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Combining ability studies in post rainy sorghum by using the line x tester analysis

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Abstract
The experiment was undertaken on Line x Tester analysis for ancillary data of grain yield and its component traits in crosses of A line and R line of *rabi* sorghum at All India Co-ordinated Sorghum Improvement Project, M.P.K.V., Rahuri, during the year 2017-18 with objectives to study the general and specific combining ability of parents and hybrids. Combining ability studies for grain yield and its component traits was studied using four male sterile lines and ten testers at Sorghum Improvement Project, MPKV, Rahuri, Maharashtra. Observation recorded on Days to 50% flowering, Days to physiological maturity, Seedling height at 14 (DAE), Plant height, Grains per panicle, Panicle weight, 1000 grain weight, Dry fodder weight, Dry matter content, Grain yield per plant and Harvest index. The mean squares due to lines, testers and lines x tester were highly significant indicating the presence of variability for most of the characters. Estimates of general combining ability (GCA) and specific combining ability (SCA) variances indicated the predominance of non-additive gene action for most of the characters. The line Parents, line RMS-2010-10A and testers, RSV-2015, RSV-2124, RSV-2138 and RSV-1850 were observed good general combiner for grain yield and yield contributing characters. The hybrid *viz.*, RMS-2010-16A x RSV-2124 (12.55), RMS-2010-24A x RSV-2015 (9.65), CMS-185A x RSV-1850 (8.25) and RMS-2010-10A x CSV-26 (6.94) etc. exhibited highly significant and positive SCA effects for grain yield which could be exploited for development of hybrids.

Keywords: Combining ability, sorghum, *Rabi*

Introduction

The crop sorghum was described by Linnaeus in 1753 under the name *Holcus*. In 1794 Moench distinguished the genus *Sorghum* from genus *Holcus* (Celarier, 1959; Clayton, 1961) [7, 8] and brought all the sorghum together under *Sorghum bicolor* (House, 1978; Clayton, 1961) [17, 8]. Sorghum is classified under the family Poaceae, tribe Andropogoneae, sub-tribe Sorhinae and genus *Sorghum* Moench (Clayton and Renvoize, 1986) [9].

Cultivated sorghum divided into five basic groups or races: bicolor, guinea, caudatum, kafir and durra (Harlan and de wet, 1972) [16]. Sorghum genera divided into five subgenera: sorghum, chaetosorghum, heterosorghum, parasorghum and stiposorghum. *Sorghum bicolor* divided into three subspecies bicolor, drummondii and verticilliflorum (Garber, 1950; Celarier, 1959) [13, 7]. The cereal sorghum consists of four wild races and five cultivated races. Cultivated sorghum placed under *S. bicolor* subsp. *bicolor* and are represented by grain sorghum, sweet sorghum, sudangrass, and broomcorn (Berenji and Dahlberg, 2004) [6].

Sorghum was among the top 10 crops that feed the world. It is the dietary staple of more than 500 million people in over 30 countries primarily in the developing world. It was grown in more than 90 countries in Africa, Asia, Oceania and the Americas. The top ten sorghum producers globally are the United States, India, Mexico, Nigeria, Sudan, Ethiopia, Australia, Brazil, China and Burkina Faso (Rakshit *et al*., 2014) [35].

It is fifth important cereal in the world after wheat, maize, rice and barley (Dillon *et al*., 2007) [12]. Sorghum is believed to be originated in Africa and spread all over the world. Sorghum [*Sorghum bicolor* (L.) Moench] known as great millet and guinea corn in West Africa, kafir corn in South Africa, dura in Sudan, mtama in Eastern Africa, jowar in India, and kaoliang in China (Purseglove, 1972) [34].

In world sorghum is cultivated over 44 million hectare land with a production of 65 million tonnes and productivity 1463 kg per hectare. The large hectare of sorghum occurs in the arid and semiarid areas of India and Africa. In India 4.48 million hectares area is under sorghum with an annual production of 4.38 million tonnes and 1051 kg per hectare productivity.

In India, sorghum is cultivated in Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Gujarat, and Rajasthan (Anonymous 2020) [3]. The Maharashtra state is the main sorghum producing state of the country India has a total of 21.90 lakh ha. area under its cultivation with an annual production of 18.09 lakh tonnes and 826 kg per productivity. Out of these 2.80 lakh hectares are grown in *kharif* with an annual production of 1.77 lakh tonnes and 630 kg per hectare productivity. In the *rabi* season, it is grown on 19.09 lakh hectare with annual production of 16.33 lakh tonnes and recorded 855 kg per hectare productivity (Anonymous 2020) [3].

