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COMBINING ABILITY ANALYSIS FOR GRAIN AND FODDER TRAITS IN SORGHUM (*SORGHUM BICOLOR* (L.) MOENCH)

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Abstract

Over the environment, on the basis of days to flowering and suitability for dual purpose analysis was carried out of 100 genotypes including 75 F_1s with 20 parents and 5 checks. Data were collected for grain yield, dry fodder yield, protein content in grain, protein content in fodder, TSS and juiciness. Variations between lines, testers and line × tester was significant for all characters. As both grain and dry fodder yield are important dual-purpose attributes, lines ICSA 202, ICSA 349 and ICSA 357 and ICSA 481 were found to be good general combiners for both grain and dry fodder yield. Two crosses *viz*., ICSA 29002 × SU 1565 and ICSA 356 × SU 1570 exhibited significant SCA effects in all the four environments whereas hybrids ICSA 552 × SU 1561, ICSA 202 × SU 1570,, ICSA 349 × SU 1561, ICSA 208 × SU 1561, ICSA 474 × SU 1561 and ICSA 357 × SU 1565 showed good SCA effects in normal spacing (E_1 and E_3) and ICSA 481 × SU 1561 and ICSA 399 × SU 1557 in wider spacing (E_2 and E_4) for both grain and dry fodder yield. These lines and crosses also expressed positive significant GCA and SCA effects for majority of the remaining fodder quality traits.

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench), an important cereal crop all over the world belongs to Poaceae (Poehlman and Sleper 1995). Because of its adaptation to a wide range of ecological conditions, suitability for low input cultivation and diverse uses it is very popular in semi-arid tropics. In temperate regions it is cultivated for fodder, in tropical areas for grains and in subtropical for dual purpose. In Rajasthan, India it is grown for dual purpose with high emphasis on fodder. Sorghum green fodder is one of the cheapest sources of feed for milch, meat and draft animals. Among the cereals, sorghum plays an important role in India, as a major grain cum fodder crop. It is extensively grown as fodder crop in north India and dual purpose in south India. Sorghum is widely used as fodder crop on account of its quick growth, tillering ability, high dry matter content, leafiness, high palatability, hardiness and suitability for silage making.

The hybridization is used to generate the recombinational variability. Maximum potential of parents is expressed in F_1. To decide which breeding methodology is to be followed depends on the gene action involved in the expression of heterosis which can be judged from combining ability. Sprague and Tatum (1942) developed the concept of combining ability and coined two terms general combining ability (GCA) and specific combining ability (SCA). General combining ability reflects additive and additive × additive gene effects while specific combining ability reflects non additive i.e. dominance and dominance based epistatic gene effects.

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Materials and Methods

On the basis of days to flowering and suitability for dual purpose 15 lines *viz.*, ICSA 202, ICSA 208, ICSA 349, ICSA 356, ICSA 357, ICSA 363, ICSA 380, ICSA 399, ICSA 474, ICSA 481, ICSA 552, ICSA 29001, ICSA 29002, ICSA 29003 and ICSA 29004 were received from ICRISAT and five restorer testers *viz.*, SU 1557, SU 1561, SU 1565, SU 1570 and SU 1571 were identified from station trials. The national checks CSH 16 (grain hybrid), CSV 23 and CSV 27 (dual purpose varieties) and CSV 21 F and PC 1080 (fodder varieties) were included for economic heterosis. These 15 MS lines were crossed with 5 restorers in line × tester fashion during Kharif 2014 at RCA Udaipur and during winter, 2014 -15 at off season sorghum breeding nursery of IIMR, Hyderabad situated in Warangal to obtain 75 hybrids.

The 75 crosses along with the parents *i.e.* 15 lines and 5 testers and 5 checks were planted in simple lattice design in two replications in two intra row spacings of 12.5 cm and 20 cm during Kharif 2015 and Kharif 2016 at the instructional farm, Rajasthan College of Agriculture, MPUAT, Udaipur. The environments were denominated as E_1 (45 × 12.5 cm in Kharif 2015), E_2 (45 × 20 cm in Kharif 2015), E_3 (45 × 12.5 cm in Kharif 2016) and E_4 (45 × 20 cm in Kharif 2016). The inter row spacing was 45 cm. Each genotype was sown in single row plot of 2.0 m length. Data were collected for six dual purpose attributing traits *viz.*, grain yield, dry fodder yield, protein content in grain, protein content in fodder, TSS, and juiciness. Grain yield and dry fodder yield were measured as quintal per hectare. Protein content in grain and fodder was estimated by using Micro Kjeldahl's method given by Lindner (1944). Juiciness was measured at days to 50 per cent flowering on five randomly tagged plants on the basis of juiciness of leaf midrib color on 1 - 5 scale, where 1 stand for non-juicy (pithy) and 5 for juicy and average was worked out. TSS was measured on border plants with hand refractometer at days to 50 per cent flowering. The relative efficiency of lattice was found only up to 108 per cent therefore further analysis was performed as per RBD. Kempthorne (1957) suggested the analysis of variance for L × T factorial mating design using random effect model. But later on, it was extended by various workers for fixed effect model. Singh (1973) suggested the method of diallel analysis over the environments. The same principles were used in present investigation to analyze the data over the environments.

