additive and additive x additive interaction (Griffing, 1956) and represent fixable genetic component of variation, these parents appeared to be worthy of exploitation in recombination breeding programme.

Evaluation of the cross combinations at 4 environments revealed that one hybrid at Patancheru (2004 *kharif*), 42 hybrids at Rajendranagar (2004 *kharif*), 12 hybrids at Patancheru (2005 *kharif*) at 15 hybrids at Rajendranagar (2005 *kharif*) recorded significant negative SCA effects (Table 4). Desirable cross combinations with significant negative SCA effects at all environments except Patancheru (2004 *kharif*) were ICSA 370 × IS 18758C-618-3 and ICSA 101 × ICSV 96094. Twelve crosses exhibited significant negative SCA effects in two environments. These results suggested the need for diversity among parents in terms of their GCA effects to realize hybrids with higher level of grain mold resistance.

Table 3. Estimates of general combining ability effects for PGMR in four environments.

	Parents/Hybrids	Patancheru 2004	Rajendranagar 2004	Patancheru 2005	Rajendranagar 2005
	Lines				
1	ICSA 369	-0.28 **	-0.69 **	-1.03 **	-0.62 **
2	ICSA 370	-0.30 **	-0.74 **	-1.18 **	-0.76 **
3	ICSA 371	-0.12	-0.73 **	-1.01 **	-0.65 **
4	ICSA 400	0.02	0.03	0.46 **	0.12 *
5	ICSA 384	-0.04	0.54 **	0.54 **	0.50 **
6	ICSA 382	0.06	0.23 **	0.32 **	0.24 **
7	ICSA 52	0.85 **	0.99 **	1.19 **	0.87 **
8	ICSA 101	-0.19 **	0.36 **	0.71 **	0.30 **
	S.E.(i)	0.14	0.07	0.12	0.08
	Testers				
1	IS 41720	-0.17	-0.13	0.27	-0.74 **
2	IS 41397	0.57 *	-0.20	0.39 *	0.35 *
3	IS 41675	-0.47 *	-0.64 **	-0.81 **	-0.87 **
4	IS 18758C-618-2	1.33 **	0.56 **	1.43 **	1.42 **
5	IS 18758C-618-3	1.32 **	0.72 **	1.88 **	2.05 **
6	IS 30469C-140-2	-0.66 **	-0.61 **	-0.26	-0.38 *
7	IS 30469C-1508-2	-0.51 *	-0.51 **	-0.32	-0.27
8	ICSV 96105	-0.27	-1.46 **	-1.42 **	-0.92 **
9	ICSV 96094	1.29 **	-0.15	-0.17	0.54 **
10	IS 84	3.44 **	3.81 **	3.33 **	3.31**
11	SPV 462	-0.20	-0.20	-0.35	-0.35 *
12	ICSR 89013	0.78 **	0.97 **	1.14 **	1.01 **
13	ICSR 91011	-0.99 **	-0.76 **	-0.69 **	-0.58 **
14	ICSR 89018	0.23	-0.03	-0.15	0.69 **
15	ICSR 89058	-0.55 *	-0.27 *	-0.67 **	-0.79 **
16	PVK 801	-1.02 **	-0.25 *	-0.90 **	-1.12 **
17	GD 65028	-1.51 **	-1.54 **	-2.08 **	-1.88 **
18	GD 65055	-1.61 **	-1.26 **	-1.95 **	-1.93 **
19	ICSR 92001	-0.76 **	0.34**	-0.19	-0.59 **
20	ICSR 91019	-0.25	0.89 **	0.64 **	0.51 **
21	ICSR 91029	0.00	0.74 **	0.88 **	0.53 **
	S.E.(j)	0.22	0.11	0.19	0.13

Table 4. Estimates of specific combining ability effects for PGMR in four environments.

Location	Hybrid	SCA	S.E.(ij)
Patancheru 2004	ICSA 382 x ICSR 89013	-1.24 *	0.63
Rajendranagar 2004	ICSA 369 x IS 30469C-140-2	-0.70 *	0.31
	ICSA 369 x IS 30469C-1508-2	-0.90 **	
	ICSA 369 x ICSR 89013	-1.28 **	
	ICSA 369 x ICSR 89018	-1.28 **	
	ICSA 369 xICSR 89058	-0.63 *	
	ICSA 369 x ICSR 92001	-1.76 **	
	ICSA 369 x ICSR 91019	-1.21 **	
	ICSA 370 x IS 18758C-618-3	-1.09 **	
	ICSA 370 x IS 30469C-140-2	-0.75 *	
	ICSA 370 x IS 30469C-1508-2	-0.85 **	
	ICSA 370 x ICSR 89018	-0.63 *	
	ICSA 370 x ICSR 92001	-1.21 **	
	ICSA 370 x ICSR 91019	-1.26 **	
	ICSA 371 x IS 18758C-618-2	-0.94 **	
	ICSA 371 x IS 30469C-140-2	-0.75 *	
	ICSA 371 x IS 30469C-1508-2	-0.85 **	
	ICSA 371 xICSR 89013	-0.64 *	

Continued…

Table 4. Estimates of specific combining ability effects for PGMR in four environments.