Sorghum is adapted to a wide range of ecological conditions and suited, to low input agriculture. By nature sorghum is an efficient converter of nutrients even under moisture stress conditions. Rabi sorghum grains offer opportunities for the processing industry as it would be consumed by a large population in the form of value-added food products in urban and semiurban areas. Thus, sorghum has maintained its importance and dependability as it is well suited for drylands which are generally unsuitable for the cultivation of other major cereals. Its drought tolerance and adaptability made sorghum as an important cereal crop in drought-prone areas. Therefore, improvement of this crop will have great opportunity to improve socio-economic status of people living in drought prone areas. Though strong efforts have been made to develop hybrids with wider adaptability to varied production environments, the results are not encouraging (Madhusudana *et al*., 2003) [28]. Productivity depends not only on moisture availability but also on the soil types under which it is grown (Jirali *et al*., 2007) [21]. Among the factors influencing the adoption of sorghum varieties, farmers rated grain and fodder quality attributes as their priority (Nagaraj *et al*., 2011) [31].

Combining ability study gives information about the general combining ability of parents and specific combining ability of hybrids. Griffing (1956) [15] reported that general combining ability involved additive gene action and additive × additive interaction and also higher-order interactions. The nature of gene effects for yield and its component traits has a bearing on the development of the efficient breeding procedure. Kramer (1959) [25] was the first to study general and specific combining ability for yield and other related traits in sorghum. Hybrid vigor and its commercial exploitation have paid rich dividends in *kharif* sorghum leading to a quantum jump in sorghum production. However, the progress in *rabi* sorghum is limited and there is need for critical studies on combining ability and heterosis involving diverse sources of germplasm and landraces.

Combining ability analysis provides the information for selection of the desirable parents and cross combinations for exploitation. The choice of parents in any breeding programme has to be based on complete genetic information and knowledge of combining ability of parents and not merely on field performance.

Material and Methods

The experimental material for the present study comprised of four male sterile line (RMS-2010-10A, RMS-2010-16A, RMS-2010-24A, CMS-185A), ten restorers, (RSV-2015, RSV-2121, RSV-2138, RS-585, RSV-1996, RSV-1850, RSV-1837, RSV-2124, PSR-34, CSV-26) their resulting 40 hybrids and one hybrid check CSH-15R. During *rabi* 2017-18 four male sterile lines and ten restores were sown at Sorghum Improvement Project, M.P.K.V., Rahuri lies between 73° 15' 0" to 76° 22' 12" North latitude and 15° 46' 48" to 22° 3' 0" East longitude. These lines and testers were crossed in Line x Tester design to produce 40 possible hybrids. The experiment was conducted during *Rabi* 2018 by using 14 parents, their 40 hybrids along with one standard check CSH-15R at Sorghum Improvement Project, M.P.K.V., Rahuri. Data were recorded on five randomly selected plants in each replication for the characters *viz.,* Days to 50% flowering, Days to physiological maturity, Seedling height at 14 (DAE), Plant height, Grains per panicle, Panicle weight, 1000 grain weight, Dry fodder weight, Dry matter content, Grain yield per plant and Harvest index. The data was subjected to the analysis of combining ability as per Kempthorne (1957) [23] and modified by Arunachalam (1974) [4].

Results and Discussion

The analysis of variance for combining ability is presented in Table 1. The ANOVA indicated that the genotypes were differing significantly for all the traits studied indicating the presence of genetic variability in the material used in the present study. It was observed that, the mean squares due to lines, testers as well as lines vs tester interaction and hybrids were found significant for all the characters under studies except line, tester and line vs tester in days to 50% flowering and seedling height at 14 DAE. The estimates of gca and sca variance found significant for all the characters under studies, however the estimates of sca variance found non-significant plant height and 1000 grain weight. Ratio of variance of general to specific combing ability was less than unity for traits seedling height at 14 DAE, grains per panicle, panicle weight, dry matter content, grain yield per plant and harvest index studied indicating the preponderance of non-additive gene action for these traits. These findings are in agreement with earlier reports of Jain and Patel (2014) [20], Kumar and Chand (2015) [26], Kute *et al*., (2015) [27], Khose *et al*., (2016) [24], Massaoudou *et al*., (2016) [30], Chaudhari *et al*., (2017) [10], Malaghan and Kajjidoni (2018) [29], Ingle *et al*., (2018) [18] and Tambe *et al*., (2019) [37].

The ratio of combining ability variance components determines the type of gene action involved in the expression of traits and allows inferences about optimum allocation of resources in hybrid breeding. The analysis of combining ability partition of the total genetic variance into variance due to general combining ability representing additive type of gene action and variance due to specific combining ability regards as a measure of non-additive gene action.

The estimates of general combining ability effects of female and male parents for grain yield and its contributing traits in *rabi* sorghum is presented in Table 2.