Results and Discussion

Homogeneous error variance was observed for protein content in grain, juiciness and TSS. Therefore, pooled analysis was performed only for these characters. For rest of the characters combining ability was estimated in individual environments. There was significant difference between lines, testers and hybrids in individual and over the environments as the case may be. The interaction of these sources with environment was also significant for these three characters. The magnitude of $\sum^2$ SCA was higher than the $\sum^2$ GCA_T and $\sum^2$ GCA_L for three characters in individual environments and for three characters over the environments which suggest the importance of SCA effects for these characters and confirmed the findings of Showemimo (2005) and Umakanth and Kuriakose (2005) (Tables 1 and 2).

General combining ability is very important tool for identification of the parents for any breeding programme. For grain yield lines, ICSA 202, ICSA 349, ICSA 357 and ICSA 481 exhibited significant positive GCA effects in all the four environments, ICSA 363 and ICSA 29001 in normal spacing of both the years i.e. E_1 and E_3 and ICSA 380 in wider spacing of both the years i.e. E_2 and E_4. Among the testers, SU 1561 was having significant and positive GCA effects in all the four environments and SU 1571 in E_1 and E_3 i.e. normal spacing of both the years. For dry fodder yield lines, ICSA 202, ICSA 349, ICSA 357, ICSA 481 and ICSA 29001 in all the four environments, ICSA 380 in wider spacing of both the years i.e. E_2 and E_4 and ICSA 363 and ICSA

Table 1. Variance due to model I in different environments.

Sl. No.	Characters	Env.	Tester $\sum^2 GCA_T$	Lines $\sum^2 GCA_L$	L × T $\sum^2 SCA$	Error σ^2
1	Grain yield	1	156.68	887.30	8857.43	12.38
		2	69.43	2564.14	18591.82	10.52
		3	168.39	1122.68	10542.30	13.96
		4	53.43	832.28	5831.93	8.13
2	Dry fodder yield	1	1538.08	34189.20	161126.51	70.31
		2	729.97	19606.95	118587.12	32.23
		3	1274.54	32039.85	152424.49	152.58
		4	969.06	16325.58	119243.56	77.82
3	Protein content in fodder	1	0.61	8.42	198.71	0.06
		2	0.41	6.59	200.71	0.04
		3	0.49	7.05	238.94	0.03
		4	0.37	7.90	223.51	0.02

Table 2. Varience due to model I over the environments for protein content in grain, juiciness, TSS.

Sl. No.	Source	Variance	Protein content in grain	Juiciness	TSS
1.	Genotype		671.54	49.81	578.65
2.	Parent		122.47	9.72	118.62
3.	Cross		473.53	31.69	367.01
	Tester	$\sum^2 GCA_T$	0.19	0.11	2.53
	Line	$\sum^2 GCA_L$	15.70	3.12	7.56
	L × T	$\sum^2 SCA$	392.22	14.44	291.20
4.	G × E		79.74	56.91	1016.89
5.	P × E		25.35	12.08	470.51
6.	Cross × E		50.92	41.50	511.50
	T × E	$\sum^2 GCA_T \times E$	0.09	0.16	4.08
	L × E	$\sum^2 GCA_L \times E$	2.02	0.98	17.18
	L × T × E	$\sum^2 SCA \times E$	39.53	34.26	364.42
7.	Pooled error		0.11	0.20	3.10

474 in E_1 and E_3 i.e. normal spacing of both the years exhibited significant positive GCA effects. Testers, SU 1561 and SU 1571 were having significant and positive GCA effects in E_1 and E_3 i.e. normal spacing of both the years and SU 1565 in E_2 and E_4 i.e. wider spacing of both the years. Among fodder quality traits, GCA was significant and positive for 8 lines *viz.*, ICSA 29001, ICSA 357, ICSA 481, ICSA 208, ICSA 29004, ICSA 202, ICSA 552 and ICSA 399 and three testers *viz.*, SU 1571, SU 1561 and SU 1570 for protein content in grain. For protein content in fodder

lines, ICSA 208, ICSA 357, ICSA 29001, ICSA 29003 and ICSA 29004 in all the four environments and ICSA 202 in wider spacing of both the years i.e. E_2 andE_4. Testers, SU 1570 and SU 1571 were having significant and positive GCA effects in all the four environments and SU 1561 in normal spacing of both the years i.e. E_1 and E_3. For juiciness it was significant and positive for 6 lines out of which ICSA 208 expressed highest magnitude. Likewise, for TSS, it was significant and positive for 4 lines *viz.,* ICSA 481, ICSA 29003, ICSA 357 and ICSA 356 and one tester, SU 1571 (Table 3).

On the whole, for both grain yield and dry fodder yield, lines ICSA 202, ICSA 349 and ICSA 357 and ICSA 481 in all the four environments, ICSA 29001 and ICSA 363 in normal spacing (E_1 and E_3) and ICSA 380 in wider spacing (E_2 and E_4) exhibited significant positive GCA effects. Similarly. testers, SU 1571 exhibited significant and positive GCA effects for both grain and dry fodder yield in normal spacing (E_1 and E_3). These parents also exhibited significant GCA effects for majority of the fodder quality traits. Therefore, these parents were noted as good sources of favorable genes for dual purpose attributes and use of these parental lines would be more rewarding for boosting grain and fodder yield in sorghum (Table 3).

