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Research Article

Heterosis and combining ability for quantitative traits in fodder Sorghum (*Sorghum bicolor* L.)

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Abstract
Combining ability and heterosis for some fodder yield and its component traits were studied among nine sorghum crosses and their six parents in a randomized complete block design with three replications under irrigated conditions. Highly significant differences for genotype, general combining ability and specific combining ability were observed for all the characters under assessment. However, general combining ability variances were lower than the specific combining ability variances for all the evaluated parameters. All the traits under study showed greater dominant variance than the additive variance having degree of dominance greater than unity. The sorghum line V-1 indicated the highest general combining ability effects in the desired directions for plant height, TSS-9 for number of tillers plant^{-1} and CVS-13 for stem thickness, fresh weight plant^{-1} and dry weight plant^{-1}. All the nine crosses depicted significant and positive mid-parent as well as better parent heterosis for fresh weight plant^{-1} and dry weight plant^{-1}. The present study indicated that improvement in fodder yield is feasible due to overall better performance of genotypes having significant better parent heterosis along with good general combiner parents (CVS—13).

Key Words
Sorghum bicolor, Combining ability, Gene action, Partial diallel, Heterosis,

Introduction

Agricultural crops and livestock play an important role to fulfill the basic necessities of life to the people (Tahir *et al*., 2005). Regular supply of adequate and nutritious fodder is a basic requirement for livestock production to meet the demand of milk, butter and other by-products for human consumption. The available fodder production is less than the actual requirement (Ayub *et al*., 1999). Average fodder yield of sorghum at present is less than the potential of 50-100 tons per hectare (Chaudhry *et al*., 2006).
The importance of sorghum as a fodder crop is growing in many regions of the world due to its high productivity and ability to utilize water efficiently even under drought conditions. Sorghum has good genetic variability that allows the breeding and development of new cultivars adapted to different agro-ecological regions around the globe (Zhang *et al*., 2010).

Improvement of fodder productivity in sorghum by breeding obliges to focus on traits that might affect the yield and nutritive quality of the fodder (Miron, 2005). The traits like yield and its components are governed by polygenes with complex gene action. Knowledge about the nature and magnitude of gene action would help the breeder in selection of a suitable breeding method. The selection of suitable parents is the most important for yield improvement in sorghum crop, which could combine well and produce desirable hybrids. Estimation of heterosis and determination of the gene action governing the quantitative traits would be helpful to bring desired improvement in sorghum (Premalatha *et al*., 2006).

The exploitation of heterosis by developing the hybrids is one of the quickest and simplest ways to improve productivity for grain as well as fodder yield with special reference to combining ability. This could be realized only when desired combining ability is identified and used in the development of sorghum hybrids (Prabhakar, 2002). Information on nature and magnitude of gene action for the traits of economic importance and proper selection of' parents in sorghum depends upon combining ability analysis which is one of the powerful tools for identification of the best combiner (Gaikwad *et al*., 2002).

Combining ability analysis allows broad inferences on the nature of the gene effects for a trait under selection. The breeder can make use of such information to find the best strategy to select desirable parents or determine which breeding procedure will efficiently improve the performance of the traits of interest in sorghum (Kenga *et al.* 2004)

The objective of present study was to find out nature of gene action, assessment of desirable parents for crossing and estimation of heterosis in sorghum for fodder yield and its components under irrigated conditions.

Material and Methods

The experimental material consisted of six sorghum parents and nine crosses. The crosses among the parents were made in partial diallel pattern (circulant design) proposed by Kempthorne and Curnow, 1961 (Table-1). Kempthorne and Curnow (1961) presented the concept of partial diallel in which only a random samples of crosses "s" is analyzed where "s" is less than n-1. Both "s" and 'n" should be neither odd nor even. With "n" lines the total number of crosses to analyze in a partial diallel is thus (ns/2).
The precision of estimates in partial diallel depends on the sample size "s" in relation to number of parental lines "n". Thus observations by various workers have shown that biases in the estimates are more common when "s" is less than n-1.Partial diallel have a tendency to ignore certain crosses according to a definite plan, thus reducing number of crosses per parent exerting less crossing load without losing much of precision. Using the circulant design of partial diallel mating, we can rapidly screen the genetic stock.