In *rabi* sorghum positive gca effects are desirable for all the characters studied except days to 50% flowering and days to maturity for which negative gca effects are desirable. Most of the male and female parents showed the significant differences for all the characters. The characters wise gca effects of the parents are presented below.

General combining ability effects for grain yield and its contributing traits in *rabi* sorghum.

1. Days to 50 per cent flowering

Genotypes which flower early with negative gca values are preferred, because it matures early and escape from abiotic stresses. For days to 50 per cent flowering, the female parent CMS-185A (-2.19) showed significant gca effects in the desirable direction. The male parents *viz.*, PSR-34 (-1.52), RSV-2121(-1.28) and RSV-2015 (-1.23) displayed significant gca effects in the desirable direction. From the parents, CMS-185A, PSR-34, RSV-2121 and RSV-2015 were good general combiners for early days to 50% flowering (Table 3).

2. Days to physiological maturity
For days to physiological maturity, significant negative gca effects were recorded by female parent CMS-185A (-2.32) while, RMS-2010-10A and RMS-2010-24A displayed significant positive gca effect (0.94) and (1.16) respectively. Among male parents, RSV-2015 (-2.31), RSV-2121 (-1.95) and PSR-34 (-1.67) displayed significant gca effects in the desirable direction. Parents CMS-185A, RSV-2015, RSV-2121 and PSR-34 found good general combiner for days to physiological maturity (Table 3).

3. Seedling height at 14 DAE (cm)
Genotypes which are taller and having positive values of gca are preferred. Significant positive gca effect was recorded by female parent RMS 2010-10A (1.09), while CMS-185A (-1.12) displayed significant negative gca effects. As regards to male parents, RSV-2015 (0.95) recorded highest significant positive gca effect, followed by male parent RSV-1850 (0.56) and RSV-2124 (-0.66) recorded significant positive and negative gca effect.

4. Plant height (cm)
Genotypes which are taller and having positive values of gca are preferred. Significant positive gca effect was recorded by female parent RMS 2010-10A (16.74), while CMS-185A (-8.03) and RMS 2010-24A (-6.86) displayed significant negative gca effects. As regards to male parents, RSV-2138 (12.32) recorded highest significant positive gca effect.

5. Grains per panicle (no.)
Genotypes which have maximum grains per panicle values of gca are preferred. Non of the female parents recorded significant positive gca effects.

6. Panicle weight (g)
Genotypes which have maximum panicle weight values of gca are preferred. No significant positive gca effect was recorded by female parents. As regards to male parents, RSV-2124 (12.46) recorded highest significant positive gca effect. Whereas, male parent RS-585 (-8.76) was recorded highest significant negative gca effect.

7. 1000 grain weight (g)
Genotypes which have higher 1000 grain weight of gca are preferred. Significant positive gca effect was recorded by female parents CMS-185A (1.50). As regards to male parents, RSV-2015 (4.60) recorded highest significant positive gca effect.

8. Dry fodder weight (g)
Genotypes which have maximum dry fodder weight of gca are preferred. Significant positive gca effect was recorded by female parents RMS 2010-16A (10.39) and significant negative gca effect recorded by RMS 2010-24A (-7.12). As regards to male parents, CSV-26 (7.78) recorded highest, significant positive gca effect.

9. Dry matter content (g)
Genotypes which have maximum dry matter content values of gca are preferred. Significant positive gca effect was recorded by female parents RMS 2010-16A (5.95). As regards to male parents, RSV-2124 (15.42) recorded highest significant positive gca effect.

10. Grain yield per plant (g)
Genotypes which have maximum grains yield per plant of gca are preferred. No significant positive gca effect was recorded by female parents. As regards to male parents, RSV-2124 (6.38) recorded highest significant positive gca effect followed by RSV-2138 (4.48). Whereas, male parent RSV-1996 (-4.95) and PSR-34 (-4.63) recorded highest significant negative gca effect.

