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ELUCIDATION OF MEAN PERFORMANCE AND RANGE OF HETEROSIS OF FODDER YIELD AND ITS ATTRIBUTES TRAITS IN SORGHUM [*SORGHUM BICOLOR* (L.) MOENCH]

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SUMMARY

The present investigation was undertaken to reveal mean performance and percent heterosis level in sorghum [*Sorghum bicolor* (L.) Moench]. The 15 (F_1) hybrids were produced using a half-diallel fashion. Analysis of the *per se* performances of the parents and their hybrid offspring for various traits demonstrated that Malwan and IS 3338 among the parents and CSV 46F × IS 3338, IS 3265 × Malwan and CSV 46F × IS 3284 among the hybrids showed improved mean performance for the green fodder yield per plant, the dry fodder yield per plant and some of the traits that are associated with yield. The analysis of variance revealed highly significant differences due to genotypes for all the investigated traits, which explained why appropriate amounts of heterosis were represented in crosses for many of the traits that contribute to forage yield. Studies on heterosis demonstrated that the following factors were crucial forage yield components: total plant height (cm), number of leaf per plant, stem diameter (mm), leaf length of blade (cm), leaf width of blade (cm), leaf: stem ratio, green fodder yield per plant (g), and dry fodder yield per plant (g). Numerous hybrids were observed to have significant heterobeltiosis and standard heterosis for various component traits. The F_1 hybrids, CSV 46F × IS 3338 (74.08 & 208.13 %), CSV 46F × IS 3284 (152.40 & 152.41 %) and IS 3314 × IS 3284 (145.58 & 25.20 %) manifested significant and positive heterosis over better parent and the standard check CSV 46F for green fodder yield per plant. While CSV 46F × IS 3284, IS 3314 × IS 3284 and CSV 46F × IS 3338 registered highly significant and positive heterotic effects in terms of heterobeltiosis (*i.e.*, 144.10, 104.36 and 83.06 %) and standard heterosis over check CSV 46F (*i.e.*, 144.11, 20.98 and 179.54 %) for dry fodder yield per plant, respectively.

Key words: Mean performance, forage yield, heterobeltiosis and standard heterosis

After wheat, rice, maize, and barley, sorghum [*Sorghum bicolor* (L.) Moench] is the fifth-most important crop in the world. It is an often-cross-pollinated crop, with an average natural cross-pollination rate of six percent. In low-rainfall regions of India, sorghum is a significant kharif crop that serves as a primary source of food for the needy and animal fodder. It is a crop that can be eaten and provides healthy animal feed. There is a significant requirement for green and dry fodder in semi-arid and arid regions, particularly during the short winter and summer seasons. With chromosome number 2n = 2x = 20, it belongs to the *Poaceae* (*Gramineae*) family. The word sorghum is derived from Latin word "sorgo" which means rising above i.e., Growing taller. In India, sorghum is most commonly known as "*Jowar*". Sorghum is a C_4 plant with greater photosynthetic efficiency and greater tolerance to abiotic stress (Reddy *et al.*, 2009).

Sorghum may be seen as one of the crops best suited to future climate change due to its ability to adapt to drought, salinity and high temperatures (ICRISAT, 2015). 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. Depending on their morphology or end-use, different races or cultivars of S. bicolor may be described as fodder sorghum, grain sorghum or sweet sorghum.

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*., IS 3265, CSV 46F, IS 3338, IS 3314, IS 3284, Malwan, including check CSV 46F) and their 15 half-diallel crosses. The seeds of 15 F_1 hybrids were produced during summer 2022 at Center for Millets Research, S. D. Agricultural University, Deesa by manual emasculation and crossing. The seeds of parental lines were maintained through selfing. A set of 21 genotypes comprising of six parents (including check CSV 46F) and their 15 F_1 hybrids were sown in Randomized Block Design (RBD) with three replications, during *Kharif* 2022. Each entry was sown in 2.0 m length with 30 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 from June to October 2022. The observations were recorded on five randomly selected plants from each genotype in each replication for all the mentioned characters except days to flowering were recorded on a plot basis. The dry fodder yield measured after leaves including leaf sheath and stem were chopped after dried at 100ºC for 48 hours in hot air oven. The data were recorded for all the entries in each replication.

