Forage Res., **48**(3) : pp. 343-348 (2022) **http://forageresearch.in**

GENERAL AND SPECIFIC COMBINING ABILITY ANALYSIS OF MULTICUT FORAGE SORGHUM FOR YIELD AND YIELD-RELATED TRAITS

REENU[1], SATYAWAN ARYA[1], PUMMY KUMARI[1], RAVISH PANCHTA[1], KAVITA RANI[1]*, HARSH CHAURASIA[1] AND PRIYANKA DAHIYA[2]

[1]Department of Genetics & Plant Breeding
CCS Haryana Agricultural University, Hisar-125 004 (Haryana), India
[2]Sher-e-Kashmir University of agriculture Sciences & Technology, Jammu, (J&K), India
(e-mail : kavitadhanday22@yahoo.com)
(Received : 7 April 2022; Accepted : 29 December 2022)

SUMMARY

An investigation was conducted in *Sorghum bicolor* with line x tester (3 females x 6 males) to study the combining ability effects for fodder yield and other yield related traits. Analysis of variance revealed the presence of sufficient variation in the study material. The SCA variance was greater in magnitude than the GCA variance for most of the traits under study indicating predominance of non-additive gene action in the genetic control of those traits. Line 14A found good general combiner for GFY in 1st and 2nd cut, regeneration potential, DFY in 1st cut, GFY in 2nd cut, plant height whereas tester HJ 541 emerged as a good combiner for GFY in 1st cut, DFY in 2nd cut, no. of leaves per plant, leaf breadth. For GFY in 1st cut significant high SCA effects exhibiting crosses were 31A × SSG 59-3, 9A × SGL 87, 31A × S 437 and 9A × HJ 541.

Key words : Forage sorghum, GCA, SCA, multi cut

Forage sorghum has captured an important place among summer forages because it has a lot of advantages to offer to dairy farmers. It is a short-season forage that attains its complete bloom in 52-60 days after sowing if harvested at 50% flowering or heading stage. It has the potential to give high forage yield (Iqbal, 2015). Forage sorghums include sudangrass, sorghum varieties, hybrids, and sorghum×sudangrass (SSG) hybrids (Kalton, 1988). Sorghum plants grow 150-360 cm tall and produce a higher dry matter yield than grain sorghum. Forage sorghum has been proven to be more affordable than other cereal forages due to fewer requirements for irrigation and fertilizers. An extensive adventitious fibrous root system of sorghum that grows up to 140 cm depth can draw extra moisture and vitamins at a far quicker rate from the soil. The dry-matter accumulation rate of forage sorghum is one of the maximum among the cultivated annuals. Sorghum is an ideal forage crop because it has a quick growth, high-yielding ability, high dry matter content, leafiness, wider adaptability, and drought resistance. The development of forage sorghum cultivars having good shoot (tillers) and biomass regenerability makes them more suitable for multiple cuts, which is more useful for cut-and-carry production in semiarid zones. Thus sorghum × sudangrass hybrids which have higher regenerative potential are very productive in a warm climate.

In India, an estimated area of 2.5-3.0 m ha is under forage sorghum. However, seed production and trade-based estimation suggested that the area that can be covered extends to 4-5 million ha (IIMR, 2013). Sorghum is an often cross-pollinated crop where cross-pollination extends from 5% to 15% with an average of about 6% (Poehlman, 1987), which in turn brings homozygosity or heterozygosity in the genetic structure made it suitable to exploit breeding procedures applicable for both self- and cross-pollinated crops. This means that either a homozygous line as a variety or hybrids through heterosis exploitation can be developed in sorghum.

Although India is the highest milk producing country yet per capita milk production is very low due to the huge deficit in the availability of feedstuffs. The area under forage production has not increased considerably in the last few decades and our natural grazing lands and pastures are fastly degrading and decreasing. Therefore, by developing the varieties/hybrids giving high yield per unit area, and per unit time, the target of high production and productivity of forage sorghum can be achieved.