11. Harvest index (%)
Genotypes which have maximum harvest index of gca are preferred. Significant positive gca effect was recorded by female parents RMS 2010-10A (1.00) and significant negative gca effect recorded by RMS 2010-16A (-0.80). As regards to male parents, RSV-2138 (1.53) recorded highest significant positive gca effect.
When gca variances higher than sca variances, early generation examining of genotypes becomes more efficient and promising hybrids can be recognized and selected based on their prediction from gca effects. The gca performance of relatively later lines can be predicted by using a gca of a line in an early generation and the scientific reason for this observation is that the gca is controlled by genetic material, is heritable and can be transmitted to the offspring. This makes hybrid cultivar improvement more effective and less costly via less time taken to release hybrids and fewer materials carried in breeding programs.
In the present investigation highly significant differences were obtained for gca effects for all the eleven traits studied, it was found that the parent RSV-2015 was good general combiner for six traits, *i.e.* days to 50% flowering, days to physiological maturity, seedling height at 14 DAE, grains per panicle, panicle weight and 1000 grain weight. Among all 14 parents, none of the parents expressed significant gca effects for all the eleven traits studied. Parents, line RMS-2010-10A and testers, RSV-2015, RSV-2124, RSV-2138 and RSV-1850 also have good per se performance for most of the characters indicating scope for their exploitation in future breeding programme to isolate desirable transgressive segregants for grain yield and its components. Therefore, parents recorded high mean performance with desirable general combining ability effects that particular characters could be utilized in further crossing programme as per the objectives for improvement in various traits of *rabi* sorghum. The results in the present investigation are in accordance with the findings reported by various workers Prabhakar (2013) [33], Akabari *et al*., (2012) [1] Desmukh *et al*., (2012) [11], Vinaykumar *et al*., (2011) [39], Umakantha *et al*., (2012) [38], Jain and Patel (2014) [20], Bahadure *et al*., (2015) [5], Kumar and Chand (2015) [26], Kute *et al*., (2015) [27], Khose *et al*., (2016) [24], Vekariya *et al*., (2017) [40] and Ingle *et al*., (2018) [18].

Specific combining ability effects for grain yield and its contributing traits in *rabi* sorghum.
In *rabi* sorghum, positive sca effects are desirable for all the traits studied except for days to 50% flowering and days to physiological maturity for which negative sca effects are desirable.

The results of specific combining ability effects of forty crosses for yield and yield contributing characters in *rabi* sorghum is presented in Table 5.

1. Days to 50 per cent flowering
For days to 50 per cent flowering, three cross combinations exhibited significant negative sca effects, it indicates earliness. The cross combination RMS-2010-10A x RSV-1850 (-4.40) was showed highest magnitude of significant negative sca effect followed by RMS-2010-24A x RSV-2138 (-1.95) and RMS-2010-16A x CSV-26 (-1.90).

2. Days to physiological maturity
Out of forty crosses, one cross combinations exhibited significant negative sca effects for the days to maturity. The cross combination, RMS-2010-10A x RSV-1850 (-4.55) was exhibited highest magnitude of significant negative sca effect. The cross combination, RMS-2010-24A x RSV-1996 was (4.27) was exhibited highest magnitude of significant positive sca effect.

3. Seedling height at 14 DAE (cm)
Among forty crosses under study, significant positive and negative sca effects were recorded by nine and ten cross combinations, respectively for seedling height at 14 DAE. The hybrids, RMS-2010-10A x RSV-1850 (3.81), RMS-2010-16A x RSV-1837 (2.38) and CMS-185A x RSV-2121 (1.93) recorded higher magnitude of significant positive sca effects for seedling height at 14 DAE.

4. Plant height (cm)
Out of forty crosses, one cross combinations exhibited significant positive sca effects for the plant height. The cross combination, RMS-2010-10A x RSV-2121 (15.50) was exhibited highest magnitude of significant positive sca effect.

5. Grains per panicle (no.)
Among forty crosses, significant positive and negative sca effects were recorded by three and four cross combinations, respectively for grains per panicle. The hybrids, RMS-2010-16A x RSV-2124 (371.59), RMS-2010-24A x RSV-2015 (307.48) and RMS-2010-24A x RS-585 (200.79) recorded higher magnitude of significant positive sca effects for grains per panicle.

6. Panicle weight (g)
For panicle weight, four cross combinations exhibited significant positive sca effects. The cross combination RMS-2010-16A x RSV-2124 (20.89) showed highest magnitude of significant positive sca effect followed by RMS-2010-10A x CSV-26 (20.37) and RMS-2010-24A x RSV-1996 (20.31).

7. 1000 grain weight (g)
For 1000 grain weight, four cross combinations exhibited significant positive sca effects. The cross combination CMS-185A x RSV-2121 (5.33) showed highest magnitude of significant positive sca effect followed by RMS-2010-10A x RSV-1837 (4.88) and RMS-2010-16A x RSV-1850 (3.93). The cross combination CMS-185A x CSV-26 (-3.58) was showed highest magnitude of significant negative sca effect.

8. Dry fodder weight (g)
Among forty crosses, significant positive and negative sca effects were recorded by three and three cross combinations, respectively for dry fodder weight. The hybrids, RMS-2010-16A x CSV-26 (24.21), CMS-185A x RSV-1850 (12.98) and RMS-2010-10A x RSV-1837 (11.57) recorded higher magnitude of significant positive sca effects for dry fodder weight.

9. Dry matter content (g)
Among forty crosses, significant positive and negative sca effects were recorded by four and four cross combinations, respectively for dry matter content. The crosses, RMS-2010-16A x RSV-2124 (35.56), CMS-185A x RSV-1850 (23.77) and RMS-2010-16A x CSV-26 (20.88) recorded higher magnitude of significant positive sca effects for dry matter content. The cross combination RMS-2010-10A x RSV-2124 (-31.03) was showed highest magnitude of significant negative sca effect.

