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Combining ability for foliar diseases, insect-pests and quality in forage sorghum (*Sorghum bicolor*)

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ABSTRACT

Combining ability analysis was carried out following Line × Tester analysis for green fodder yield, stem girth, ºBrix, important foliar diseases, shoot fly and stem borer in nine male sterile lines, four testers and their thirty six hybrids in forage sorghum [*Sorghum bicolor* (L.) Moench.]. Highly significant variances for lines as well as testers were observed indicating presence of wide range of genetic variation among the lines and testers for most of the traits. Variance due to Lines × Testers interaction was also found highly significant for all the characters studied except sooty stripe disease. The estimates of *sca* variances were higher than those of *gca* for all the characters suggesting predominance of non-additive gene action in all the traits studied. Among the lines ICSA 725 and ICSA 467 were found to be the best combiners whereas among the testers G 203 and SDSL 92113 were found to be superior when yield and resistance to diseases and insect were considered together. Among the hybrids, 95A × SSG 59-3, 296A × SSG 59-3, 467A × SSG 59-3, 467A × SDSL 92113 and 725A × SSG 59-3 were having better *sca* effects for yield and resistance traits.

Key words : ºBrix, Combining ability, Forage sorghum, Grey leaf spot, Shoot fly, Sooty stripe, Stem borer, Zonate leaf spot

Sorghum (*Sorghum bicolor* (L.) Moench.) is grown mainly as a grain crop in most parts of the world, however, in Northern India it is grown primarily as a fodder crop. It serves as a very good fodder crop because of its inherent potentialities of faster growth rate, good ratoonability, palatability, digestibility and its wide range of uses as green fodder, dry roughage and silage and thus can be the best option to bridge the gap between demand and supply of fodder. Sorghums giving many cuts in a season (multicut types) are more advantageous in terms of saving cost, providing higher fodder yield in shorter period and they also offer continuous supply of green fodder over longer durations. Many superior multicut hybrids of forage sorghum have been developed to bridge the vast gap between the fodder requirement and availability, however, their quality has been affected greatly due to increased stem girth, reduced sweetness, infestation of foliar diseases and insect-pests. To initiate such a hybrid breeding programme blending good quality and resistance traits, the knowledge of combing ability of the parents and hybrids for these characters is essential which in turn will help in the selection of suitable parents for producing qualitatively superior high fodder yielding, disease and insect-pest resistant hybrids. Line × Tester analysis has frequently been used in combining ability analysis of sorghum genotypes, however, negligible studies have been made in multicut sorghums for these traits. In the present study, an attempt has been made to unravel the magnitude of combing ability for fodder yield, some fodder quality affecting traits, foliar diseases and pests resistance in forage sorghum utilizing the male sterile lines.

MATERIALS AND METHODS

Thirty six hybrids of forage sorghum were developed by crossing nine male sterile lines (ICS 9A, ICS 95A, IMS 296A, ICSA 467, ICSA 725, ICSA 733, 88015A, 41152A, and 46230A) with four testers (SSG 59-3, G 203, SDSL 92113 and CSV 216) in all possible combinations during *kharif* 2008 and were grown in Randomized Block Design along with parents in three replications during *kharif* 2009 and 2010 at Forage Research Area, CCS HAU, Hisar. Each genotype was accommodated in four rows of 4m length spaced at 30 cm. Plant to plant spacing was maintained 10 cm. The study material comprised of few genotypes highly susceptible to the foliar diseases and they served as infector rows for the foliar diseases (SSG 59-3 is highly susceptible to grey and zonate leaf spot diseases and G 203 is susceptible to sooty stripe), also border rows of these genotypes were

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planted to provide enough inoculums . Hisar is hot spot for shoot fly and stem borer attack hence observations were recorded on natural infestation basis. All the recommended crop management practices were followed to raise a good crop, however, plant protection measures were not adopted as observations on diseases and pests incidence were to be recorded.