Prerequisites for forage sorghum hybrid development are the availability of good combining male sterile lines and restorers, the presence of dominance component of genetic variance for forage yield, and a high degree of heterosis for economic and multicut traits. Analysis of combining ability is essential to select desirable parents and high-performing progenies for population development or to exploit heterosis (Singh and Chaudhary 1985). L×T mating design is a commonly used scheme to assess progeny performance based on general combining ability (GCA) and specific combining ability (SCA) effects. Combining ability analysis aims to find out the nature of gene action underlying the expression of yield and yield-related traits (Sprague and Tatum 1942; Griffing 1956). GCA measures the mean performance of a genotype in a series of crosses, whereas SCA measures the deviation from the predicted performance of a cross, based on the summed general abilities of the associated parents (Schlegel 2010). Additive and non-additive gene action are associated with GCA and SCA effects, respectively (Acquaah 2009). Breeding for yield and yield-related traits using locally adapted and genetically complementary sorghum germplasm should be a viable way to boost sorghum production. The objective of this study was to determine the combining ability effects of selected sorghum lines for yield, and yield-related traits as a basis for choosing superior parents and families for further selection and breeding.

METHODS AND MATERIALS

Using L×T mating design (Kempthorne 1957) 18 hybrids were developed by crossing three restorer lines (9A, 14A, 31A) and six CMS testers (HJ 541, GFS 5, G 46, SGL 87, S 437, SSG 59-3). F_1 seeds were sown in the field, along with their parents, in a randomized complete block design with three replications. Each F_1 and its parents were sown in 4 row of 5m with inter row spacing of 25 cm and plant to plant spacing of 15 cm. All the recommended practices were followed to raise good crop of sorghum during *kharif* 2019.

Observations recorded : Data were recorded on five randomly chosen plants for yield and various yield related traits that affect the biomass production directly or indirectly. Mean of five plants for each entry for each character was calculated and used for statistical analysis. After first cut, regenerability potential was recorded as per score given by (Anon, 2014). The green fodder yield was recorded by taking the fresh weight of the plants in the plot at 1st cutting *i.e.* 60 days after sowing and at 2nd cutting *i.e.* 45 days after 1st cutting. The plants harvested for recording green plant weight were first sun dried and then oven dried for recording dry fodder yield.

Statistical analysis : Data were analyzed using INDOSTAT software for estimation of general and specific combining ability and their effects. The combing ability analysis was carried out according to the model suggested by Kempthorne (1957) which is related to design II of Comstock and Robinson (1952) in terms of covariance of half sibs and full sibs. This analysis was based on following model.

$$X_{ijk} = m + g_{ii} + g_{jj} + s_{ij} + r_k + e_{ijk}$$

Where,

X_{ijk} = Phenotypic expression of ijth genotype in kth replication

m = General mean

g_{ii} = General combining ability effects of ith female parent

g_{jj} = General combining ability effects of jth male parent

s_{ij} = Specific combining ability effects of crosses between ith female X jth male parent

r_k = The kth block effect

e_{ijk} = Random error associated with ijth genotype and kth block

Additive and dominance genetic variances (σ^2 A and σ^2 D) were calculated by taking inbreeding coefficient (F) equal to one; that is, F=1 because both lines and testers were inbred. Significance test for general combining ability and specific combining ability effects were performed using t-test. A GCA/SCA ratio that is greater than unity indicates the predominance of additive gene action, whereas ratios of less than unity indicate the predominance of non-additive gene action for the trait (Baker 1978).

RESULTS AND DISCUSSION

Analysis of variances

Analysis of variances for combining ability indicated that general combining ability (GCA) variances were significant (Table 1) for plant height, number of leaves per plant, leaf breadth, leaf length, internode length, green fodder yield in 1st cut and dry

TABLE 1
Analysis of variance for combining ability for different morphological characters in forage sorghum

Sources of variation	D. F.	Plant height	No. of tillers/ plant	No. of leaves/ plant	Internode length	Leaf breadth	leaf : stem ratio	Stem diameter	Leaf length	Regeneration potential	GFY in 1st cut	GFY in 2nd cut	DFY in 1st cut	DFY in 2nd cut
Replication	2	465.8	0.08	0.47	4.89	1.57*	0.008	33.96**	21.03	0.46	5.78*	0.092	175.01	63.38*
Hybrids	17	1404.95**	0.93**	124.04**	21.65**	2.85**	0.011**	27.99**	129.25*	1.29**	15.07**	3.20**	677.93**	546.56**
Lines	2	6736.63**	2.90	250.85	61.22*	15.54*	0.009	132.74**	417.08	3.75	52.53	5.88	630.91	88.39
Testers	5	339.3	0.34	185.97**	19.38	1.38	0.002	18.90	50.41	0.34	8.54*	1.19	811.75	1236.12*
Lines X Testers	10	871.43**	0.83**	67.71	14.88**	1.05**	0.016**	11.58*	111.1	1.27**	10.85**	3.67**	620.42**	293.41**
Error	34	196.44	0.26	8.07	2.80	0.37	0.003	4.39	53.10	0.42	1.33	0.19	92.05	13.36