10. Grain yield plant^{-1} (g)
As regards to grain yield, four crosses showed significant positive sca effects. The highest positive sca effect was exhibited by RMS-2010-16A x RSV-2124 (12.55), RMS-2010-24A x RSV-2015 (9.65) followed by CMS-185A x RSV-1850 (8.25). The highest significant negative sca effect was recorded RMS-2010-10A x RSV-2124 (-18.74) (Table 5).

11. Harvest index (%)
For harvest index, two cross combinations exhibited significant positive sca effects. The cross combination RMS-2010-10A x RSV-1996 (2.68) showed highest magnitude of significant positive sca effect followed by RMS-2010-10A x RSV-2121 (2.58). The cross RMS-2010-10A x RSV-2124 (-5.43) was showed highest magnitude of significant negative sca effect.

In the present investigation different cross patterns on the basis of sca have been used to make inferences on gene action. High sca effects resulting from crosses where both parents are good general combiners (*i.e.,* good gca × good gca) may be described to additive × additive gene action. The high sca effects derived from crosses including good × poor general combiner parents may be attributed to favourable additive effects of the good general combiner parent and epistatic effects of poor general combiner. High sca effects manifested by low × low crosses may be due to dominance × dominance type of non-allelic gene interaction producing over dominance thus being non-fixable.

These findings are in agreement with earlier reports of Vinaykumar *et al.*, (2011) [39], Akabari *et al.*, (2012) [1], Ghorade *et al.*, (2014) [14], Kumar and Chand (2015) [26], Al-Arief *et al.*, (2016) [2], Kale and Desai (2016) [22], Khose *et al.*, (2016) [24], Jadhav and Desmukh (2017) [19], Vekariya *et al.*, (2017) [40], Naik *et al.*, (2018) [32], Sen *et al.*, (2018) [36] and Ingle *et al.*, (2018) [18].

Table 1: Analysis of variance for combining ability in *rabi* sorghum

Sources	DF	Days to 50% flowering	Days to physiological maturity	Seedling height at 14 DAE (cm)	Plant height (cm)	Grains per panicle (no.)	Panicle weight (g)	1000 grain weight (g)	Dry fodder weight (g)	Dry matter content (g)	Grain yield per plant (g)	Harvest index (%)
Replications	2	1.07	47.22**	8.58**	265.62	129953.71**	196.30	45.90**	30.27	2725.37**	33.81	17.34*
Treatments	53	13.40**	22.07**	8.80**	1546.37**	132943.91**	559.93**	41.66**	456.61**	1319.82**	155.51**	17.34**
Parents	13	3.03	16.76**	1.30	3540.38**	160844.19**	675.45**	71.50**	475.64**	1932.65**	236.12**	12.87**
Line	3	5.66	21.12*	0.74	686.84**	48218.65	2206.62**	4.30	58.43	249.98	62.76	24.06**
Testers	9	2.08	15.62**	1.61	606.72**	139852.04**	228.99	58.03**	99.35	1323.37**	167.11**	9.24
Line vs. Tester	1	3.65	14.00	0.16	38503.94**	687650.07**	100.15	394.40**	5113.96**	12464.15**	1377.26**	12.02
Parent vs. hybrid	1	80.55**	115.01**	82.64**	11360.11**	999520.58**	278.30	29.35**	2790.35**	12405.80**	186.77*	86.63**
Hybrids	39	15.14**	21.45**	9.41**	630.07**	101423.90**	528.64**	32.03**	390.43**	831.28**	127.84**	17.06**
Error	106	2.40	5.80	0.93	168.89	19771.94	167.83	2.81	92.52	237.04	31.25	4.92

Note: * Significant at 5% level of significance, ** Significant at 1% level of significance

Table 2: Estimates of combining ability in *rabi* sorghum

Estimates	Days to 50% flowering	Days to physiological maturity	Seedling height at 14 DAE (cm)	Plant height (cm)	Grains per panicle (no.)	Panicle weight (g)	1000 grain weight (g)	Dry fodder weight (g)	Dry matter content (g)	Grain yield per plant (g)	Harvest index (%)
σ^2_{gca}	1.8042**	2.1592**	0.6555*	105.4407**	3606.7121	8.2268	3.1135	41.9674**	25.7846	3.1187	0.8453*
σ^2_{sca}	2.4902**	2.7510**	2.8027**	10.4999	23175.9934**	127.39**	5.0730	65.4107**	195.0548**	32.2124**	3.4655**
σ^2_A	3.6084	4.3185	1.3109	210.88	7213.4242	16.4536	6.2270	83.9348	79.0161	6.2375	1.6906
σ^2_D	2.4902	2.7510	2.8027	10.4999	23175.9934	127.3987	5.0730	65.4107	195.0548	32.2124	3.4655
σ^2_A/ σ^2_D	1.4490	1.5698	0.4677	20.08	0.3112	0.1292	1.2275	1.2832	0.2644	0.1936	0.4878

Note: * Significant at 5% level of significance, ** Significant at 1% level of significance

Table 3: General combining ability effects of parents for grain yield and its contributing traits in *rabi* sorghum.