On the basis of GCA alone one cannot take the decision of which breeding methodology is to be followed for a cross. SCA along with GCA is essential for taking the decision about breeding methodology. For grain yield, crosses ICSA 399 × SU 1557, ICSA 29004 × SU 1557, ICSA 208 × SU 1561, ICSA 363 × SU 1565, ICSA 552 × SU 1565, ICSA 29002 × SU 1565 and ICSA 356 × SU 1570 in all the four environments, ICSA 357 × SU 1565, ICSA 481 × SU 1565, ICSA 29002 × SU 1561, ICSA 349 × SU 1561, ICSA 552 × SU 1561 and ICSA 202 × SU 1570 and ICSA 357 × SU 1571 in normal spacing of both the years i.e. E_1 and E_3, ICSA 552 × SU 1571, ICSA 552 × SU 1557, ICSA 481 × SU 1561, ICSA 380 × SU 1565 and ICSA 29002 × SU 1570 in E_2 and E_4 *i.e.* wider spacing environments of both the years i.e. E_2 and E_4 exhibited significant and positive SCA effects. For Dry fodder yield, crosses ICSA 474 × SU 1557, ICSA 29003 × SU 1557, ICSA 202 × SU 1561, ICSA 474 × SU 1561, ICSA 208 × SU 1565, ICSA 357 × SU 1565, ICSA 29002 × SU 1565, ICSA 356 × SU 1570, ICSA 202 × SU 1571, ICSA 399 × SU 1571 and ICSA 552 × SU 1571 in all the four environments, ICSA 208 × SU 1561, ICSA 552 × SU 1561 and ICSA 202 × SU 1570, ICSA 481 × SU 1571, ICSA 208 × SU 1561, ICSA 349 × SU 1561, ICSA 380 × SU 1561, ICSA 29001 × SU 1565 and ICSA 399 × SU 1570 in E_1 and E_3 *i.e.* normal spacing of both the years and ICSA 399 × SU 1557, ICSA 349 × SU 1570, ICSA 29003 × SU 1571, ICSA 29001 × SU 1570, ICSA 481 × SU 1561, ICSA 29004 × SU 1561 and ICSA 356 × SU 1565 in E_2 and E_4 i.e. wider spacing of both the years exhibited significant and positive SCA effects. For quality traits, it was significant and positive for 32 crosses, the highest magnitude being exhibited by cross ICSA 474 × SU 1557 for protein content in grain. With respect to protein content in fodder, crosses ICSA 349 × SU 1557, ICSA 363 × SU 1557, ICSA 380 × SU 1561, ICSA 474 × SU 1557, ICSA 552 × SU 1557, ICSA 29001 × SU 1557, ICSA 202 × SU 1561, ICSA 208 × SU 1561, ICSA 380 × SU 1561, ICSA 474 × SU 1561, ICSA 552 × SU 1561, ICSA 29001 × SU 1561, ICSA 29003 × SU 1561, ICSA 202 × SU 1565, ICSA 356 × SU 1565, ICSA 357 × SU 1565, ICSA 474 × SU 1565, ICSA 481 × SU 1565, ICSA 29002 × SU 1565, ICSA 357 × SU 1570, ICSA 399 × SU 1570, ICSA 29001 × SU 1570, ICSA 29002 × SU 1570, ICSA 349 × SU 1571, ICSA 363 × SU 1571, ICSA 481 × SU 1571, ICSA 552 × SU 1571, ICSA 29002 × SU 1571, ICSA 29003 × SU 1571 and ICSA 29004 × SU 1571 in all the four environments, ICSA 202 × SU 1570 in normal spacing of both the years i.e. E_1 and E_3 and ICSA 29004 × SU 1561, ICSA 349 × SU 1570, ICSA 399 × SU 1565 and ICSA 356 × SU 1570 in E_2 and E_4 i.e. wider spacing of both the years exhibited significant and positive SCA effects. For juiciness, 19 crosses exhibited positive significant SCA effects and the cross ICSA 29002 × SU 1571 exhibited the highest value. Likewise, 21 crosses were positive significant for TSS, the highest magnitude being expressed by ICSA 208 × SU 1570 (Tables 4 and 5).

Table 3. GCA effects of different parents for all characters.