TABLE 2
Genetic variance for different characters in forage sorghum

S. No.	Parents	PH	TP	LP	IL	LB	LSR	SD	LL	RP	GFY 1st	GFY 2nd	DFY 1st cut	DFY 2nd cut
1.	σ^2 GCA	197.52**	0.10	15.57**	2.77*	0.23**	0.0002	2.39*	13.37*	0.12	2.16*	0.24	46.61	48.06*
2.	σ^2 SCA	224.99**	0.18*	19.87**	4.02**	0.60**	0.0042**	5.29**	19.31	0.28**	3.17**	1.15**	176.12**	93.34**
3.	σ^2 GCA/σ^2 SCA	0.8779	0.53	0.70	0.69	0.38	0.04	0.45	0.69	0.42	0.68	0.21	0.26	0.51

PH=Plant height (cm), TP=Tillers per plant, LP=Leaves per plant, LL=length of leaf (cm), LB=Leaf breadth (cm), SD=Stem diameter (cm), LSR=Leaf : Stem ratio, RP=Regeneration potential, GFY 1st and 2nd =Green fodder yield in 1st and 2nd cut (kg/plot), DFY in 1st and 2nd cut= Dry fodder yield in 1st and 2nd cut (kg/plot), σ^2 GCA = GCA variance, σ^2 SCA = SCA variance. * and ** Significant at 5 % and 1 % level, respectively.

fodder yield in 2nd cut while specific combining ability variances were identified highly significant for all the characters. The evaluation of components of variances revealed that the magnitude of SCA variances were greater than GCA variances for all the characters. This indicated pre-dominance of non-additive gene action which emphasized the use of heterosis breeding approach to exploit the available vigour. It is also manifested by a very low ratio of σ^2GCA/σ^2SCA represented in table 2. The findings were supported by several other workers Indhubala *et al.* (2010); Prakash *et al*. (2010); Ghazy *et al.* (2011) and Chaudhari *et al.* (2017); Wagaw *et al*. (2020); Rachman *et al*. (2022) who also had been reported predominance of SCA variance in forage sorghum for fodder yield and its component characters.

General combining ability effects

Selection of parents based on *per se* performance alone may not be always effective because many times two phenotypically superior lines may produce poor hybrids. In such cases, the general combining ability effect of parental lines which indicate the presence of additive and additive x additive type of gene action can help in selecting parents to develop hybrids having potential for yield and other traits. Parents showing a high average combining ability in crosses are considered to have good GCA while, if their potential to combine well is bounded to a particular cross, they are considered to have good SCA. The estimates of general combining ability (GCA) effects for each line and tester are presented character wise in Table 3. Among lines 14A emerged as a good general combiners for plant height, internode length, regeneration potential and green fodder yield in 1st cut and 2nd cut. For tillers/plant, leaves/plant stem diameter and dry fodder yield in 2nd cut among lines 9A found to be good general combiner. Line 31A exhibited good general combining ability for traits like leaf breadth. Among testers HJ 541, for leaves per plant leaf breadth stem diameter GFY in 1st cut and DFY in 2nd cut found to be good general combiner. Tester G 46 emerged as a good general combiner for GFY in 1st cut. For trait like GFY in 2nd cut, tester SGL 87 had significant general combinig ability. S437 tester exhibited significant general combinig ability for DFY in 1st cut. For traits like Internode length, DFY in 1st cut and DFY in 2nd cut, tester SSG 59-3 had significant general combining ability. These results are uniform with findings of Kadam *et al.* (2007); Sharma *et al.* (2007) and Kumar and Chand (2015); Kumari *el al. (*2018); Rocha *et al*. (2018); Rathod *et al*. (2019); Veldandi *et al*. (2021).

