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ELUCIDATION OF *PER SE* PERFORMANCE AND HETEROSIS FOR FORAGE YIELD AND ITS RELATED TRAITS IN SORGHUM [*SORGHUM BICOLOR* (L.) MOENCH]

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SUMMARY

The present investigation carried out to study *per se* performance and magnitude of heterosis in sorghum [*Sorghum bicolor* (L.) Moench]. The per se performance of parents revealed that the parent CSV 21F was top ranking for green fodder yield per plant and dry fodder yield per plant. The parent GFS 4 was found better for days to flowering, days to maturity, stem girth and protein content. The *per se* performance indicated that F_1 hybrids GFS 4 × UTFS 91, PSVGS 313 × UTFS 91 and CSV 21F × GFS 4 recorded maximum green fodder yield per plant and dry fodder yield per plant among studied genotypes. The analysis of variance revealed highly significant differences due to genotypes for all the traits investigation which explained sufficient amount of heterosis was reflected in crosses for many of the fodder and grain yield attributing traits. Heterosis studies showed that plant height (cm), number of leaves per plant, stem girth (cm), leaf length (cm), leaf width (cm), leaf: stem ratio, green fodder yield per plant (g), and dry fodder yield per plant (g) were important forage yield components. A comparative study of best heterotic hybrid, GFS4 × UTFS 91 and PSVGS 313 × UTFS 91 for green fodder yield per plant and dry fodder yield per plant manifested significant positive heterosis over both better parent and standard check. These hybrids also exhibited significant and positive heterosis over better parent or combination of a standard check for various component traits *viz.*, leaf width, leaf: stem ratio, dry fodder yield per plant, protein content and Brix value.

Key words : *Per se* performance, heterobeltiosis, standard heterosis, yield

Sorghum [*Sorghum bicolor* (L.) Moench] has been classified under family Poaceae, sub family Panicoideae, tribe Andropogonae and genus Sorghum having 2n=20 chromosome number. Harlan and De Wet (1972) portioned the primary gene pool of *Sorghum bicolor* (L.) Moench into five basic races designated as bicolor, guinea, caudatum, kafir and durra as well as ten intermediate races from the combination of the five primary races. Different races or cultivars of *S. bicolor* may be described as fodder sorghum, grain sorghum or sweet sorghum depending on their morphology or end-use. In some cases, sorghum is used as a dual-purpose crop; after the grain is harvested, cattle are grazed on the stubble. Its potential as a biofuel crop has been identified and is gaining in importance (CGIAR 2015, Rathod *et al*, 2020). Sorghum is the fifth largest and most important cereal crop in the world after wheat, maize, rice and barley. Sorghum is an important crop that serves as human staple and is a major livestock feed in intensive production systems. Sorghum may be seen as one of the crops best suited to future climate change due to its ability to adapt to conditions such as drought, salinity and high temperatures (ICRISAT 2015). Due to its versatile use, drought hardiness, stability of yield and adaptability over wide range of climates, sorghum has maintained its importance and dependability. Therefore, improvement of this crop will have a great impact on the socio-economic status of the people living in semi-arid regions. The heterosis study helps to exploit the genetic variability in the crops. The commercial exploitation of heterosis has attracted the attention of the plant breeders ever since Shull (1908) noticed an apparent rise in grain yield of hybrids in maize. Heterosis has been successfully exploited both in cross-pollinated and self-pollinated crops. One of the aims of the present study was to estimate hybrid vigour to know the genetic make-up of parents and to create Mendelian variability through segregation or recombination in advanced generations of the crosses.

In practical plant breeding, the heterosis measured over better parent and popular variety/hybrid is more realistic and is of more practical importance.