Parents	Grain yield				Dry fodder yield				Protein content in fodder				Protein content in grain	Juiciness	TSS
Testers	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4	Pool	Pool	Pool
SU 1557	-7.81**	-2.42**	-7.89**	-0.36	-17.99**	-17.81**	-11.77**	-14.31**	-0.37**	-0.36**	-0.36**	-0.36**	-0.39**	0.04	0.06
SU 1561	8.64**	5.18**	7.08**	6.06**	4.32*	-5.92**	7.26**	-1.21	0.19**	0.11**	0.14**	-0.00	0.10**	0.07	-1.02**
SU 1565	-4.13**	-3.96**	-5.21**	-3.82**	-10.50**	17.92**	-14.28**	25.12**	-0.47**	-0.32**	-0.39**	-0.24**	0.06	0.06	-0.42*
SU 1570	1.71*	2.38**	0.51	-1.74**	-7.95**	7.61**	-9.62**	2.14	0.40**	0.33**	0.37**	0.30**	0.07*	-0.30**	0.21
SU 1571	1.60*	-1.18	5.51**	-0.14	32.12**	-1.80	28.41**	-11.73**	0.25**	0.24**	0.24**	0.30**	0.16**	0.13**	1.17**
Lines															
ICSA 202	9.54**	12.54**	9.30**	11.55**	55.11**	64.31**	39.27**	9.47**	0.18*	0.32**	0.04	0.13**	0.38**	-1.14**	-0.46
ICSA 208	-14.43**	-11.71**	-14.67**	-15.37**	-39.14**	-36.34**	-37.16**	-26.68**	0.77**	0.82**	0.61**	0.77**	0.88**	0.81**	-0.12
ICSA 349	2.67*	5.63**	9.38**	2.25*	41.23**	34.64**	32.51**	31.89**	-0.03	0.05	-0.03	0.03	-1.10**	0.46**	-0.12
ICSA 356	-5.31**	-2.41	-8.90**	-10.14**	-64.41**	-27.59**	-56.03**	-8.20**	-0.71**	-0.64**	-0.59**	-0.62**	-0.46**	-0.42**	0.57*
ICSA 357	8.98**	2.65*	10.00**	8.86**	65.65**	58.91**	56.65**	67.70**	0.90**	0.83**	1.17**	1.19**	1.22**	-0.19**	0.73*
ICSA 363	11.84**	9.18**	9.78**	-0.80	13.75**	-12.36**	25.61**	-0.04	-0.34**	-0.32**	-0.22**	-0.48**	0.03	0.18*	-1.06**
ICSA 380	2.07	6.37**	3.79**	6.58**	-3.74	4.15*	13.44**	6.01*	-1.81**	-1.61**	-1.79**	-1.85**	-2.66**	-0.22**	-0.28
ICSA 399	-0.79	-3.04*	1.39	-0.52	-49.37**	-41.15**	-47.42**	-32.14**	-0.08	-0.05	-0.27**	0.02	0.23**	-0.09	-1.28**
ICSA 474	-0.65	-5.09**	-1.60	-2.37*	41.46**	-12.07**	42.17**	2.57	-0.89**	-0.80**	-0.71**	-0.76**	-1.04**	0.03	-0.09
ICSA 481	2.61*	5.77**	5.86**	7.63**	64.71**	34.61**	56.57**	48.05**	-0.22**	-0.08	0.30**	0.07	0.92**	0.21**	1.33**
ICSA 552	-0.25	-1.38	-0.67	0.91	-25.64**	-27.59**	-25.89**	-41.42**	-0.07	-0.19**	-0.16**	-0.20**	0.36**	-0.12	-0.84**
ICSA 29001	5.26**	0.72	4.99**	6.39**	30.99**	29.66**	44.27**	38.23**	0.68**	0.75**	0.74**	0.76**	1.42**	-0.27**	0.50
ICSA 29002	-4.27**	-6.13**	-5.72**	-6.83**	-54.72**	-40.40**	-51.13**	-35.67**	-0.25**	-0.25**	0.02	-0.12*	-0.07	-0.27**	-0.47
ICSA 29003	-0.22	1.29	-4.27**	1.33	4.03	16.19**	-0.06	-16.77**	0.78**	0.38**	0.20**	0.35**	-0.64**	0.56**	1.29**
ICSA 29004	-17.06**	-14.41**	-18.65**	-9.45**	-79.90**	-44.97**	-92.82**	-43.00**	1.10**	0.79**	0.67**	0.72**	0.53**	0.46**	0.32

*,**significant at 5 and 1% level.

Table 4. SCA effects for grain yield, dry fodder yield and protein content in fodder.