Specific combining ability effects

In a systematic breeding programme, criterion like selection of parents with desirable characteristics and good general combining ability for yield as well as its components, high heterosis coupled with good *per se* performance in desirable direction, not only over better parent but also over check along with high estimates of specific combining ability effects are obviously essential (Grewal and Paroda, 1975). The different cross combinations showing significant estimates of *sca* effects for forage yield, its components traits which is given in table 4. However, further study of such crosses with significant *sca* effects mance for ultimate expression of significant and desirable *sca* effects of crosses. For plant height, significant positive SCA effects were shown by crosses 31A × G 46 and 14A × SGL 87. Among these crosses 31A × G 46 also showed significant positive SCA effect for leaf breadth. For tillers per plant the cross 9A × SSG 59-3 (good × poor) had significant positive SCA effects. For leaves/plant maximum SCA effect were recorded for crosses 14A × HJ 541 (poor × good) followed by 14A × G 46 (poor × good) 31A × GFS 5 (poor × poor) and 31A × SSG 59-3 (poor × poor). Among these hybrids, cross 14A × HJ 541 and 31A × SSG 59-3 recorded maximum SCA effect for regeneration potential. The cross 31A × HJ 541 showed the significant positive SCA effect for Internode length. For leaf : stem ratio, the cross 9A × HJ 541 exhibited a significant SCA effect. Out of 18 crosses, four crosses named 31A × SSG 59-3 followed by 9A × SGL 87, 31A × S 437 and 9A × HJ 541 showed positive significant SCA effects for green fodder yield in the 1st cut. Among these later three crosses also show significant SCA effects for green fodder yield in the 2nd cut along with cross 14A × SSG 59-3 along with 31A × S 437, 14A × SGL 87, 9A × HJ 541, 9A × G 46, 14A × SSG 59-3, 31A × G 46 and 9A × SGL 87. Significant SCA effects for dry fodder yield in 1st cut were recorded by cross 31A × S 437 (20.46) followed by 9A × SSG 59-3 (13.01), 14A × HJ 541(12.63). For dry fodder yield in 2nd cut significant SCA effects were recorded for cross 14A × G 46 followed by 31A × HJ 541, 31A × S 437, 9A × GFS 5. These results are in agreement with findings of Kumar and Shrotria (2016), Chaudhari *et al.* (2017), Vekariya *et al.* (2017), Rocha *et al.* (2018), Muturi *et al.* (2019) and Rathod *et al.* (2019).

TABLE 3
General combining ability effects of parents for different morphological characters in forage sorghum

Female parents	Plant height	Tillers/ plant	Leaves/ plant	Internode length	Leaf breadth	Leaf : stem ratio	Stem diameter	Leaf length	Regeneration potential	GFY in 1st cut	GFY in 2nd cut	DFY in 1st cut	DFY in 2nd cut
9A	-7.35*	0.30*	0.30*	0.30	-0.94**	0.02	-2.75**	-5.54**	-0.24	-0.92**	0.09	2.76	2.50**
14A	21.94**	0.15	0.15	3.57**	0.03	-0.02	0.08	2.42	0.52**	1.97**	0.52**	4.04	-1.72
31A	-14.59*	-0.45**	-0.45**	-3.87**	0.91**	0.01	2.67**	3.12	-0.29	-1.04**	-0.61**	-6.79**	-0.78
SE (d)	3.30	0.12	1.36	0.39	0.14	0.01	0.49	1.72	0.15	0.27	0.10	2.26	0.86
Male parents													
HJ 541	-0.81	0.16	8.25**	1.08	0.49*	0.01	2.25**	1.87	0.04	1.24**		4.87	12.83**
GFS 5	1.22	-0.14	-1.85	-2.27**	-0.35	-0.02	-0.15	2.05	-0.18	-0.24	-0.43**	-12.46**	-18.27**
G 46	7.56	-0.19	2.25*	0.58	0.33	-0.01	0.48	-0.25	-0.069	0.84*	-0.25	-7.35*	-1.50
SGL 87	-0.81	0.08	-2.59**	-1.34*	0.16	-0.01	-2.11**	-2.02	0.34	-0.18	0.5**	-4.69	-2.72*
S 437	-10.75*	-0.18	-3.88**	0.58	-0.12	0.02	-0.79	1.90	-0.18	-1.54**	-0.24	8.53*	-3.27*
SSG 59-3	3.60	0.26	-2.18*	1.39*	-0.5*	0.01	0.33	-3.54	0.043	-0.13	0.19	11.09**	12.94**
SE (d)	4.67	0.17	1.93	0.56	0.20	0.02	0.70	2.43	0.22	0.38	0.15	3.20	1.22