MATERIALS AND METHODS

The present investigation was carried out to study *per se* performance and magnitude of heterosis in sorghum [*Sorghum bicolor* (L.) Moench]. The experimental material consisted of six parents (*viz,*. CSV 21F, Malwan, GFS 4, PSVGS 313, UTFS 91, including check GJ 43(C) and CSV 32F (forage)) and their 15 half-diallel crosses. The seeds of 15 F_1 hybrids were produced during summer 2019 at Sorghum Research Station, S. D. Agricultural University, Deesa by manual emasculation and crossing. The seeds of parental lines were maintained through selfing. A set of 22 genotypes comprising of six parents (including check GJ 43 and CSV 32F) and their 15 F_1 hybrids were sown in Randomized Block Design (RBD) with three replications, during *Kharif* 2019. Each entry was sown in 1.5m length in two rows with 45 × 15 cm spacing. The recommended agronomical practices and plant protection measures were adopted for raising a good crop. It was typical semi-arid climate with moderate rainfall during June to October 2020. The observations were recorded on five randomly selected plants from each genotype in each replication for all the mentioned traits except days to flowering and days to maturity which were recorded on a plot basis. The dry fodder yield measured after leaves including leaf sheath and stem were chopped after dried at 100º C for 48 hours in hot air oven. The data were recorded for all the entries in each replication. The analysis of variance was carried out as per the procedure suggested by Sukhatme and Ambe (1985). Heterosis was estimated as per cent increase or decrease in the mean value of F_1 hybrid over the better parent, *i.e.*, heterobeltiosis (Fonesca and Patterson, 1968) and over standard check *i.e.*, standard heterosis Meredith and Bridge (1972) for each character.

RESULTS AND DISCUSSION

The analysis of variance for all the characters studied is presented in Table 1. The results revealed significant differences due to genotypes for all the traits studies. This supports that parents and their hybrids studied possessed a sufficiently high amount of genetic variability. Further, partitioning of the mean sum of square due to genotypes implied that the differences among parents were significant for all the traits excluding plant height, leaf length and grain yield per plant. The significant differences among parents showed greater diversity in the parental lines. In the case of hybrids, significant differences were found for

TABLE 1

Analysis of variance (mean sum of squares) for experimental design of thirteen traits in sorghum

Sources of Variation	d. f.	Days to flowering	Days to maturity	Plant height	No. of leaves/ plant	Stem girth	Leaf length	Leaf width
Replications	2	3.68	2.61	217.90	2.28	4.86	92.50	0.12
Genotypes	21	162.40**	167.59**	5316.82**	2.10*	5.42*	119.95*	1.40**
Parents	5	294.13**	304.40**	2284.43	4.11**	9.99**	127.11	2.69**
Hybrids	14	136.66**	140.95**	5413.89**	1.35	3.92	133.88*	0.64
Parents Vs Hybrids	1	26.53**	24.21**	24436.63*	4.58*	9.09	9.22	6.95**
Error	42	2.19	2.51	1162.30	1.08	2.51	60.90	0.46

*P≤0.05, **P≤0.01

Table. 1 Conti…

Sources of Variation	d. f.	Leaf : stem ratio	Grain yield/ plant	Green fodder yield/plant	Dry fodder yield/plant	Protein content	Brix value
Replications	2	0.0001	5.27	6340.69	797.58	1.25	0.04
Genotypes	21	0.002**	17.37**	24443.01**	2633.81**	4.82**	9.79**
Parents	5	0.002**	3.64	36802.30**	3811.97**	5.93**	8.83**
Hybrids	14	0.004**	24.19**	18817.82**	1939.26**	4.72**	9.87**
Parents Vs Hybrids	1	0.001	6.32	65842.20**	9100.51**	5.42*	23.30**
Error	42	0.0004	1.68	3355.38	350.48	0.75	0.72

*P≤0.05, **P≤0.01

all the traits except the number of leaves per plant, stem girth and leaf width, indicating the varying performance of cross combinations. Mean sum of squares due to parents *Vs* hybrids were significant for all the traits exclusive of stem girth, leaf length, leaf: stem ratio and grain yield per plant, which explained sufficient amount of heterosis was reflected in crosses due to yield attributing traits.

Perusal of mean value of parents revealed that none of the parental genotypes was superior for all the traits under study. The mean performance of parents revealed that the parent CSV 21F was top ranking for green fodder yield per plant and dry fodder yield per plant. The parent GFS 4 was found better for days to flowering, days to maturity, stem girth and protein content. The mean performance of hybrids (Table.2) disclosed that none of the hybrids were found superior for all the traits under study. The hybrid GFS 4 × UTFS 91, PSVGS 313 × UTFS 91 and CSV 21F × GFS 4 recorded maximum green fodder yield per plant and dry fodder yield per pant population studied. Keeping in view of practical importance, heterosis was measured over better parent and standard checks *i.e.* CSV 32F and GJ 43. The results revealed that extent of heterosis varied from the cross to cross for all the traits. For one trait certain cross combinations expressed considerable high heterosis. At the same time, it was low for other traits, suggesting that the selection of parents has an essential bearing on the performance of any hybrid. The superiority of hybrids over better parent ability to produce a high level of transgressive of parental combination indicates