Genotypes	Grain yield				Dry fodder yield				Protein content in fodder			
	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4
ICSA 202 × SU 1557	-4.18	2.47	-4.13	8.36**	-95.50**	-79.17**	-71.53**	-31.60**	-2.85**	-2.02**	-2.16**	-2.83**
ICSA 208 × SU 1557	2.97	-2.78	4.66	-5.40*	-0.38	-11.59*	19.40	0.86	-2.17**	-2.50**	-2.45**	-2.09**
ICSA 349 × SU 1557	6.37*	0.89	4.63	-3.39	-3.23	-37.69**	16.90	-10.13	2.23**	2.47**	2.80**	2.50**
ICSA 356 × SU 1557	-12.32**	-17.25**	-14.57**	-9.47**	-35.09**	-24.55**	-21.73*	-26.76**	0.08	0.02	-0.51**	-0.27*
ICSA 357 × SU 1557	-11.45**	-8.64**	-14.97**	-20.30**	-7.88	18.32**	-10.91	-14.72*	-1.42**	-1.50**	-1.16**	-1.53**
ICSA 363 × SU 1557	3.25	3.00	0.72	-8.23**	-3.04	0.35	-1.70	-6.00	3.08**	3.18**	3.26**	3.42**
ICSA 380× SU 1557	-0.52	-7.68**	-13.26**	-0.83	-48.65**	13.15**	-14.20	-0.64	1.27**	1.20**	0.96**	1.12**
ICSA 399 × SU 1557	22.35**	17.34**	26.82**	11.02**	16.87*	24.77**	8.00	24.29**	-1.05**	-1.02**	-1.59**	-1.49**
ICSA 474 × SU 1557	0.69	3.10	0.63	5.28*	46.87**	40.42**	29.07**	20.52**	3.10**	3.10**	3.54**	3.38**
ICSA 481 × SU 1557	0.43	-4.76	-3.83	-2.23	48.40**	-8.71	18.67	-11.02	-3.43**	-3.59**	-3.81**	-3.51**
ICSA 552 × SU 1557	-4.37	9.39**	4.70	16.50**	-28.03**	1.16	-23.36*	15.96*	1.47**	1.41**	1.91**	1.83**
ICSA 29001 × SU 1557	-12.72**	3.79	0.54	7.01**	39.07**	-15.43**	11.14	4.30	0.94**	0.79**	1.50**	1.16**
ICSA 29002 × SU 1557	-13.34**	-14.01**	-11.10**	-5.33*	-27.95**	4.54	-49.13**	7.76	-1.15**	-1.31**	-1.35**	-1.41**
ICSA 29003 × SU 1557	-0.75	-3.78	-4.87	-7.21**	80.08**	54.15**	70.30**	28.55**	0.06	0.28	-0.97**	-0.20
ICSA 29004 × SU 1557	23.60**	18.92**	24.02**	14.22**	18.45**	20.27**	19.07	-1.37	-0.15	-0.51**	0.04	-0.06
ICSA 202 × SU 1561	-3.47	7.87**	-5.75	10.44**	24.29**	75.04**	28.11**	56.91**	1.63**	1.98**	1.62**	2.46**
ICSA 208 × SU 1561	6.50*	10.12**	9.73**	7.47**	21.27**	-2.04	20.21*	-19.91**	1.39**	1.33**	1.79**	1.12**
ICSA 349 × SU 1561	13.91**	2.78	10.24**	-3.42	39.12**	-10.17*	49.05**	-6.30	-0.73**	-1.00**	-0.88**	-1.19**
ICSA 356 × SU 1561	-1.62	1.31	-5.74	-5.07*	-13.29	-17.95**	-35.24**	-32.24**	0.28	-0.09	0.11	-0.01
ICSA 357 × SU 1561	-24.12**	-11.25**	-28.12**	7.13**	-16.35*	-54.67**	-32.44**	-45.10**	-1.16**	-0.95**	-1.26**	-1.13**
ICSA 363 × SU 1561	-8.38**	-1.05	-6.76*	3.05	-9.57	-1.21	-8.55	-1.42	-2.22**	-2.36**	-2.51**	-2.55**
ICSA 380 × SU 1561	2.68	0.21	1.03	-3.65	33.21**	8.87	20.28*	7.46	2.23**	1.94**	2.26**	1.90**
ICSA 399 × SU 1561	-19.70**	-11.45**	-17.86**	-17.46**	-63.87**	-13.56**	-52.34**	-14.70*	-1.13**	-1.50**	-1.70**	-1.00**
ICSA 474 × SU 1561	23.60**	1.34	19.49**	5.30*	82.84**	39.25**	98.54**	76.64**	0.58**	0.92**	0.55**	0.93**
ICSA 481× SU 1561	-12.57**	5.64*	-7.64*	9.35**	-13.63*	32.58**	-18.36	49.04**	0.14	-0.01	0.20	0.20
ICSA 552 × SU 1561	8.73**	-8.71**	13.48**	-11.52**	72.71**	29.78**	68.45**	1.41	0.48*	0.55**	0.53**	0.51**

(Contd.)