Location	Hybrid	SCA	S.E.(ij)
	ICSA 400 x IS 41675	-0.98 **	
	ICSA 400 xICSV 96105	-0.66 *	
	ICSA 400 xICSV 96094	-0.87 **	
	ICSA 400 x SPV 462	-0.82 **	
	ICSA 384 x IS 41397	-0.94 **	
	ICSA 384 x IS 41675	-1.80 **	
	ICSA 384 xIS 18758C-618-2	-0.86 **	
	ICSA 384 x IS 18758C-618-3	-0.87 **	
	ICSA 384 x ICSV 96094	-0.99 **	
	ICSA 384 x ICSR 91011	-1.48 **	
	ICSA 384 x GD 65028	-0.64 *	
	ICSA 384 x GD 65055	-1.08 **	
	ICSA 382 x ICSR 91011	-0.86 **	
	ICSA 52 x IS 41720	-1.00 **	
	ICSA 52 x ICSV 96105	-1.22 **	
	ICSA 52 x IS 84	-0.90 **	
	ICSA 52 x SPV 462	-1.99 **	
	ICSA 52 x GD 65028	-1.54 **	
	ICSA 52 x ICSR 91029	-0.82 **	
	ICSA 101 x IS 41397	-0.76 *	
	ICSA 101 x ICSR 89058	-1.28 **	
	ICSA 101 x PVK 801	-1.61 **	
	ICSA 101 x ICSR 91029	-1.59 **	
Patancheru 2005	ICSA 370 x IS 41397	-1.09 *	0.54
	ICSA 370 x IS 18758C-618-3	-1.82 **	
	ICSA 371 x IS 41397	-1.36 *	
	ICSA 371 x IS 18758C-618-2	-1.09 *	
	ICSA 371 x IS 18758C-618-3	-1.44 **	
	ICSA 400 x ICSR 91019	-1.12	
	ICSA 384 x IS 41397	-1.11 *	
	ICSA 382 x ICSR 92001	-1.21 *	
	ICSA 52 x GD 65028	-1.07 *	
	ICSA 52 x GD 65055	-1.10 *	
	ICSA 101 x ICSV 96105	-1.11 *	
	ICSA 101 x ICSV 96094	-1.16 *	
Rajendranagar 2005	ICSA 369 x IS 18758C-618-3	-1.02 *	0.38
	ICSA 369 x IS 30469C-140-2	-0.86 *	
	ICSA 370 x IS 18758C-618-3	-1.21 *	
	ICSA 371 x IS 18758C-618-3	-1.22 *	
	ICSA 371 x ICSR 91019	-0.88 *	
	ICSA 400 x ICSR 91011	-0.86 *	
	ICSA 400 x ICSR 91019	-0.86 *	
	ICSA 384 x ICSV 96094	-0.96 *	
	ICSA 384 x ICSR 91011	-0.94 *	
	ICSA 384 x ICSR 89018	-1.01 *	
	ICSA 382 x ICSR 91019	-1.07 *	
	ICSA 52 x ICSV 96105	-1.26 **	
	ICSA 101 x ICSV 96105	-1.29 **	
	ICSA 101 x ICSV 96094	-1.55 **	
	ICSA 101 x PVK 801	-1.09 *	

CONCLUSION

Panicle grain mold resistance (PGMR) is the direct visual rating of the presence of grain mold on the complete panicles. Information on nature of gene action is required to facilitate breeding of resistant cultivars. Predominance of additive gene action was found in governing grain mold resistance (PGMR). Due to additive gene action for these mold measuring parameters, selection procedure like pedigree breeding may be useful to isolate lines with grain mold resistance. Among the parents, two A-lines ICSA 369 and ICSA 370 and six testers *viz*., IS 41675, ICSR 91011, ICSR 89058, PVK 801, GD 65028, GD 65055 in all the 4 environments were identified as a good general combiners for grain mold resistance. These parents can be utilized for the development of grain mold resistant hybrids.

ACKNOWLEDGEMENTS

We gratefully acknowledge the assistance of the sorghum unit, ICRISAT.

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