TABLE 4
Specific combining ability effects of hybrids of different morphological and quality characters in forage sorghum

Hybrids	Plant height	Tillers/ plant	Leaves/ plant	Internode length	Leaf breadth	Leaf : stem ratio	Stem diameter	Leaf length	Regeneration potential	GFY in 1st cut	GFY in 2nd cut	DFY in 1st cut	DFY in 2nd cut
9A × HJ 541	10.58	0.11	2.37	-0.81	0.11	0.13**	1.98	-1.83	0.01	1.59*	0.88**	-14.09*	-4.28
9A × GFS 5	14.30	-0.16	-0.41	1.55	-0.05	-0.02	1.36	1.54	0.24	0.01	-0.10	5.91	7.83**
9A × G 46	-14.01	0.23	-3.18	1.48	-0.17	0.05	0.03	4.51	0.12	-1.04	0.83**	5.46	-5.27*
9A × SGL 87	0.13	-0.92**	0.01	0.41	-0.33	-0.04	-1.55	-11.27*	0.05	2.23**	0.52*	8.13	3.94
9A × S 437	-1.95	0.11	1.19	-2.40*	0.06	-0.067*	0.56	1.58	-0.43	-0.59	-0.95**	-18.42**	-1.17
9A× SSG 59-3	-9.05	0.65*	0.04	-0.22	0.39	-0.06	-2.38	5.47	0.01	-2.21**	-1.18**	13.01*	-1.06
14A × HJ 541	-24.16**	0.26	5.75**	-2.85**	0.03	-0.071*	-1.40	-1.90	0.91*	0.26	-0.36	12.63*	-7.38**
14A × GFS 5	-6.20	0.22	-4.57**	-1.72	0.18	0.05	0.87	-0.53	-0.19	0.54	0.24	-9.37	-5.61*
14A × G 46	-6.09	0.12	5.09**	0.09	-0.80*	-0.07*	-1.37	-6.34	-0.3	0.59	-1.39**	-8.48	16.94**
14A × SGL 87	19.50*	0.33	-0.28	1.24	-0.20	0.04	-0.58	5.99	0.52	0.21	0.94**	2.19	3.83
14A × S 437	3.08	-0.30	-2.32	1.87	0.31	0.02	-0.30	3.17	-0.19	-1.10	-0.27	-2.04	-7.27**
14A × SSG 59-3	13.87	-0.63*	-3.68*	1.39	0.47	0.03	2.77*	-0.38	-0.75	-0.50	0.83**	5.07	-0.50
31A × HJ 541	13.59	-0.36	-8.12**	3.66**	-0.14	-0.06	-0.57	3.73	-0.93*	-1.84**	-0.52*	1.46	11.66**
31A × GFS 5	-8.11	-0.06	4.98**	0.17	-0.13	-0.04	-2.23	-1.01	-0.04	-0.56	-0.14	3.46	-2.22
31A × G 46	20.10*	-0.35	-1.92	-1.57	0.97**	0.02	1.33	1.84	0.18	0.45	0.55*	3.02	-11.66**
31A × SGL 87	-19.63*	0.60	0.28	-1.64	0.53	0.00	2.12	5.28	-0.57	-2.44**	-1.46**	-10.32	-7.77**
31A × S 437	-1.14	0.20	1.13	0.54	-0.37	0.04	-0.27	-4.75	0.62	1.69*	1.21**	20.46**	8.44**
31A× SSG 59-3	-4.82	-0.02	3.65*	-1.16	-0.86*	0.03	-0.39	-5.09	0.74**	2.71**	0.35	-18.09**	1.56
SE (d)	8.09	0.30	1.64	0.97	0.34	0.03	1.21	4.21	0.37	0.67	0.26	5.54	2.11
5% significant value	16.44	0.60	3.34	1.96	0.69	0.07	2.46	8.55	0.76	1.35	0.52	11.26	4.29
1% significant value	22.08	0.81	4.48	2.64	0.93	0.09	3.30	11.48	1.02	1.82	0.7	15.11	5.76