The hybridization work was carried out at Koont Farm, PMAS- Arid Agriculture University Rawalpindi during *Kharif*, 2009. The nine sorghum crosses along with six parents were sown in a Randomized Complete Block Design with three replications during July, 2010 at Arid Zone Agricultural Research Institute (AZRI), Bhakkar under irrigated conditions. The row length was kept at 4 meters and row-to-row and plant-to-plant distance was maintained at 30 centimeters. Three irrigations were applied at critical stages of crop growth. Approved production technology was followed for better crop stand.

Data regarding different plant traits were recorded during cropping season. The traits under evaluation were plant height (cm) , number of leaves plant^{-1}, number of tillers plant^{-1}, stem thickness (cm), fresh weight plant^{-1} (g) and dry weight plant^{-1} (g). Data were subjected to analysis of variance (Steel *et. al*., 1980) and combining ability analysis following circulant mating design (Kempthorne and Curnow, 1961).

Results and Discussion

Analysis of variance:

The mean squares of the six parameters under evaluation for nine crosses are given in Table 2. The mean squares for genotype, general combining ability and specific combining ability were significant for all the traits under investigation.
The presence of genetic variability among the genotypes for the trait of interest is important for efficient selection. In the present study, significant mean squares for genotypes for all the traits indicated the presence of genetic variability to be manipulated for the improvement of yield and its various contributing traits. However, significant mean squares for general combining ability and specific combining ability showed existence of both additive and non-additive type of gene action. Kamdi *et al.* (2009), Prakash *et al.* (2010) and Muhammad and Talib (2008) also reported significant variability for genotype, general combining ability and specific combining ability for different characters in sorghum.

Estimates of genetic components of variance :

The estimates of genetic components and their derivatives for the assessed morphological traits of nine crosses are given in Table 3. Phenotypic component of variance was greater than the genotypic component of variance for all the traits. Similarly the estimates of general combining ability variance (σ^2_{gca}) were lower than those of specific combining ability variance (σ^2_{sca}) for all the traits under assessment. It was supported by ratio of variance of general to specific combining ability (σ^2_{gca}/ σ^2_{sca}) which was less than unity (Table 3).

All the traits under study had higher phenotypic variance than genotypic variance suggesting that these parameters were greatly affected by environmental influences. The ratio between specific combining ability variance and general combining ability variance was less than unity and this indicated the preponderance of non-additive type of gene action for the inheritance of the evaluated traits. Therefore, it appeared that the inheritance of all parameters was controlled by non-additive type of gene effects showing that selection process was difficult under such conditions. Such type of gene action clearly indicated that heterosis breeding would be an ideal technique for their improvement. However for the evolution of desirable genotypes with improved yield and yield components by recombination breeding, the selection of superior plants should be deferred to later generation. Premalatha *et al*. (2006), Gaikwad *et al*. (2002) and Vinaykumar *et al*. (2011) reported greater specific combining ability variances than general combining ability variances and described the non-additive type of gene actions for different traits in sorghum.

Estimates of general combining ability effects and gene action :

The estimates of additive and dominance variance along with degree of dominance for all the traits under evaluation are presented in Table 4. All the morphological parameters indicated higher dominance variance than the additive variance with the degree of dominance greater than unity.

The estimates of general combining ability effects pertaining to various traits are shown in Table 5. The estimates of general combining ability effects showed that the parents V-1 (19.33) and SPV-462 (12.89) were good general combiners for plant height and CVS-13 for stem thickness (0.19), fresh weight plant^{-1} (48.44) and dry weight plant^{-1} (12.99).