Based on mean data, the analysis of variance (ANOVA) was carried out as per the method suggested by Snedecor and Cochran (1967) and reviewed by Panse and Sukhatme (1985). The per cent heterosis was estimated as increase or decrease in the mean value of F_1 hybrid over better parent, *i.e.,* heterobeltiosis (Fonesca and Patterson, 1968) and over standard check, *i.e.,* Standard heterosis (Meredith and Bridge, 1972) for each character.

Heterobeltiosis was measured in percentage by using the following formula

$$\text{Heterobeltiosis (\%)} = \frac{F_1 - BP}{BP} \times 100$$

The standard heterosis was measured in percentage by using the following formula

$$\text{Standard heterosis (\%)} = \frac{F_1 - SC}{SC} \times 100$$

Where,
BP = Mean performance of better parent
SC = Mean performance of standard check *i.e.*, CSV 46F, and
F_1 = Mean value of F_1.

The significance of the heterosis value was tested using ‘t’ test

$$t = \frac{F_1 - \text{BP OR SC}}{\text{Standard error of heterosis over BP of SC}}$$

Calculated ‘t’ value was compared with table’t’ values at error degree of freedom for test of significance.

The heterosis can be classified as low, moderate and high based on estimates. The level of heterosis varies from character to character. In the present study following criteria was used to classify heterosis level, *i.e.,* low, moderate and high.

Lowest range = X + lowest value,
Moderate range = 2X + lowest value, and
High range = 3X + lowest value (rest upper).

Where,
X= Mean value obtained by total range value divided by three

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 character studies. This supports that the parents and their hybrids studied possessed a sufficiently high amount of genetic variability. Further, partitioning of the mean sum of squares due to genotypes implied that the differences among parents were significant for all the characters. The significant differences among parents showed greater diversity in the parental lines. In the case of hybrids, significant differences were found for all the characters except the leaf length of blade, indicating the varying performance of cross combinations. The mean sum of squares due to parents *Vs* hybrids were significant for all the characters exclusive of days to flowering, total soluble solids, crude protein content in dry fodder, which explained the sufficient amount of heterosis was reflected in crosses due to yield attributing traits.

The *per se* performance of parents and hybrids for yields and their traits is presented in (Table 2).

TABLE 1

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

Sources of Variation	d. f.	Days to flowering	Total plant height	No. of leaf/ plant	Stem diameter	Leaf length of blade	Leaf width of blade	Leaf: stem ratio	Green fodder yield/plant	Dry fodder yield/plant	Total soluble solids	Crude protein content in dry fodder
Replications	2	1.86	902.40	12.25	7.58	17.98	1.83	0.001	2772.90	219.16	3.41	0.55
Genotypes	20	346.98**	4356.77**	23.57**	28.52**	146.30**	5.55**	0.006**	134037.90**	13124.20**	9.13**	11.37**
Parents	5	356.66**	7363.03**	12.92*	46.88**	229.09**	10.56**	0.003**	143658.10**	13235.20**	7.98*	9.00**
Hybrids	14	368.27**	1890.08**	22.14**	16.80**	61.82	3.54**	0.006**	119335.00**	11703.40**	9.87**	12.95**
Parents Vs Hybrids	1	0.51	23859.06**	96.84**	100.89**	915.14**	8.56**	0.030**	291776.70**	32460.60**	4.57	1.12
Error	40	6.86	475.11	4.20	4.96	58.33	0.57	0.00013	2011.87	241.44	2.28	0.41

*P 0.05, **P 0.01.

None of the parents shows consistently good performance for all the traits. Considering the primary breeding objectives, *i.e.,* high yielding, earliness and quality parameters, the parental genotype Malwan was rewarded higher green fodder yield per plant and dry fodder yield per plant. The parent IS 3314 was earliest, with minimum stem diameter and highest crude protein content in dry fodder. The parent IS 3338 was found superior for total plant height and leaf length of blade. The parent CSV 46F was found superior for leaf: stem ratio and total soluble solids. The mean performance of hybrids (Table.2) disclosed that none of the hybrids were found superior for all the characters under study. In the case of hybrids, the crosses CSV 46F × IS 3338, CSV 46F × IS 3284 and IS 3265 × Malwan was exhibited its superiority for green fodder yield per plant and dry fodder yield per plant. On the other hand, the hybrid IS 3314 × Malwan showed better mean performance for total plant height and the number of leaves per plant. The hybrids IS 3265 × IS 3284, IS 3265 × CSV 46F, IS 3338 × Malwan and IS 3314 × IS 3284 were found better for stem diameter, leaf length of blade, leaf width of the blade and crude protein content in dry fodder, respectively. The cross combination IS 3265 × IS 3338 and IS 3265 × IS 3314 took a minimum day to attain flowering. The