TABLE 2
Mean performance of the parents and their F1 hybrids for thirteen traits in sorghum

S. No.	Parents/hybrids	Days to flowering	Days to maturity	Plant height (cm)	No. of leaves/ plant	Stem girth (mm)	Leaf length (cm)	Leaf width (cm)
	Parent							
1.	CSV21F	78.67	108.00	300.53	14.07	12.87	73.18	5.89
2.	Malwan	74.33	105.67	313.73	14.27	12.34	70.45	4.85
3.	GJ 43(c)	72.33	101.67	305.47	13.67	13.50	75.08	6.29
4.	GFS4	52.33	81.00	260.67	11.33	9.79	63.30	4.59
5.	PSVGS 313	77.00	103.00	266.93	12.07	15.40	83.05	6.17
6.	UTFS 91	77.33	106.67	247.00	13.33	13.14	75.69	7.13
7.	CSV 32F(c)	74.67	104.00	290.00	13.33	14.07	71.88	5.67
	Parental mean	72.38	101.43	282.55	13.15	13.10	73.23	5.80
	F_1 hybrids							
8.	CSV21F × Malwan	78.00	109.00	333.87	13.53	12.84	71.01	5.93
9.	CSV21F × GJ 43	74.33	102.67	322.20	14.33	12.69	75.71	6.77
10.	CSV21F × GFS 4	76.00	105.33	357.40	14.40	13.00	71.04	6.28
11.	CSV21F × PSVGS 313	71.33	102.33	345.80	13.53	12.58	85.33	6.99
12.	CSV21F × UTFS 91	77.67	107.00	362.87	13.87	11.87	90.45	6.48
13.	Malwan × GJ 43	77.33	106.67	359.27	13.87	12.47	78.17	6.80
14.	Malwan × GFS 4	72.33	101.67	333.87	13.07	12.16	70.65	6.10
15.	Malwan × PSVGS 313	71.33	100.67	367.53	14.53	13.29	74.49	5.88
16.	Malwan × UTFS 91	73.00	102.33	363.93	14.00	13.03	71.15	6.19
17.	GJ 43 × GFS 4	70.67	100.67	255.47	13.47	13.13	66.81	6.09
18.	GJ 43 × PSVGS 313	66.67	96.00	269.53	12.60	12.38	72.01	6.36
19.	GJ 43 × UTFS 91	66.33	95.67	253.00	12.47	13.26	64.84	6.27
20.	GFS 4 × PSVGS 313	67.00	96.33	334.60	13.40	14.41	69.90	6.83
21.	GFS 4 × UTFS 91	52.67	82.00	349.07	14.80	15.40	73.09	7.55
22.	PSVGS 313 × UTFS 91	79.67	109.00	262.40	13.80	15.86	70.49	6.83
	F_1 hybrids mean	71.62	101.16	324.72	13.71	13.23	73.68	6.49
	General mean	71.86	101.24	311.62	13.53	13.19	73.74	6.27
	Range	52.33 to 79.67	81.00 to 109.00	253.00 to 367.53	11.33 to 14.80	9.79 to 15.86	63.30 to 90.45	4.59 to 7.55
	S. Em±	0.85	0.91	19.68	0.6	0.91	4.51	0.39
	C. D. (P=0.05)	2.44	2.61	56.18	1.71	2.61	12.86	1.11
	CV %	2.06	1.57	10.94	7.66	12.02	10.61	10.78

contd.