The mean performance of parents and hybrids is believed to be one of the imperative measures for their assessment. However, the parents with high mean value may or may not pass on their high performance to their hybrids. This parental ability is projected in terms of general combining ability effects. The general combining ability effects in the desired direction provide an aid in selection process. The parents with greater general combining ability effects in desired direction for traits of interest could be selected for further hybridization and evaluation programmes. In the present evaluation, the parent CVS-13 had the highest positive general combining ability effects for stem thickness, fresh weight plant^{-1} and dry weight plant^{-1}. Similarly the parents V-1 and SPV-462 had the highest and significant general combining ability effects for plant height. Thus, based on information generated by general combining ability effects the parents CVS-13, V-1 and SPV-462 could be better choice for improvement of fodder yield and its components through hybridization. Kamdi *et al.* (2009), Fouman *et al.* (2003) and Prakash *et al.* (2010) reported similar findings for these traits in sorghum.

Heterosis :

Estimates of mid parent heterosis for characters under evaluation are given in Table 6. Perusal of this table indicated that all the morphological traits showed significant mid parent heterosis in the desired direction except for number of leaves plant^{-1} (Table 6). Highest, significant and positive mid parent heterosis in the desired direction was observed for plant height (33.82%), stem thickness (41.53%) and fresh weight plant^{-1} (145.79%) in cross V-1 x SPV-462, for number of leaves per plant^{-1} (14.98) in cross V-1 x SPV-462, for number of tillers plant^{-1} (111.11%) in cross CVS-13 x RARI-S-10, and for dry weight plant^{-1} (128.52%) in cross SV-6 x RARI-S-10. Whereas, the cross CVS-13 x RARI-S-10 showed the lowest mid parent heterosis for plant height (-3.31%) and number of leaves plant^{-1} (-16.92%), the cross SV-6 x RARI-S-10 for number of tillers plant^{-1} (17.07%) and stem thickness (13.08%) and the cross V-1 x RARI-S-10 for fresh weight plant^{-1} (48.56% and dry weight plant^{-1} (24.95%). Significant and positive relative heterosis among all the crosses was observed for the traits fresh weight plant^{-1} and dry weight plant^{-1}.

The estimates of better parent heterosis for the traits under study are given in Table 7. Significant and positive better parent heterosis in the desired direction was observed for the traits, number of tillers plant^{-1} (45.78%), fresh weight plant^{-1} (57.47%) and dry weight plant^{-1} (58.66%). The cross V-1 x SPV-462 indicated highest better parent heterosis in the desired direction for the traits plant height (28.09%), stem thickness (27.95%), fresh weight plant^{-1} (117.72%) and dry weight plant^{-1} (105.33%). The crosses V-1 x RARI-S-10 (100%) and CVS-13 x RARI-S-10 (100%) showed significant and positive better parent heterosis for number of tillers plant^{-1} whereas no cross indicated significant positive heterobeltiosis for number of leaves plant^{-1}. The lowest better parent heterosis was observed in cross CVS-13 x RARI-S-10 for plant height (-17.04) and number of leaves plant^{-1} (-18.73%). The cross SV-6 x RARI-S-10 showed minimum better parent heterosis for number of tillers plant^{-1} (9.09%). The cross V-1 x RARI-S-10 indicated the lowest heterobeltiosis for stem thickness (-5.79%), fresh weight plant^{-1} (19.81%) and dry weight plant^{-1} (18.50%) during study. All the crosses showed a uniform trend of significant and positive heterobeltiosis for fresh weight plant^{-1} and dry weight plant^{-1} (Table-7).

In improving the genetic structure of the crop through breeding process, utilization of heterosis is important for maximization of yield in sorghum. Variable amount of two types of heterosis i.e. relative heterosis and heterobeltiosis as displayed by different crosses for the parameters under evaluation indicated sufficient deviation from the parental material for these characters. In the present assessment, all the crosses showed significant and positive relative heterosis and heterobeltiosis for number of tillers plant^{-1}, fresh plant^{-1} and dry weight plant^{-1} during evaluation indicating the presence of non additive gene action (dominance and epistasis).