Sr. No.	Parents	Days to 50% flowering	Days to physiological maturity	Seedling height at 14 DAE (cm)	Plant height (cm)	Grains per panicle (no.)	Panicle weight (g)
	Females						
1.	RMS 2010-10A	0.95**	0.94*	1.09**	16.74**	-21.04	1.964
2.	RMS 2010-16A	0.309	0.217	0.149	-1.85	43.46	-0.016
3.	RMS 2010-24A	0.92**	1.16**	-0.118	-6.86**	-24.05	-1.372
4.	CMS -185 A	-2.19**	-2.32**	-1.12**	-8.03**	1.64	-0.576
	SE (gi) ±	0.28	0.44	0.18	2.37	25.67	2.36
	Males						
5	RSV-2015	-1.23**	-2.31*	0.94**	6.87	81.66*	11.13**
6	RSV-2121	-1.28**	-1.94*	0.13	-0.11	30.78	0.02
7	RSV-2138	0.19	0.14	-1.02**	12.32**	72.23	4.17
8	RS-585	0.30	0.31	0.20	-4.22	-74.47	-8.75**
9	RSV-1996	0.07	0.61	-0.47	-11.56**	-159.2*	-7.16
10	RSV-1850	0.00	0.86	0.56*	-13.58**	-0.32	-3.07
11	RSV-1837	0.76	1.18	0.48	4.95	52.63	-1.26
12	RSV-2124	0.85	1.06	-0.66*	-3.22	217.74**	12.46**
13	PSR-34	-1.52**	-1.67*	-0.31	3.51	-149.70**	-3.02
14	CSV-26	1.82**	1.75*	0.14	5.03	-71.31	-4.50
	SE(gi) ±	0.44	0.69	0.28	3.75	40.59	3.73

Note: * Significant at 5% level of significance, ** Significant at 1% level of significance

Table 3: Contd…

Sr. No.	Parents	1000 grain weight (g)	Dry fodder weight (g)	Dry matter content (g)	Grain yield per plant (g)	Harvest index (%)
	Females					
1.	RMS-2010-10A	0.200	-0.19	-1.19	1.40	1.00*
2.	RMS-2010-16A	0.567	10.39**	5.94*	0.08	-0.80*
3.	RMS-2010-24A	-2.26**	-7.127**	-5.12	-0.31	0.58
4.	CMS-185A	1.50**	-3.07	0.37	-1.17	0.77
	SE (gi) ±	0.30	1.75	2.81	1.02	0.40

	Males					
5	RSV-2015	4.60**	-7.31*	-8.24	-0.17	1.14
6	RSV-2121	-0.90	-4.47	2.49	1.28	0.21
7	RSV-2138	0.60	1.74	4.04	4.48**	1.53*
8	RS-585	-1.40**	-0.26	3.39	-2.04	-1.39*
9	RSV-1996	-1.98**	-2.07	-13.11**	-4.94**	-0.60
10	RSV-1850	1.76**	-7.52*	-9.64*	-1.02	0.99
11	RSV-1837	1.85**	4.07	3.58	1.93	0.64
12	RSV-2124	-0.31	1.40	15.42**	6.38**	0.95
13	PSR-34	-2.56**	2.37	-5.03	-4.63**	-1.64*
14	CSV-26	-1.65**	7.78**	7.09	-1.26	-1.83**
	SE(gi) ±	0.48	2.77	4.44	1.61	0.64

Note: * Significant at 5% level of significance, ** Significant at 1% level of significance

Table 4: Best five parents showing significant high GCA effects in desirable direction for different characters**.**

Sr. No.	Parents	No. of haracters	Characters (gca effects)
1	RMS-2010-10A (Line No. 1)	3	Seedling height at 14 DAE (1.09**), Plant height (16.74**), Harvest index (1.00*)
2	RSV-2015 (Tester No.1)	6	Days to 50% flowering (- 1.23**), Days to physiological maturity (-2.31*), Seedling height at 14 DAE (1.09**), Grains per panicle (81.67**), Panicle weight (11.13**), 1000 grain weight (4.60**)
3	RSV-2124 (Tester No. 8)	4	Grains per panicle (217.74**), Panicle weight (12.47**), Dry matter content (15.42**), Grain yield per plant (6.38**)
4	RSV-2138 (Tester No. 3)	3	Plant height (12.33**), Grain yield per plant (4.48**), Harvest index (1.53*)
5	RSV-1850 (Tester No. 6)	2	Seedling height at 14 DAE (0.56**), 1000 grain weight (1.77**)