Data were recorded on five randomly selected plants from each genotype in each replication for stem girth (cm) and ºBrix. Observations on ºBrix were recorded at the time of 50% flowering with the help of Spectrophotometer. Disease scoring was done using visual standards employing 1-5 scale (1-resistant to 5-highly susceptible) for incidence of three most important foliar diseases, viz. grey leaf spot (*Cercospora sorghi*), zonate leaf spot (*Gloeocercospora sorghi*) and sooty stripe (*Ramulispora sorghi*) and infestation by major insects affecting the crop yield and quality, i.e. stem borer (*Chilo partellus*) and shoot fly (*Atherigona soccata*) on plot basis. For foliar diseases observations were recorded at 35 and 55 days after sowing. Observations for stem borer attack were recorded as prescribed by Mathur *et al*. (1991) at 35 and 45 days after germination, however, for shoot fly, scoring was done at 20 and 30 days after germination on dead hearts formation. Green fodder yield/plot (kg) was also recorded. The data over two years was pooled after testing the homogeneity of error variances using Bartlett's test and combining ability analysis was carried out following Line × Tester model as suggested by Kempthorne (1957).

RESULTS AND DISCUSSION

A large number of foliar diseases attack sorghums, however, out of these grey leaf spot, zonate leaf spot and sooty stripe are most common. These diseases cause heavy reduction in the fodder yields and the quality of the fodder (Rathi *et al*. 2007). Likewise, stem borer and shoot fly are the major insects attacking sorghum crop affecting both quantity and quality of green fodder produced (Sharma *et al.* 2007). These insect-pests and diseases reduce the quality of fodder by decreasing the *in vitro* dry matter digestibility of the whole plant up to 3-6% due to corresponding increase in tannin content. Increase in fibre content due to stem tunneling by the stem borer acts as an additional factor in reducing the digestibility of the fodder (Yadav *et al*. 2010). All these reduce the palatability and digestibility of the green fodder.

The male sterile lines selected for this study were almost resistant to the major foliar diseases though susceptible to stem borer and shoot fly. These were also having pithy and wider stem girth and lesser sweetness. Stem girth is an important parameter for quality as well as insect resistance. Increased stem girths are mostly prone to stem borer attack as well as they are more fibrous and hardy thereby deteriorating the fodder palatability and quality. The testers used in this study were high fodder yielding genotypes and were having lesser incidence of stem borer and shoot fly in comparison to the male sterile lines. Two of them (SSG 59-3 and SDSL 92113) had very thin stem and were sweet and juicy, thus, rated as qualitatively superior genotypes. The genotypes G 203 and SDSL 92113 were resistant to gray leaf spot and zonate leaf spot, however, susceptible to sooty stripe. Reverse was the case for SSG 59-3 and CSV 216.

Line × Tester mating design is most appropriate for evaluation of relatively large number of genotypes for their genetic worth as well as valuable information regarding combining ability of parents and hybrids can be worked out. Further, combining ability analysis also provides an insight into the nature and magnitude of fixable and non-fixable genetic effects and thus also helps in deciding proper breeding method. Combining ability analysis gives information on genetic architecture of the crosses under study and helps in selecting the potential lines on the basis of the performance for the characters under study. Analysis of variance for the fodder yield, foliar diseases, insect-pests and sweetness are presented in Table 1.

Perusal of the table revealed highly significant variances for females (male sterile lines) indicating presence of wide range of genetic variation among the lines for the traits under study. Same trend was observed for the testers except for zonate leaf spot. Variance due to Lines × Testers was also found highly significant for all the characters studied except sooty stripe indicating presence of considerable amount of variability in the hybrids for all the characters. Brar and Chaudhary (2007) and Tariq *et al*. (2012) for green fodder yield; Indhubala *et al.* (2010) and Umakanth *et al.* (2012) for stem thickness, fodder yield and ºBrix; Sharma *et al.* (2007)

Table 1 Analysis of variance (mean squares) for combining ability in forage sorghum

Source	df	Shoot fly	Stem borer	Grey leaf spot	Zonate leaf spot	Sooty stripe	ºBrix	Stem girth	Green fodder yield
Reps	2	1.91**	0.67**	0.003	0.058	0.46*	9.98**	4.51**	463.72**
Hybrids	35	2.54**	0.94**	3.11**	1.17**	2.14**	29.51**	1.61**	187.62**
Lines	8	7.64**	1.12**	4.89**	2.02**	3.56**	53.04**	1.5**	193.26**
Testers	3	1.42**	2.33**	6.97**	0.083	2.78*	5.27**	1.25**	255.67**
Lines × Testers	24	0.98**	0.71**	2.03*	1.02**	1.59	24.69**	1.69**	208.87**
Error	70	0.07	0.05	0.023	0.036	0.10	0.49	0.06	1.60
$\sigma^2 gca/\sigma^2 sca$		0.18	0.24	0.29	0.006	0.16	–0.08	–0.03	0.028

in stem borer; Dhillon *et al.* (2006) and Aruna and Padmaja (2009) for shoot fly, Haussmann *et al.* (2001) for sooty stripe and Prakash *et al.* (2012) for stem diameter and fodder yield reported similar findings. However, no reports on combining ability studies could be traced in literature on grey and zonate leaf spot diseases of sorghum.