Table 2 : conti…

S. No.	Parents/ hybrids	Leaf : stem ratio	Grain yield/ plant (g)	Green fodder yield/plant	Dry fodder yield/plant (g)	Protein contain (%)	Brix value
	Parent						
1.	CSV21F	0.13	10.73	464.47	145.69	9.39	10.73
2.	Malwan	0.16	11.55	299.27	92.71	8.65	11.37
3.	GJ 43(c)	0.11	14.02	342.67	106.26	7.00	8.43
4.	GFS 4	0.16	11.53	134.00	39.39	10.68	11.73
5.	PSVGS 313	0.15	12.70	369.87	115.46	8.82	7.93
6.	UTFS 91	0.17	12.18	376.40	117.59	7.07	11.80
7.	CSV 32F (c)	0.13	11.95	483.87	161.18	8.02	7.63
	Parental mean	0.14	12.10	352.93	111.18	8.52	9.95
	F_1 hybrids						
8.	CSV21F ×Malwan	0.14	12.71	347.73	108.78	7.64	11.28
9.	CSV21F ×GJ 43	0.12	11.33	399.53	125.13	8.96	9.67
10.	CSV21F × GFS 4	0.12	11.42	428.73	134.77	8.60	9.06
11.	CSV21F × PSVGS 313	0.14	10.88	428.13	133.58	10.16	8.07
12.	CSV21F × UTFS 91	0.16	11.24	404.33	125.75	10.28	9.43
13.	Malwan×GJ 43	0.18	12.05	393.27	121.97	8.40	12.63
14.	Malwan× GFS 4	0.24	11.46	243.60	74.71	10.65	10.73
15.	Malwan× PSVGS 313	0.17	12.30	275.40	84.75	10.42	13.00
16.	Malwan× UTFS 91	0.18	11.64	329.80	102.74	9.44	10.83
17.	GJ 43× GFS 4	0.09	13.57	325.20	100.81	7.26	7.33
18.	GJ 43× PSVGS 313	0.11	22.61	280.20	86.03	6.91	7.97
19.	GJ 43× UTFS 91	0.12	13.60	351.93	109.07	7.83	11.63
20.	GFS 4× PSVGS 313	0.15	12.34	374.20	115.38	9.96	11.77
21.	GFS 4× UTFS 91	0.17	11.83	548.13	172.27	10.41	12.10
22.	PSVGS 313 × UTFS 91	0.13	12.35	466.73	146.36	9.30	12.17
	F_1 hybrids mean	0.15	12.76	373.13	116.14	9.08	10.51
	General mean	0.15	12.55	366.70	114.56	8.90	10.33
	Range	0.09 to 0.24	10.73 to 22.61	134.00 to 548.13	39.39 to 172.27	6.91 to 10.68	7.33 to 13.00
	S. Em±	0.01	0.75	33.44	10.81	0.5	0.49
	C. D. (P=0.05)	0.03	2.13	95.45	30.85	1.43	1.4
	CV %	13.02	10.33	15.8	16.34	9.75	8.19

segregation (Fonseca and Patterson, 1968). In case of fodder yield two cross reported heterobeltiosis significant and positive. The estimation of heterosis over standard check GJ 43 out of 15 F_1's, three hybrids expressed standard heterosis in desired direction. A wide range of heterosis over better parent and the standard check was recorded, *i.e.* -25.54 to 45.63 per cent (heterobeltiosis), -49.66 to 13.28 per cent over CSV32F and -28.91 to 59.96 per cent over GJ 43. The hybrids GFS-4 × UTFS 91and PSVGS 313 × UTFS 91 evinced significant and positive heterosis over better parent and standard check GJ 43. In case of dry fodder yield per plant out of total hybrids, two hybrids exhibited significant and positive heterosis over better parent and standard check GJ 43. The broad spectrum of heterosis over better parent and the standard check was recorded, *i.e.* -26.60 to 46.50 per cent (heterobeltiosis) and 29.69 to 62.12 per cent over GJ 43. The hybrid GFS 4 × UTFS 91 and PSVGS 313 × UTFS 91 exhibited significant and desirable heterosis over better parent and standard check GJ 43 (Table 3, 4, 5 and Fig. 1). The wide level of heterosis for dry fodder yield and related traits in sorghum also reported by Prakash *et al.* (2010), Pandey and shrotia (2012), Sakhare (2015), More *et al.* (2016), Patel *et al.* (2018) and Rathod *et al.* (2020), for dry fodder yield per plant.

A comparative study of best heterotic hybrid, GFS4 × UTFS 91 and PSVGS 313 × UTFS 91 for green fodder yield per plant and dry fodder yield per plant manifested significant positive heterosis over both better parent and standard check. These hybrids also exhibited significant and positive heterosis over better parent or combination of a standard check for various component traits *viz.*, leaf width, leaf: stem