Heterosis for fodder yield is evident as the cumulative effect of heterosis for component traits. In the present investigation, the elaborative study of nine crosses indicated this fact as most of crosses that showed positive and significant heterosis for yield, also showed heterosis for plant height, number of tillers plant^{-1} and stem thickness, the major yield contributing traits. The findings of the present investigation on the magnitude of heterosis for fresh weight plant^{-1} and dry weight plant^{-1} are consistent with the earlier findings of Desai *et al*. (1999) Shaug *et al*. (2000) and Desai *et al*. (2000).

Conclusion

In the present study, dominant variance was greater than the additive variance for all the characters under evaluation with a degree of dominance greater than unity. Parent CVS-13 was a good general combiner for stem thickness, fresh weight plant^{-1} and dry weight plant^{-1}. All the crosses showed significant and positive relative heterosis and heterobeltiosis for all the characters under study. Based on the present study, parent CVS-13 had shown promising result and should be used in future sorghum hybridization programmes aimed at fodder yield improvement.

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Table 1: Format for Partial Diallel Crosses

Parents	V-1	SV-6	CVS-13	SPV-462	RARAI-S-10	TSS-9
V-1			x	x	x	
SV-6				x	x	x
CVS-13					x	x
SPV-462						x
RARI-S-10						
TSS-9						

Sample crosses with n= 6, s= 3, k= 2

n= Number of line/parents involved in crossing
s=sample size
k= number of lines/parents after which crossing will start
x= cross made

Table 2: Mean squares for morphological traits of nine sorghum crosses grown under irrigated conditions during the year 2010

Parameters	MSg	MSe	MS gca	MS sca
Plant height (cm)	2052.26**	274.25	2486.85**	1327.95*
Number of leaves plant^{-1}	4.29**	1.12	4.56*	3.84*
No. of tillers plant^{-1}	1.12*	0.05	1.17**	1.05**
Stem thickness (cm)	0.09**	0.02	0.09**	0.07*
Fresh weight plant^{-1} (g)	13830**	1961.92	15578.79**	10915.35**
Dry weight plant^{-1} (g)	2144.26**	193.21	2204.59**	2043.71**

*Significant at 5% level **Significant at 1% level

MSg= Mean square for genotype, MSe= Mean square for eroor

MSgca = Mean square for general combining ability

MSsca= Mean square for specific combining ability

Table 3: Estimates of genetic components and their derivatives for morphological traits of nine sorghum crosses grown under irrigated conditions during the year 2010

Parameters	σ^2_{g}	σ^2_{p}	σ^2_{gca}	σ^2_{sca}	$\sigma^2_{gca}/ \sigma^2_{sca}$
Plant height (cm)	593	867	160.96	361.39	0.45
Number of leaves plant^{-1}	1.06	2.18	0.10	0.95	0.11
No. of tillers plant^{-1}	0.36	0.41	0.02	0.34	0.05
Stem thickness (cm)	0.02	0.04	0.005	0.02	0.18
Fresh weight plant^{-1} (g)	3956.	5918	647.70	3057.14	0.21
Dry weight plant^{-1} (g)	650	844	22.35	623.99	0.04

σ^2_{g} = Estimates of genotypic variance,
σ^2_{p}= Estimates of phenotypic variance
σ^2_{gca}= Estimates of general combining ability variance,
σ^2_{sca}= Estimates of specific combining ability variance

Table 4: Estimates of additive and dominant components of variance and degree of dominance for morphological traits of nine sorghum crosses grown under irrigated conditions during the year 2010

Parameters	σ^2_a	σ^2_d	σ^2_a / σ^2_d	$\sigma^2 d / \sigma^2 a$	D.D.
Plant height (cm)	321.92	361.39	0.89	1.12	1.06
Number of leaves plant^{-1}	0.20	0.95	0.21	4.74	2.18
No. of tillers plant^{-1}	0.03	0.34	0.09	10.72	3.27
Stem thickness (cm)	0.01	0.02	0.37	2.72	1.65
Fresh weight plant^{-1} (g)	1295.40	3057.14	0.42	2.36	1.54
Dry weight plant^{-1} (g)	44.69	623.99	0.07	13.96	3.74