Among the lines and testers, the contribution of lines was more towards the total variance as compared to the testers for all the characters studied except green fodder yield, stem borer attack and grey leaf spot disease where the contribution of testers was more, indicating the larger contribution of lines towards *gca* effects than that of testers for these characters. The analysis further revealed that estimates of *sca* variances were higher than those of *gca* for all the characters under study implying predominance of non-additive gene action for these traits and strong possibilities of improvement of these traits through heterosis breeding. Preponderance of non-additive gene action were also reported for green fodder yield (Kamdi *et al*. 2009), for fodder yield, yield components and juice quality characters (Indhubala, *et al.* 2010) and for green fodder yield and stem girth (Prakash *et al.* 2012) whereas additive gene action for sooty stripe was also reported by Haussmann *et al.* (2001).

The significant negative estimates of *gca* effects for grey and zonate leaf spot diseases of lines ICS 9A, ICS 95A, ICSA 467, ICSA 733 and 46230A suggested them as good general combiners for these two important foliar diseases (Table 2). Similarly, the lines 296A, ICSA 467, ICSA 725 and 88015A were found good general combiners for green fodder yield; ICSA 725, 88015A and 41152A for stem girth and sooty stripe resistance; 296A, ICSA 467 and ICSA 725 for ºBrix; ICSA 733 and 41152A for stem borer and ICS 9A and 41152A for shoot fly. Among the lines ICSA 467 and ICSA 725 can be considered as overall good general combiners. All the testers exhibited good general combining ability for fodder yield whereas, G 203 and SDSL 92113 were also good combiners for grey and zonate leaf spot; SSG 59-3 and SDSL 92113 for stem girth; SSG 59-3, G 203 and SDSL 92113 for stem borer; SSG 59-3 and G 203 for ºBrix; G 203 for shoot fly and CSV 216 for sooty stripe besides fodder yield. Among the testers G 203, SDSL 92113 and SSG 59-3 can be considered as overall good combiners as they showed better *gca* effects for fodder yield, resistance to insect-pests and foliar diseases. Considering the *gca* effects *vis-a vis* the *per se* performance of the parents, majority of them with high mean exhibited high *gca*, thus *per se* performance itself could be an indicator of *gca* of the parents involved. Thus, it would be worthwhile to use the above parents in breeding programme for exploiting additive gene effects for these characters.

In the present study, the main objective was to obtain hybrids with thin stalk and high green fodder yield with more sweetness and resistance to foliar diseases and insect-pests that can be utilized for feeding cattle. The foliar diseases, insect-pests and stem girth are the essential traits required with negative values of *gca* and *sca* in forage sorghum whereas, green fodder yield and ºBrix are required with positive values. In the present study, none of the hybrids exhibited significant and negative *sca* effects for all the foliar diseases, insect-pests and stem thickness and positive significant *sca* effects for green fodder yield and ºBrix (Table 3). However, 12 hybrids exhibited the desirable *sca* effects for at least four traits. Among them eight were having highly significant positive *sca* effects for green fodder yield which is the most essential trait in any hybrid breeding programme.

The hybrid ICS 9A × SSG 59-3 was found having desirable *sca* effects for green fodder yield, stem girth, grey and zonate leaf spot. Likewise the hybrid ICS 95A × SSG 59-3 for green fodder yield, stem girth, stem borer, grey and

Table 2 Estimates of general combining ability effects of lines and testers for different traits in forage sorghum