Genotypes	Grain yield				Dry fodder yield				Protein content in fodder			
	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4
ICSA 29001 × SU 1561	-1.86	-0.82	-3.58	-4.69*	-45.63**	-17.63**	-64.55**	-53.31**	0.60**	0.77**	0.69**	0.35**
ICSA 29002 × SU 1561	19.21**	2.54	22.28**	7.71**	-34.26**	-23.33**	-16.16	-25.90**	-2.95**	-2.70**	-2.60**	-2.71**
ICSA 29003 × SU 1561	4.80	5.12	6.32*	1.37	-71.71**	-75.66**	-54.72**	-20.52**	0.40*	0.73**	0.98**	0.70**
ICSA 29004 × SU 1561	-7.71**	-3.66	-7.13*	-6.01**	-5.13	30.71**	-2.28	27.94**	0.47*	0.39*	0.23	0.42**
ICSA 202 × SU 1565	-10.59**	-10.99**	-12.01**	-10.96**	-55.43**	-48.30**	-84.85**	-52.53**	3.04**	2.41**	2.63**	2.62**
ICSA 208 × SU 1565	-6.10*	-5.74*	-6.28*	-3.43	40.76**	44.85**	31.09**	82.73**	0.26	0.28	0.51**	0.70**
ICSA 349 × SU 1565	-9.81**	-9.58**	-10.06**	-9.72**	-85.49**	25.37**	-72.92**	13.16	-3.21**	-3.29**	-3.01**	-3.62**
ICSA 356× SU 1565	-19.05**	-19.05**	-16.27**	-12.43**	-28.47**	47.60**	-53.07**	37.25**	2.71**	2.64**	3.37**	3.13**
ICSA 357 × SU 1565	17.68**	6.89*	14.53**	-0.12	28.19**	139.10**	35.10**	164.85**	1.40**	1.49**	1.26**	1.56**
ICSA 363 × SU 1565	6.90*	6.42*	11.53**	13.42**	35.03**	-9.11*	-13.02	-33.02**	-0.98**	-1.22**	-1.62**	-1.47**
ICSA 380 × SU 1565	-6.21*	7.68**	-1.94	7.80**	3.47	-13.72**	10.82	2.65	-2.57**	-2.05**	-2.13**	-1.71**
ICSA 399 × SU 1565	-3.43	1.21	-6.15*	-8.42**	-9.01	-23.84**	-2.32	-38.68**	0.39	0.35*	0.44**	0.29*
ICSA 474 × SU 1565	-9.09**	-1.74	-5.93	5.48*	-39.92**	-60.86**	-50.42**	-61.53**	1.43**	1.48**	1.66**	1.30**
ICSA 481 × SU 1565	14.06**	9.38**	11.97**	1.13	-59.92**	-9.15*	1.69	-13.67	2.54**	2.67**	2.60**	2.32**
ICSA 552 × SU 1565	15.17**	8.93**	11.02**	12.12**	9.72	-31.75**	-17.02	-27.53**	-2.04**	-2.25**	-2.66**	-2.63**
ICSA 29001 × SU 1565	10.20**	-0.68	3.54	-6.53**	51.63**	-32.67**	69.48**	-72.40**	-1.27**	-1.49**	-1.54**	-1.37**
ICSA 29002 × SU 1565	6.16*	11.22**	9.09**	6.13**	153.34**	58.92**	151.88**	42.72**	0.95**	0.69**	0.85**	0.58**
ICSA 29003 × SU 1565	-4.93	-2.74	-1.04	-0.52	-44.41**	-54.17**	-18.18	-40.32**	-2.36**	-1.84**	-2.05**	-1.62**
ICSA 29004 × SU 1565	-0.95	-1.21	-1.99	6.04**	0.52	-32.28**	11.75	-3.67	-0.30	0.13	-0.31*	-0.09
ICSA 202 × SU 1570	17.65**	-2.83	14.77**	-4.94*	75.25**	26.51**	77.98**	-0.21	1.00**	0.26	1.04**	0.78**
ICSA 208 × SU 1570	1.96	0.92	5.09	9.49**	-12.07	-11.85*	-1.59	-35.03**	0.46*	0.57**	0.20	-0.04
ICSA 349 × SU 1570	-11.21**	3.09	-13.71**	14.99**	74.34**	76.68**	-6.92	51.14**	0.61**	0.88**	0.24	1.15**
ICSA 356 × SU 1570	26.82**	26.12**	34.37**	25.09**	88.93**	19.07**	108.28**	29.53**	0.28	0.72**	0.89**	0.81**
ICSA 357 × SU 1570	0.59	8.88**	9.63**	1.43	-8.08	-25.59**	-0.56	-31.17**	0.75**	0.94**	1.03**	0.98**
ICSA 363 × SU 1570	-0.06	5.03	1.49	-7.31**	-16.73*	2.49	10.82	57.07**	-0.87**	-0.85**	-0.60**	-0.86**
ICSA 380 × SU 1570	-1.50	-7.60*	5.84	-3.64	-10.24	-3.94	-31.69**	-34.31**	-0.56**	-0.45**	-0.75**	-0.66**

(Contd.)