CONCLUSION

Among lines, 14A had significant positive GCA effects for green fodder yield in 1st and 2nd cut, regeneration potential, plant height. Among testers, HJ 541 and G 46 were found to be good general combiners GFY in 1st cut and SGL 87 in 2nd cut. Maximum SCA effects for green fodder yield in 1st cut were recorded by crosses 31A × SSG 59-3 followed by 9A × SGL 87, 31A × S 437 and 9A × HJ 541. For green fodder yield, in 2st cut, significant SCA effects were recorded for crosses 31A × S 437, 14A × SGL 87, 9A × HJ 541, 9A × G 46, 14A × SSG 59-3, 31A × G 46 and 9A × SGL 87. On the basis of above study, some parents viz. 14A, HJ 541, G 46 were identified as good general combining ability, therefore, these parents can be used for development of hybrids with high yield potential. Among hybrids, 14A × HJ 541, 31A × S 437 and 9A × HJ 541, 9A × SGL 87, 14A × G 46 and 31A× SSG 59-3 performed better for green fodder production and have potential to meet the growing fodder demand and could also be analyzed by molecular approach too to confirm their reliability.

REFRENCES

Acquaah, G., 2009 : *Principles of plant genetics and breeding*. John Wiley & Sons.

Baker, R.J., 1978 : Issues in diallel analysis. *Crop Sci*., **18** : 533-536.

Chaudhari, N., M. Gangani, M. Chaudhari and R. Anjana, 2017 : Combining ability and gene action analysis for green forage yield and its components in fodder sorghum (*Sorghum bicolor* L.). *Trends in Biosciences,* **10**(32).

Comstock, R.E. and R.H. Robinson, 1952 : Genotype-environment interaction. *Symposium on Statistical Genetics and Plant Breeding. NAS-NRC Publication No. 982*. pp. 164-196.

Ghazy, M. and O. Sakr, 2011 : Line x tester analysis across years to study combining ability in forage sorghum (*Sorghum bicolor* (L.) Moench). *Journal of Agricultural Chemistry and Biotechnology*, **2** : 111-123.

Grewal, R. P. S., and R. S. Paroda, 1974 : Heterosis and combining ability in forage sorghum. *Maydica*.

Griffing, B. R. U. C. E., 1956 : Concept of general and specific combining ability in relation to diallel crossing systems. *Australian journal of biological sciences*, **9**(4): 463-493.

IIMR, 2013 : ICAR-Indian Institute of Millets Research-Vision 2050.

Indhubala, M., K. Ganesamurthy and D. Punitha, 2010 : Combining ability studies for quality traits in sweet sorghum (*Sorghum bicolor* (L.) Moench). *Madras Agricultural Journal*, **97**(1): 17-20.

Iqbal, M. A., 2015 : Agronomic management strategies elevate forage sorghum yield: A Review. *J Adv Bot Zoo*, **3** : 1-6.

Kadam, D.E., V.M. Kulkarni, B.K. Katule and S.V. Patil, 2007 : Combining ability studies in rabi sorghum (*Sorghum bicolor* (L.) Moench). *Advances in Plant Sciences*, **20**(1): 39-41.

Kalton, R. R., 1988 : Overview of the forage sorghums. In *Report of Forty-third Annual Corn and Sorghum Research Conference (Wilkinson W, ed.). American Seed Trade Association Publication*, **43** : 1-12

Kempthorne, O., 1957 : An Introduction to Genetic Statistics, New York, John Wiley and Sons, 1st Edition. pp. 456-471.

Kumar, P. and P.K. Shrotria, 2016 : Combining ability and heterosis studies for yield and component traits in forage sorghum (*Sorghum Bicolor* (L.) Moench).*Green Farming*, **7**(1): 1-7.

Kumar, S. and P. Chand, 2015 : Combining ability and heterosis for grain yield, fodder yield and other agronomic traits in sorghum [*Sorghum bicolor* (L.) Moench]. *Journal of Applied and Natural Science*, **7**(2): 1001-1005.