Lines	Shoot fly	Stem borer	Grey leaf spot	Zonate leaf spot	Sooty stripe	ºBrix	Stem girth	Green fodder yield
ICS 9A	–1.69**	–0.17	–0.39**	–0.31**	–0.17	–0.19	–0.07	–1.38**
ICS 95 A	0.81**	0.33**	–0.69**	–0.31**	0.58**	0.30	0.44**	–2.64**
296 A	0.81**	–0.17	0.361**	0.94**	0.33**	0.93**	0.29**	4.27**
ICSA 467	0.31**	0.08	–0.14*	–0.26**	0.33**	3.05**	0.09	4.02**
ICSA 725	–0.19	0.33**	0.61**	0.19**	–0.42**	2.80**	–0.31**	4.65**
ICSA 733	0.06	–0.42**	–0.64**	–0.31**	0.83**	–0.29	0.22*	–5.73**
88015 A	0.56**	0.08	1.11**	0.19**	–0.67**	–0.95**	–0.56**	2.59**
41152 A	–0.69**	–0.42**	0.36**	–0.06	–0.67**	–3.20**	–0.41**	–4.85**
46230 A	0.06	0.33**	–0.64**	–0.31**	–0.17	–2.45**	0.29**	–0.93
Testers								
SSG 59-3	–0.03	–0.16**	0.14**	0.03	–0.06	0.46*	–0.19**	0.28*
G 203	–0.25**	–0.17**	–0.64**	–0.13*	0.39**	0.54**	0.13	0.30*
SDSL 92113	–0.03	–0.28**	–0.08*	–0.13*	0.06	–0.24	–0.30**	0.29*
CSV 216	0.31**	0.39**	0.58**	–0.01	–0.39**	0.16	0.17*	0.29*

Table 3 Estimates of specific combining ability effects of hybrids for different traits in forage sorghum

Hybrid	Shoot fly	Stem borer	Grey leaf spot	Zonate leaf spot	Sooty stripe	ºBrix	Stem girth	Green fodder yield
ICS 9A × SSG 59-3	0.03	–0.06	–0.39**	–0.54**	–0.34	–0.41	–0.67**	6.13**
ICS 95A × SSG 59-3	0.53*	–0.56**	–0.74**	–0.53**	0.31	0.09	–1.13**	8.60**
296A × SSG 59-3	–0.06	–0.47*	0.86**	0.72**	–0.56*	1.96**	–1.32**	11.52**
ICSA 467 × SSG 59-3	0.03	–0.51*	–0.64**	–0.58**	0.56*	1.66**	0.13	10.73**
467A × SDSL 92113	0.03	0.03	–0.42**	–0.58**	0.44	4.11**	–0.57**	10.40**
ICSA 725 × SSG 59-3	–0.47*	–0.56**	1.39**	0.64**	0.31	2.91**	–0.63**	2.39*
ICSA 725 × G 203	0.75**	–0.33	–0.61**	–0.53**	0.86**	1.41*	–0.11	3.83**
ICSA 733 × SSG 59-3	0.28	–0.49**	–0.14	–0.03	0.06	2.69**	–1.00**	5.48**
ICSA 733 × G 203	0.50*	–0.42*	–0.64**	–0.63**	–0.39	3.19**	–0.63**	–3.45**
ICSA 733 × SDSL 92113	–0.72**	–0.47*	–0.68**	–0.54**	–0.06	–4.54**	–0.50*	–2.59*
41152A ×G 203	–0.97**	–0.58**	–0.36**	–0.54**	0.11	–1.91**	0.70**	–3.83**
41152A × SDSL 92113	0.25	–0.47*	–0.92**	–0.53**	0.44	–0.64	–0.47*	1.14

zonate leaf spot; hybrid 296A × SSG 59-3 for stem girth, green fodder yield, stem borer, sooty stripe and ºBrix; hybrid ICSA 467 × SSG 59-3 for stem borer, green fodder yield, ºBrix, grey and zonate leaf spot; hybrid ICSA 467 × SDSL 92113 for ºBrix, green fodder yield, stem girth, grey and zonate leaf spot; hybrid ICSA 725 × SSG 59-3 for ºBrix, stem girth, green fodder yield, stem borer and shoot fly; hybrid ICSA 725 × G 203 for ºBrix, green fodder yield, grey and zonate leaf spot and hybrid ICSA 733 × SSG 59-3 for ºBrix, stem girth, green fodder yield and stem borer. The hybrids showing good *sca* effects for different traits, involved either good × poor or poor × poor parental combinations for *gca* effects for those particular traits indicated the prevalence of non-additive gene effects and this could easily be exploited in hybrid development. Hybrids ICS 95A × SSG 59-3, ICSA 467 × SSG 59-3 and ICSA 467 × SDSL 92113 having very good *sca* for many of the traits studied were obtained from poor × good general combiners for various desirable fodder characters indicating a genetic interaction of the additive and non-additive types. They may also have resulted due to accumulation of favorable genes and partly due to dominance and recessive interaction. These forage sorghum hybrids can further be critically tested over different seasons and locations and released for cultivation which will help in increasing productivity of forage sorghum.

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