Genotypes	Grain yield				Dry fodder yield				Protein content in fodder			
	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4
ICSA 481 × SU 1570	1.77	0.74	-4.45	-8.05**	-20.97**	0.60	-37.49**	-48.14**	-1.08**	-0.93**	-1.00**	-0.81**
ICSA 552 × SU 1570	-27.35**	-24.07**	-34.08**	-22.82**	-81.94**	-51.04**	-84.02**	-25.05**	-0.60**	-0.81**	-0.74**	-0.70**
ICSA 29001 × SU 1570	5.74*	-6.51*	-2.37	4.56*	-3.02	66.16**	29.98**	111.30**	0.43*	0.66**	0.33*	0.46**
ICSA 29002 × SU 1570	4.78	9.35**	-5.65	5.62*	-29.80**	-33.15**	-0.28	-17.73*	1.82**	1.92**	2.19**	2.18**
ICSA 29003 × SU 1570	5.03	0.92	13.19**	4.50	-9.23	-30.87**	2.65	-14.09*	0.58**	-0.61**	-0.02	-0.38**
ICSA 29004 × SU 1570	-5.89*	-7.05*	-3.73	-6.10**	19.03**	-8.77	-3.92	-27.75**	-0.67**	-0.53**	-0.83**	-0.92**
ICSA 202 × SU 1571	0.60	3.48	7.12*	-2.90	51.39**	25.92**	50.29**	27.43**	-2.81**	-2.63**	-3.14**	-3.03**
ICSA 208 × SU 1571	-5.33	-2.52	-13.19**	-8.13**	-49.58**	-19.38**	-69.11**	-28.65**	0.07	0.31*	-0.04	0.31*
ICSA 349 × SU 1571	0.74	2.82	8.90**	1.54	-24.73**	-54.19**	13.89	-47.86**	1.10**	0.94**	0.84**	1.16**
ICSA 356 × SU 1571	6.17*	8.86**	2.21	1.88	-12.09	-24.18**	1.76	-7.77	-3.35**	-3.29**	-3.86**	-3.67**
ICSA 357 × SU 1571	17.30**	4.12	18.93**	11.86**	4.13	-77.16**	8.81	-73.86**	0.42*	0.02	0.13	0.12
ICSA 363 × SU 1571	-1.71	-13.41**	-6.98*	-0.92	-5.70	7.47	12.45	-16.62*	1.00**	1.25**	1.47**	1.45**
ICSA 380 × SU 1571	5.56	7.40**	8.32**	0.32	22.21**	-4.36	14.79	24.84**	-0.37	-0.65**	-0.33*	-0.65**
ICSA 399 × SU 1571	2.14	-10.19**	0.79	16.65**	20.37**	32.60**	20.32*	29.88**	0.21	0.08	0.42**	0.19
ICSA 474 × SU 1571	1.79	7.37**	2.60	-5.04*	11.32	-12.48**	12.39	-20.86**	-1.38**	-1.63**	-1.33**	-1.59**
ICSA 481 × SU 1571	-3.68	-11.00**	3.94	-0.20	46.13**	-15.32**	35.49**	23.79**	1.83**	1.87**	2.02**	1.79**
ICSA 552 × SU 1571	7.81**	14.47**	4.88	5.72*	27.53**	51.84**	55.95**	35.21**	0.69**	1.10**	0.96**	0.99**
ICSA 29001 × SU 1571	-1.35	4.22	1.87	-0.36	-42.04**	-0.43	-46.05**	10.11	-0.70**	-0.73**	-0.99**	-0.59**
ICSA 29002 × SU 1571	-16.82**	-9.10**	-14.63**	-14.12**	-61.33**	-6.98	-86.31**	-6.86	1.32**	1.40**	0.92**	1.36**
ICSA 29003 × SU 1571	-4.16	0.48	-13.60**	1.86	45.27**	106.55**	-0.04	46.39**	1.32**	1.44**	2.07**	1.50**
ICSA 29004 × SU 1571	-9.05**	-7.00*	-11.17**	-8.15**	-32.87**	-9.93*	-24.61*	4.84	0.64**	0.52**	0.87**	0.65**
ICSA 399 × SU 1570	-1.37	3.08	-3.60	-1.79	35.65**	-19.98**	26.34**	-0.78	1.59**	2.09**	2.43**	2.01**
ICSA 474 × SU 1570	-16.98**	-10.07**	-16.79**	-11.02**	-101.11**	-6.33	-89.58**	-14.77*	-3.73**	-3.87**	-4.41**	-4.01**

*,**significant at 5 and 1% level.

Table 5. SCA effects for protein content in grain, juiciness and TSS.

Sl. No.	Genotype	Protein content in grain	Juiciness	TSS	SN	Genotype	Protein content in grain	Juiciness	TSS
		Pool	Pool	Pool			Pool	Pool	Pool
1	ICSA 202 × SU 1557	-1.08**	-0.97**	0.39	39	ICSA 474 × SU 1565	2.74**	0.22	-1.81*
2	ICSA 208 × SU 1557	-1.06**	0.21	-4.61**	40	ICSA 481 × SU 1565	1.97**	-0.83**	-3.25**
3	ICSA 349 × SU 1557	3.92**	-0.57**	0.16	41	ICSA 552 × SU 1565	-1.46**	-0.51**	-1.54*
4	ICSA 356 × SU 1557	-0.57**	0.31	1.96**	42	ICSA 29001 × SU 1565	-1.48**	0.14	1.45*
5	ICSA 357 × SU 1557	-1.13**	0.46*	-1.04	43	ICSA 29002 × SU 1565	-0.49**	-0.61**	-0.73
6	ICSA 363 × SU 1557	3.63**	0.46*	0.78	44	ICSA 29003 × SU 1565	-1.12**	0.32	1.05
7	ICSA 380 × SU 1557	4.09**	0.11	-0.98	45	ICSA 29004 × SU 1565	0.26	-0.46*	-1.98**
8	ICSA 399 × SU 1557	-3.12**	-0.52**	1.42*	46	ICSA 202 × SU 1570	-0.98**	-0.25	0.05
9	ICSA 474 × SU 1557	4.43**	-0.52**	-1.19	47	ICSA 208 × SU 1570	-1.85**	-0.57**	5.16**
10	ICSA 481 × SU 1557	-6.66**	0.56**	-0.13	48	ICSA 349 × SU 1570	0.40**	0.40*	-1.87**
11	ICSA 552 × SU 1557	1.49**	0.38*	2.22**	49	ICSA 356 × SU 1570	3.07**	0.03	0.87
12	ICSA 29001 × SU 1557	0.71**	0.16	0.36	50	ICSA 357 × SU 1570	1.40**	-0.45*	0.04
13	ICSA 29002 × SU 1557	-1.89**	-0.09	-0.68	51	ICSA 363 × SU 1570	-0.81**	0.05	-2.25**
14	ICSA 29003 × SU 1557	-2.06**	0.58**	-0.14	52	ICSA 380 × SU 1570	-1.05**	-0.67**	0.64
15	ICSA 29004 × SU 1557	-0.71**	-0.57**	1.49*	53	ICSA 399 × SU 1570	2.04**	0.45*	-3.23**
16	ICSA 202 × SU 1561	-0.09	-0.12	1.46*	54	ICSA 474 × SU 1570	-5.28**	-0.17	3.43**
17	ICSA 208 × SU 1561	2.67**	0.43*	1.41*	55	ICSA 481 × SU 1570	2.18**	0.28	2.50**
18	ICSA 349 × SU 1561	-2.07**	-0.34	0.44	56	ICSA 552 × SU 1570	-1.46**	0.60**	0.74
19	ICSA 356 × SU 1561	-0.56**	0.16	-0.34	57	ICSA 29001 × SU 1570	1.32**	0.38*	-3.90**
20	ICSA 357 × SU 1561	0.49**	-0.07	0.25	58	ICSA 29002 × SU 1570	3.30**	-0.50**	-1.32