TABLE 2

Mean performance of the parents and their F1 hybrids for various traits in sorghum

S. No.	Parents/hybrids	Days to flowering	Total plant height	No. of leaf/ plant	Stem diameter	Leaf length of blade	Leaf width of blade	Leaf: stem ratio	Green fodder yield/plant	Dry fodder yield/plant	Total soluble solids	Crude protein content in dry fodder
	Parents											
1.	IS 3265	69.00	207.33	14.00	8.26	77.91	4.93	0.223	357.83	113.18	9.85	8.40
2.	CSV 46F (Check)	80.66	206.16	14.16	7.39	59.48	5.83	0.257	281.16	99.50	14.18	7.49
3.	IS 3338	73.33	296.50	13.16	10.78	85.60	6.50	0.176	497.66	151.93	11.71	9.26
4.	IS 3314	57.00	179.66	10.66	4.31	71.40	3.36	0.237	99.33	45.06	12.80	11.41
5.	IS 3284	74.66	186.66	11.00	5.98	69.60	3.65	0.272	143.33	58.90	14.05	9.98
6.	Malwan	89.33	279.16	15.83	15.43	71.29	8.36	0.226	678.00	226.43	13.15	6.63
	F_1 hybrids											
7.	IS 3265 × CSV 46F	65.33	294.33	17.00	12.80	89.58	6.53	0.158	421.33	197.00	12.26	4.92
8.	IS 3265 × IS 3338	57.00	291.16	13.16	12.19	77.68	6.55	0.247	310.16	110.58	15.45	8.97
9.	IS 3265 × IS 3314	57.00	256.50	11.83	8.42	76.35	5.10	0.270	249.66	92.25	15.91	9.73
10.	IS 3265 × IS 3284	74.00	236.17	12.83	6.85	76.26	4.70	0.141	222.50	84.20	12.51	8.85
11.	IS 3265 × Malwan	93.66	296.67	19.33	14.73	83.20	7.66	0.151	742.00	250.16	11.16	7.88
12.	CSV 46F × IS 3338	76.33	295.17	16.16	13.86	85.11	6.81	0.152	866.33	278.13	13.20	7.67
13.	CSV 46F × IS 3314	76.00	265.50	16.00	10.64	75.31	6.68	0.225	431.16	160.51	14.36	8.55
14.	CSV 46F × IS 3284	76.66	257.17	19.00	11.98	86.73	6.10	0.174	709.66	242.88	12.60	7.79
15.	CSV 46F × Malwan	83.66	254.83	15.66	12.06	80.21	7.40	0.159	522.16	128.31	13.61	8.07
16.	IS 3338 × IS 3314	71.66	270.33	15.00	9.98	81.83	5.11	0.150	452.83	158.15	15.60	12.86
17.	IS 3338 × IS 3284	62.33	235.17	13.33	12.38	77.73	5.86	0.213	288.66	97.13	12.58	10.73
18.	IS 3338 × Malwan	87.67	292.50	18.66	15.36	84.51	8.45	0.144	686.66	217.75	9.16	10.10
19.	IS 3314 × IS 3284	66.33	244.17	13.33	8.51	85.46	4.80	0.219	352.00	120.36	13.83	13.34
20.	IS 3314 × Malwan	78.67	306.67	21.16	12.09	78.63	5.65	0.213	476.16	148.33	14.33	9.04
21.	IS 3284 × Malwan	86.67	255.83	17.83	10.56	76.20	6.43	0.140	671.66	205.46	11.76	8.83
	Parental mean	74.00	225.91	13.13	8.69	72.54	5.44	0.231	342.88	115.83	12.62	8.86
	F_1 hybrids mean	74.20	270.14	16.02	11.50	80.99	6.25	0.184	493.53	166.08	13.22	9.15
	General mean	74.14	257.50	15.19	10.69	78.57	6.02	0.198	450.49	151.72	13.05	9.07
	Range (overall)	57.00 to 93.66	179.66 to 306.67	10.66 to 20.16	4.31 to 15.43	59.48 to 89.58	3.36 to 8.45	0.140 to 0.272	99.33 to 866.33	45.06 to 278.13	9.16 to 15.91	4.92 to 13.34
	S. Em±	1.51	12.91	1.15	1.29	4.41	0.42	0.01	25.89	8.97	0.87	0.37
	C. D. (P=0.05)	4.32	36.91	3.29	3.69	12.61	1.19	0.02	74.01	25.64	2.50	1.05
	C.V.%	3.53	8.68	13.13	16.26	9.72	11.96	6.31	9.95	10.24	11.59	7.02