Kumari, P., S. K. Pahuja and S. Arya, 2018 : "Study of combining ability effects in forage sorghum hybrids for yield and quality traits." *Electronic Journal of Plant Breeding* **9**(2): 528-537.

Muturi, P., M. Mgonja, and P. Rubaihayo, 2019 : Gene action conditioning resistance traits to spotted stem borer, *Chilo partellus*, in grain sorghum. *International Journal of Tropical Insect Science,* **39**(2).

Poehlman, J. M., 1987 : Breeding sorghum and millet. In *Breeding field crops* Springer, Dordrecht, pp. 508-555.

Prakash, R., K. Ganesamurthy, A. Nirmalakumari and P. Nagarajan, 2010 : Combining ability for fodder yield and its components in sorghum [*Sorghum bicolor* (L.) Moench]. *Electronic Journal of Plant Breeding*, **1**(2): 124-128.

Rachman, Fathur, Trikoesoemaningtyas Trikoesoemaningtyas, Desta Wirnas, and Reflinur Reflinur, 2022 : "Estimation of genetic parameters and heterosis through line× tester crosses of national sorghum varieties and local Indonesian cultivars." *Biodiversitas Journal of Biological Diversity,* **23**: 3.

Rathod, D. P., R. A. Gami, R. M. Chauhan, K. G. Kugashiya and R. N. Patel, 2019 : Genetic analysis in forage sorghum [*Sorghum bicolor* (L.) Moench]. *Forage Res.*, **45**(3): 197-202.

Rathod, D. P., Gami, R. A., Chauhan, R. M., Kugashiya, K. G., & Patel, R. N. 2019: Genetic analysis in forage sorghum [*Sorghum bicolor* (L.) Moench]. *Forage Research*, *45*(3), 197-202.

Rathod, D. P., R. A. Gami, R. M. Chauhan, K. G. Kugashiya, and R. N. Patel. 2019: "Genetic analysis in forage sorghum [*Sorghum bicolor* (L.) Moench]." *Forage Res.,* **45**(3): 197-202.

Rocha, M., Nunes, J.A., Parrella, R., Leite, P., Lombardi, G., Moura, M., Schaffert, R. and Bruzi, A. 2018: General and specific combining ability in sweet sorghum. *Crop Breeding and Applied Biotechnology*, **18** : 365-372.

Rocha, Mara Jane da, et al. 2018: "General and specific combining ability in sweet sorghum." *Crop Breeding and Applied Biotechnology* **18** : 365-372.

Schlegel, R. H. J., 2010: Dictionary of Plant Breeding; CRC Press: Boca Raton, FL, USA.

Sharma, H.C., M.K. Dhillon, G. Pampapathy, and B.V.S. Reddy, 2007 : Inheritance of resistance to spotted stem borer, *Chilo partellus*, in sorghum (*Sorghum bicolor*.). *Euphytica: Netherlands Journal of Plant Breeding*, **156**(1-2):117-128.

Singh, R. K., B. D. Chaudhary, 1985 : Biometrical Methods in Quantitative Genetic Analysis.

Sprague, G. F. and L. A. Tatum, 1942 : General and specific combining ability in single crosses in corn. *Journal of the American Society of Agronomy*, **34**(1): 923-932.

Vekariya, K. J., D. A. Patel, K. G. Kugashiya and J. I. Nanavati, 2017 : Study of combining ability and gene action for forage yield and its component characters in forage sorghum [*Sorghum bicolor* (L.) Moench]. *Journal of Pharmacognosy and Phytochemistry*, **6**(4): 43-47.

Veldandi, Saikiran, D. Shivani, S. Maheswaramma, K. Sujatha, K. Sravanthi, S. Ramesh, K. N. Yamini, and C. V. Kumar. 2021: "Combining ability and heterosis studies in diferent crop sites for yield and yield contributing traits in sorghum (Sorghum bicolor (L.) Moench)." *Electronic Journal of Plant Breeding* **12** (4): 1351-1358.

Wagaw, Kidanemaryam, Kassahun Bantte, and Taye Tadesse. 2020: "Gene action, combining ability and heterotic performance of Ethiopian Sorghum (Sorghum bicolor (L.) Moench) lines under moisture stress areas in Ethiopia." *African Journal of Plant Science* **14**(9): 372-394.