Table 5: Specific combining ability (sca) effects for grain yield and its contributing traits in 40 crosses of *rabi* sorghum

Sr. No.	Crosses	Days to 50% flowering	Days to physiological maturity	Seedling height at 14 DAE (cm)	Plant height (cm)	Grains per panicle (no.)	Panicle weight (g)
1.	1 x 5	2.43**	3.76**	-2.50**	13.21	-11.45	8.68
2.	1 x 6	1.58	1.46	-2.48**	15.50*	52.13	-8.28
3.	1 x 7	0.67	0.83	-1.93*	9.93	61.54	1.27
4.	1 x 8	0.42	0.80	-1.37*	4.94	-18.54	-10.33
5.	1 x 9	-0.94	-1.90	-0.07	-10.14	129.75	1.87
6.	1 x 10	-4.40**	-4.55**	3.81**	0.83	-50.45	-2.18
7.	1 x 11	-1.06	-073	-0.70	-7.49	75.58	-1.85
8.	1 x 12	-1.25	-1.68	-0.02	-6.59	-482.69**	-22.65**
9.	1 x 13	0.99	0.59	-0.04	-10.19	157.42	13.10
10.	1 x 14	1.57	1.42	1.83**	-10.04	89.69	20.37**
11.	2 x 5	-1.61	-1.68	0.68	-2.15	-169.12*	-21.14**
12.	2 x 6	-0.33	-0.20	1.02	-4.46	-42.64	6.03
13.	2 x 7	1.45	1.23	-0.62	-10.07	-16.42	0.11
14.	2 x 8	1.34	0.87	-1.65**	-1.12	-110.15	-6.45
15.	2 x 9	-0.22	-0.50	-1.93**	1.95	-6.78	-9.043
16.	2 x 10	1.90*	1.38	-0.44	0.20	-45.20	0.27
17.	2 x 11	0.81	1.05	2.38**	3.36	24.77	14.72
18.	2 x 12	0.19	0.65	-1.48**	5.34	371.59**	20.89**
19.	2 x 13	-1.62	-0.08	0.50	4.46	-34.61	-1.45
20.	2 x 14	-1.90*	-2.70	1.54**	2.48	28.58	-3.94
21.	3 x 5	-0.86	-1.52	0.34	-12.87	307.48**	10.11
22.	3 x 6	-0.95	-1.15	-.47	-7.75	-186.59*	-13.94
23.	3 x 7	-1.95*	-2.65	1.71**	-4.82	-32.77	-5.36
24.	3 x 8	-0.47	-1.01	-0.71	-0.54	200.79*	8.06
25.	3 x 9	2.42**	4.27**	1.43*	2.03	6.83	20.31**
26	3 x 10	2.76**	3.54**	-1.54**	6.08	-27.21	-10.11
27.	3 x 11	-0.20	-0.62	0.24	9.51	-105.14	2.68
28.	3 x 12	-1.63	-1.70	1.38*	0.92	42.41	-8.05
29.	3 x 13	-0.30	-0.96	-0.16	7.28	-25.60	0.43
30.	3 x 14	1.20	1.81	-2.22**	0.16	-180.19*	-4.08
31.	4 x 5	0.05	-0.56	1.48**	1.82	-126.91	2.35
32.	4 x 6	-0.30	-0.09	1.93**	-3.28	177.10	16.19*
33.	4 x 7	-1.17	0.58	0.09	4.90	-12.34	3.98
34.	4 x 8	-1.28	-0.65	0.99	-3.27	-72.10	8.78
35.	4 x 9	-1.25	-1.86	0.57	6.16	-129.80	-13.15
36.	4 x 10	-0.25	-0.37	-1.83**	-7.11	122.88	12.02
37.	4 x 11	0.45	0.30	-1.91**	-5.38	4.78	-15.54*
38	4 x 12	2.69**	2.72	0.12	0.32	68.68	9.81
39.	4 x 13	0.94	0.46	-0.29	-1.55	-97.20	-12.09
40.	4 x 14	-0.87	-0.52	-1.15*	7.39	64.90	-12.35
SE (Sij) ±		0.89	0.69	0.27	3.75	40.59	3.73

Note: * Significant at 5% level of significance, ** Significant at 1% level of significance.