TABLE 3
Number of hybrids having significant heterotic effect in sorghum

Characters	Over better parent				Over standard check (CSV 32 F)				Over standard check (GJ 43)			
	+ve	-ve	Total	Range	+ve	-ve	Total	Range	+ve	-ve	Total	Range
Days to flowering	6	4	10	-8.29 to 45.23	4	7	11	-29.46 to 6.70	5	4	9	-27.18 to 10.15
Days to Maturity	4	6	10	-25.51 to 30.04	3	6	9	-21.15 to 4.81	5	4	9	-19.35 to 7.21
Plant Height (cm)	3	-	3	-17.18 to 33.91	6	-	6	-12.92 to 26.50	3	-	3	-17.18 to 20.32
No. Of Leaves per plant	-	-	-	-8.78 to 11.05	-	-	-	-6.48 to 11.03	-	-	-	-8.80 to 8.27
Stem Girth (mm)	5	-	5	-8.27 to 57.31	-	1	1	-19.26 to 7.90	-	-	-	-12.08 to 17.49
Leaf Length (cm)	1	3	4	-15.83 to 19.50	2	-	2	-11.83 to 23.00	1	-	1	-13.64 to 20.48
Leaf Width (cm)	1	-	1	-13.19 to 25.69	2	-	2	3.70 to 33.22	1	-	-	-6.52 to 20.08
Leaf : Stem ratio	1	5	6	-41.46 to 47.92	7	1	8	-27.95 to 82.05	10	-	10	-14.85 to 115.15
Grain Yield per plant (g)	1	1	2	-19.18 to 61.20	1	-	1	-8.99 to 89.19	1	7	8	-22.43 to 61.26
Green Fodder yield per plant (g)	2	3	5	-25.54 to 45.63	-	9	9	-49.66 to 13.28	3	1	4	-28.91 to 59.96
Dry Fodder Yield per plant (g)	2	3	5	-26.60 to 46.50	-	11	11	-53.65 to 9.19	2	1	3	-29.69 to 62.12
Protein content	1	4	5	-32.03 to 18.10	7	-	7	-13.88 to 32.83	11	-	11	-1.33 to 52.19
Brix value	1	4	5	-37.50 to 14.37	12	-	12	-3.89 to 70.38	9	-	9	-13.01 to 54.21

TABLE 4
Comparative study of heterotic crosses in sorghum for fodder yield per plant with other components.

S. No.	Hybrids (F_1's)	Heterosis over		Useful and significant heterobeltiosis/standard heterosis for components
		Better parent	Standard parent GJ 43	
Green fodder yield/plant				
1	GFS 4 × UTFS 91	45.63** (548.13)	59.96**	LW, LSR, DFY, PC and BR.
2	PSVGS 313 × UTFS 91	24.00* (466.73)	36.20**	LSR, DFY, PC and BR.
Dry fodder yield/plant				
1	GFS 4 × UTFS 91	46.50** (172.27)	62.12**	LW, LSR, DFY, PC and BR.
2	PSVGS 313 × UTFS 91	24.47* (146.36)	34.74**	LSR, GFY, PC and BR.

*P≤0.05, **P≤0.01.
Figure in the parentheses indicated mean performance.
Where :

LW	:	Leaf width (cm)	DFY	:	Dry fodder yield per plant (g)
LSR	:	Leaf : stem ratio	PC	:	Protein content (%)
GFY	:	Green fodder yield per plant (g)	BR	:	Brix value

ratio, dry fodder yield per plant, Protein content and Brix value.

CONCLUSION

The analysis of variance revealed significant differences due to genotypes for all the traits under study. This supports that parents and their hybrids under investigation possessed a sufficiently high amount of genetic variability. The mean performance of parents revealed that the parent CSV 21F was top ranking for green fodder yield per plant and dry fodder yield per plant. The parent GFS 4 was found batter for days to flowering, days to maturity, stem girth and protein content. A comparative study of best heterotic hybrid, GFS4 × UTFS 91 and PSVGS 313 × UTFS 91 for green fodder yield per plant and dry fodder yield per plant manifested significant positive heterosis over both better parent and standard check.