(Contd.)

Sl. No.	Genotype	Protein content in grain	Juiciness	TSS	SN	Genotype	Protein content in grain	Juiciness	TSS
		Pool	Pool	Pool			Pool	Pool	Pool
21	ICSA 363 × SU 1561	-2.98**	-0.19	-0.55	59	ICSA 29003 × SU 1570	-0.28*	-0.32	0.18
22	ICSA 380 × SU 1561	1.90**	-0.54**	-3.51**	60	ICSA 29004 × SU 1570	-2.01**	0.78**	-1.02
23	ICSA 399 × SU 1561	-1.13**	0.33	0.46	61	ICSA 202 × SU 1571	-0.19	0.57**	-1.27
24	ICSA 474 × SU 1561	1.30**	0.33	-1.70*	62	ICSA 208 × SU 1571	-0.62**	-0.51**	-3.06**
25	ICSA 481 × SU 1561	0.19	-0.09	-0.12	63	ICSA 349 × SU 1571	0.74**	0.09	-2.47**
26	ICSA 552 × SU 1561	-0.33*	-0.89**	-4.32**	64	ICSA 356 × SU 1571	-5.48**	-0.28	-3.07**
27	ICSA 29001 × SU 1561	-0.70**	0.26	2.45**	65	ICSA 357 × SU 1571	-0.98**	0.12	4.15**
28	ICSA 29002 × SU 1561	-3.68**	0.13	1.16	66	ICSA 363 × SU 1571	1.80**	-0.01	1.88**
29	ICSA 29003 × SU 1561	1.63**	0.31	1.40*	67	ICSA 380 × SU 1571	-1.85**	0.64**	1.83**
30	ICSA 29004 × SU 1561	3.37**	0.28	1.50*	68	ICSA 399 × SU 1571	1.88**	-0.48**	-1.89**
31	ICSA 202 × SU 1565	2.35**	0.77**	-0.63	69	ICSA 474 × SU 1571	-3.20**	0.14	1.27
32	ICSA 208 × SU 1565	0.86**	0.44*	1.10	70	ICSA 481 × SU 1571	2.33**	0.09	0.99
33	ICSA 349 × SU 1565	-2.99**	0.42*	3.74**	71	ICSA 552 × SU 1571	1.76**	0.42*	2.90**
34	ICSA 356 × SU 1565	3.54**	-0.21	0.58	72	ICSA 29001 × SU 1571	0.14	-0.93**	-0.36
35	ICSA 357 × SU 1565	0.22	-0.06	-3.39**	73	ICSA 29002 × SU 1571	2.75**	1.07**	1.58*
36	ICSA 363 × SU 1565	-1.64**	-0.31	0.14	74	ICSA 29003 × SU 1571	1.83**	-0.88**	-2.49**
37	ICSA 380 × SU 1565	-3.09**	0.47**	2.02**	75	ICSA 29004 × SU 1571	-0.91**	-0.03	0.02
38	ICSA 399 × SU 1565	0.33*	0.22	3.24**					

*,**significant at 5 and 1% level.

For grain and dry fodder yield, two crosses *viz.*, ICSA 29002 × SU 1565 and ICSA 356 × SU 1570 exhibited significant SCA effects in all the four environments. Whereas hybrids ICSA 552 × SU 1561, ICSA 202 × SU 1570, ICSA 349 × SU 1561, ICSA 208 × SU 1561, ICSA 474 × SU 1561 and ICSA 357 × SU 1565 showed good SCA effects in normal spacing (E_1 and E_3) and ICSA 481 × SU 1561 and ICSA 399 × SU 1557 in wider spacing (E_2 and E_4). These hybrids were also found significant for majority of the fodder quality traits. Previously, Rafiq *et al.* (2002) and Kaul *et al.* (2003) also reported significant SCA effects for these traits (Tables 4 and 5).

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