Contd…

Sr. No.	Crosses	1000 grain weight (g)	Dry fodder weight (g)	Dry matter content (g)	Grain yield (g)	Harvest index (%)
1.	1 x 5	-0.53	-4.24	9.40	3.71	0.67
2.	1 x 6	-2.37*	-7.41	3.66	5.98	2.58*
3.	1 x 7	-0.53	9.70	10.01	2.26	-0.24
4.	1 x 8	0.13	0.37	-8.00	-4.45	-1.18
5.	1 x 9	0.17	5.52	-7.49	2.67	2.68*

6.	1 x 10	-2.03*	-0.30	-0.23	-3.49	-2.14
7.	1 x 11	4.88**	11.57*	15.21	2.84	-0.72
8.	1 x 12	-2.95**	-14.69**	-31.03**	-18.74**	-5.43**
9.	1 x 13	0.30	2.34	-5.90	2.28	2.52
10.	1 x 14	2.38*	-2.86	14.36	6.94*	1.25
11.	2 x 5	-0.57	4.97	-8.20	-8.13*	-3.42**
12.	2 x 6	-1.73	1.80	-11.24	-3.71	-0.39
13.	2 x 7	-0.23	-12.41*	-22.06*	-4.39	0.09
14.	2 x 8	-2.57**	-7.34	-5.48	0.33	1.73
15.	2 x 9	-0.98	-0.32	-7.29	-1.18	0.37
16.	2 x 10	3.93**	-10.38	-13.83	-1.16	1.64
17.	2 x 11	-1.15	-9.41	1.40	1.10	0.72
18.	2 x 12	2.68**	7.92	35.56**	12.55**	1.42
19.	2 x 13	1.26	0.96	10.28	3.30	0.22
20.	2 x 14	-0.65	24.21**	20.88*	0.41	-2.38
21.	3 x 5	1.26	10.02	18.00*	9.65**	2.32
22.	3 x 6	-1.23	1.32	1.59	-5.43	-3.17*
23.	3 x 7	0.27	-2.62	12.54	0.43	-1.20
24.	3 x 8	0.60	7.11	10.65	5.37	0.90
25.	3 x 9	-1.15	-8.40	1.84	-0.87	-0.74
26	3 x 10	-0.57	-2.29	-9.70	-3.60	-0.68
27.	3 x 11	-2.98**	0.71	-1.59	-2.80	-1.24
28.	3 x 12	0.85	10.37	-1.10	3.49	2.17
29.	3 x 13	1.10	-3.62	-4.97	-0.45	0.45
30.	3 x 14	1.85	-12.60*	-26.37**	-5.81	1.18
31.	4 x 5	-0.16	-10.76	-19.20*	-5.23	0.43
32.	4 x 6	5.33**	4.27	5.10	3.16	0.98
33.	4 x 7	0.50	5.32	-0.49	1.69	1.35
34.	4 x 8	1.83	-0.14	2.82	-1.25	-1.45
35.	4 x 9	1.41	3.21	12.94	0.62	-2.30
36.	4 x 10	-1.33	12.98*	23.77**	8.25*	1.18
37.	4 x 11	-0.75	-2.87	-15.02	-2.04	1.24
38	4 x 12	-0.58	-3.60	-2.53	-2.70	1.83
39.	4 x 13	-2.67**	0.32	0.59	-5.13	-3.20*
40.	4 x 14	-3.58**	-8.74	-8.87	-1.53	-0.06
SE (Sij) ±		0.48	2.78	4.44	1.61	0.64

Note: * Significant at 5% level of significance, ** Significant at 1% level of significance.

Parents:

1. RMS-2010-10A
2. RMS-2010-16A
3. RMS-2010-24A
4. CMS-185A
5. RSV-2015
6. RSV-2121
7. RSV-2138
8. RS-585
9. RSV-1996
10. RSV-1850
1. RSV-1837
11. RSV-2124
12. PSR-34
13. CSV-26

Conclusions

The outcome of the present investigation aimed in selecting good combiners for grain yield and other yield contributing characters. The parents, RMS-2010-10A, RSV-2015, RSV-2124, RSV-2138 and RSV-1850 showed good general combining ability for grain yield along with other important yield contributing characters. These parents further can be exploited for sorghum hybrid development programme to develop hybrids with high heterotic values. The hybrids RMS-2010-16A x RSV-2124 (12.55), RMS-2010-24A x RSV-2015 (9.65), CMS-185A x RSV-1850 (8.25) and RMS-2010-10A x CSV-26 (6.94) recorded higher magnitude of significant positive sca effects for grain yield and also exhibiting significant sca effects for most of the contributing characters. Among 40 crosses, cross combinations *viz;* RMS-2010-16A x RSV-2124, RMS-2010-24A x RSV-2015 and CMS-185A x RSV-1850 having high mean performance and found promising with significant sca effects for more number of characters. Therefore, these hybrids can be commercially exploited using heterosis breeding after the evaluation in multilocation trials.

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