TABLE 5

The top three ranking parents their F1 hybrids with respect to mean performance and heterosis over better parent and check CSV 32F and GJ 43

Traits	Best performing parents	Best performing hybrids	Heterosis over		
			Better parent	Standard check	
				CSV 32F	GJ 43
Days to flowering	GFS 4	GFS 4 × UTFS 91	0.64	-29.46**	-27.18**
	GJ 43	GJ 43 × UTFS 91	-7.83**	-10.71**	-7.83**
	Malwan	GFS 4 × PSVGS 313	-7.36**	-4.47**	-1.38
Days to maturity	GFS 4	GFS 4 × UTFS 91	-1.23	-21.15**	-19.35**
	GJ 43	GJ 43 × UTFS 91	-5.90**	-8.01**	-5.90**
	PSVGS 313	GFS 4 × PSVGS 313	-5.58**	-7.69**	-5.58**
Plant height (cm)	Malwan	Malwan × PSVGS 313	33.91**	20.15*	14.27
	GJ 43	Malwan × UTFS 91	20.74**	24.90*	18.79*
	CSV 21F	CSV 21F × UTFS 91	17.15	26.5	20.32**
No. of leaves/plant	Malwan	GFS 4 × UTFS 91	11	11.03	8.27
	CSV 21F	Malwan × PSVGS 313	1.87	9.03	6.32
	GJ 43	CSV 21F × GFS 4	-	-	-
Stem girth (mm)	GFS 4	CSV 21F × UTFS 91	-8.27	-15.76	-8.27
	Malwan	Malwan × GFS 4	-7.78	-19.26*	-12.08
	CSV 21F	GJ 43 × PSVGS 313	-	-	-
Leaf length (cm)	PSVGS 313	CSV 21F × UTFS 91	19.50**	23.00**	20.48**
	GJ 43	CSV 21F × PSVGS 313	4.11	6.29	4.11
	CSV 21F	Malwan × GJ 43	-	-	-
Leaf width (cm)	UTFS 91	GFS 4 × UTFS 91	5.99	33.22**	20.08*
	GJ 43	CSV 21F × PSVGS 313	8.17	19.93	8.11
	PSVGS 313	GFS 4 × PSVGS 313, PSVGS 313 × UTFS 91	-	-	-
Leaf : stem ratio	UTFS 91	Malwan × GFS 4	47.92**	82.05**	115.15**
	Malwan, GFS 4	Malwan × GJ 43, Malwan × UTFS 91	10.42	35.90**	60.61**
	PSVGS 313	Malwan × PSVGS 313, GFS 4 × UTFS 91	-	-	-
Grain yield/plant (g)	GJ 43	GJ 43 × PSVGS 313	61.20**	89.19**	61.26**
	PSVGS 313	GJ 43 × UTFS 91	10.06	6.34	-9.36**
	UTFS 91	GJ 43 × GFS 4	-	-	-
Green fodder yield/plant (g)	CSV 21F	GFS 4 × UTFS 91	45.63**	13.28	59.96**
	UTFS 91	PSVGS 313 × UTFS 91	14.77	-18.72*	14.77*
	PSVGS 313	CSV 21F × GFS 4	24.00*	-3.54	36.20**
Dry fodder yield/plant (g)	CSV 21F	GFS 4 × UTFS 91	46.50**	6.88	62.12**
	UTFS 91	PSVGS 313 × UTFS 91	14.78	-24.33**	14.78
	PSVGS 313	CSV 21F × GFS 4	24.47*	9.19	37.74**
Crude protein content (%)	GFS 4	Malwan × GFS 4	9.55	28.22**	46.90**
	CSV 21F	Malwan × PSVGS 313	18.10*	29.93**	48.86**
	PSVGS 313	GFS 4 × UTFS 91	-4.55	11.72	28.00**
Brix value	UTFS 91	Malwan × PSVGS 313	14.37**	70.38**	54.21**
	GFS 4	Malwan × GJ 43	0.28	54.22	39.58**
	Malwan	PSVGS 313 × UTFS 91	3.11	59.46**	44.33**

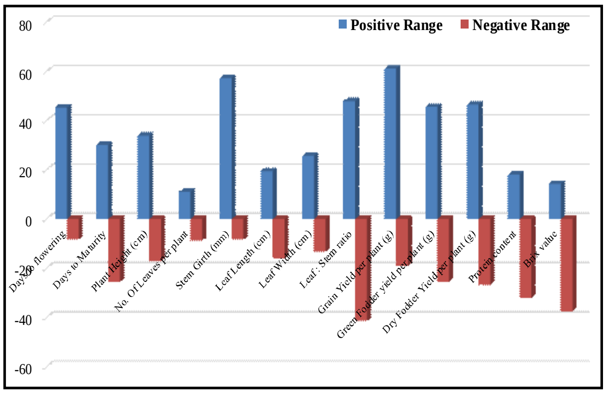

Fig. 1. Range of heterosis over better parent in sorghum.

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