σ^2_a= Estimates of additive variance
σ^2_d= Estimates of dominant variance
S.E.= Standard error
D.D.=Degree of dominance

Table 5: Estimates of general combining ability effects for morphological traits of six sorghum parents grown under irrigated condition during the year 2010

Parents	General Combining ability Effects					
	Plant height(cm)	No. of leaves plant^{-1}	No. of tillers plant^{-1}	Stem thickness (cm)	Fresh weight plant^{-1}(g)	Dry weight plant^{-1}(g)
V-1	19.33**	0.00	-0.04	-0.04	7.67	-8.00
SV-6	3.11	0.09	-0.25	-0.07	-35.67**	-0.08
CVS-13	-30.53**	-0.04	0.13	0.19**	48.44**	12.99**
SPV-462	12.89**	-0.20	-0.11	-0.02	12.59	-0.29
RARI-S-10	-8.70	-0.17	0.16	-0.01	-15.00	9.48
TSS-9	-6.84	-0.47	0.17	0.04	3.48	-6.23

*Significant at 5% level **Significant at 1% level

Table 6: Estimates of mid-parent heterosis for morphological traits from nine crosses of sorghum grown under irrigated conditions during the year 2010.

Crosses	Mid parent heterosis (%)					
	Plant height(cm)	No. of leaves plant^{-1}	No. of tillers plant^{-1}	Stem thickness (cm)	Fresh weight plant^{-1} (cm)	Dry weight plant^{-1} (cm)
V-1 x CVS-13	22.35**	14.98*	36.84**	31.44**	96.14**	52.98**
V-1 x SPV-462	33.82**	14.21*	33.33**	41.53**	145.79**	117.53**
V-1 x RARI-S-10	4.06	-3.03	110.00**	13.43	48.56**	24.95*
SV-6 x SPV-462	14.86*	-1.40	24.64**	18.52	57.59**	93.35**
SV-6 x RARI-S-10	12.43*	-0.79	17.07*	13.08	62.38**	128.52**
SV-6 x YSS-9	13.34*	5.88	50.35**	19.98	51.96**	54.43**
CVS-13 x RARI-S-10	-3.31	-16.92**	111.11**	21.53*	69.72**	83.78**
CVS-13 x YSS-9	8.93	-12.17	80.95**	33.33**	63.39**	48.05**
SPV-462 x YSS-9	16.30**	-14.05*	44.22**	31.26**	80.49**	58.58**
Mean	**13.64***	**-1.48**	**56.50****	**24.90***	**75.17****	**73.57****

*Significant at 5% level **Significant at 1% level

Table 7: Estimates of better-parent heterosis for morphological traits from nine crosses of sorghum grown under irrigated conditions during the year 2010.

Crosses	Plant height (cm)	No. of leaves plant^{-1}	No. of tillers plant^{-1}	Stem thickness (cm)	Fresh weight plant^{-1} (g)	Dry weight plant^{-1} (g)
V-1 x CVS-13	4.89	8.40	23.81**	9.54	63.38**	38.47**
V-1 x SPV-462	28.09**	11.85	25.00**	27.95*	117.72**	105.33**
V-1 x RARI-S-10	3.96	-10.46	100.00**	-5.79	19.81**	18.50
SV-6 x SPV-462	14.20*	-3.03	19.44**	14.93	52.45**	83.02**
SV-6 x RARI-S-10	8.31	-8.03	9.09	0.00	41.48**	95.51**
SV-6 x YSS-9	9.44	4.13	41.33**	13.12	34.68**	28.25**
CVS-13 x RARI-S-10	-17.04*	-18.73*	100.00**	21.03*	62.96**	74.93**
CVS-13 x YSS-9	-0.35	-15.52	52.00**	25.00**	59.92**	45.98**
SPV-462 x YSS-9	12.92*	-14.05	41.33**	27.51**	64.84**	37.97**
Mean	**7.16**	**-5.05**	**45.78****	**14.18**	**57.47****	**58.66****

*Significant at 5% level ** Significant at 1% level