TABLE 3

Number of (F_1) hybrids depicted significant heterotic effect in forage sorghum

Characters	Over better parent				Over standard check (CSV 46F)			
	+ve	-ve	Total	Range	+ve	-ve	Total	Range
Days to flowering	8	3	11	-17.39 to 38.01	3	10	13	-29.33 to 16.13
Total plant height	7	1	8	-20.68 to 41.96	15	0	15	14.07 to 48.75
Number of leaf/plant	6	0	6	-15.50 to 34.18	6	1	7	-16.48 to 49.42
Stem diameter	13	0	13	14.74 to 180.51	11	0	11	-7.10 to 108.18
Leaf length of blade	4	0	4	-9.25 to 21.65	15	0	15	26.62 to 50.61
Leaf width of blade	2	5	7	-32.41 to 31.50	5	2	7	-19.43 to 44.86
Leaf: stem ratio	2	13	15	-48.16 to 13.92	0	13	13	-45.38 to 4.94
Green fodder yield/plant	6	6	12	-42.00 to 152.40	11	1	12	-20.87 to 208.13
Dry fodder yield/plant	6	7	13	-43.33 to 144.10	11	0	11	-15.38 to 179.54
Total soluble solids	3	4	7	-30.29 to 31.86	0	4	4	-35.38 to 12.23
Crude protein content in dry fodder	4	8	12	-41.40 to 16.94	10	1	11	-34.23 to 78.20

TABLE 4

Comparative study of heterotic crosses in sorghum for green fodder yield per plant and dry fodder yield per plant with other components

S. No.	Heterotic crosses	Heterosis over		Desired and significant heterobeltiosis and/or standard heterosis registered in component traits
		Better parent	Standard check	
Green fodder yield per plant with other component traits				
1.	IS 3314 × IS 3284	145.58** (352.00)	25.20**	DF, PH, NOL, LLB, LWB, DFY
2.	CSV 46F × IS 3284	152.40** (709.66)	152.41**	DF, PH, NOL, LLB, DFY
3.	CSV 46F × IS 3338	74.08** (866.33)	208.13**	DF, PH, LLB, LWB, DFY
Dry fodder yield per plant with other component traits				
1.	CSV 46F × IS 3284	144.10** (242.88)	144.11**	DF, PH, NOL, LLB, GFY
2.	CSV46F × IS 3314	61.32** (160.51)	61.33**	DF, PH, LLB, LWB, GFY, CPDF
3.	IS 3265 × CSV 46F	74.05** (197.00)	97.99**	DF, PH, NOL, LLB, GFY

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

Where,

DF	:	Days to flowering	LWB	:	Leaf width of blade
PH	:	Total plant height	GFY	:	Green fodder yield per plant
NOL	:	Number of leaf per plant	DFY	:	Dry fodder yield per plant
LLB	:	Leaf length of blade	CPDF	:	Crude protein content in dry fodder

cross IS 3265 × IS 3314 was superior for total soluble solids.

In practical plant breeding, the heterosis measured over better parent and popular cultivar is more realistic and is of more practical importance. Hence in the present study, the heterosis was measured over better parent (Fig. 1) and standard checks (Fig. 2), *i.*e., CSV 46F (Table 3). In the present study, out of 15 hybrids, six and eleven hybrids registered significant and positive heterosis over the better parent and the standard check CSV 46F for green fodder yield per plant, respectively. The wide range of heterosis over better parent and the standard checks was recorded, *i.e.*, -42.00 to 152.40 percent over the better parent (heterobeltiosis), -20.87 to 208.13 percent over CSV 46F for green fodder yield per plant. The hybrids CSV 46F × IS 3338 (74.08 & 208.13 %), CSV 46F × IS 3284 (152.40 & 152.41 %) and IS 3314 × IS 3284 (145.58 & 25.20 %) manifested significant and positive heterosis is over better parent and the standard check CSV 46F for green fodder yield per plant. The positive and significant heterotic values were also reported by Prakash *et al.* (2010), Pandey and Shrotria (2012), Naik *et al.* (2018), Soujanya *et al.* (2018), Patel *et al.* (2018[a]), Patel *et al.* (2018[b]), Rathod *et al.* (2020) and Patel *et al.* (2020) and Chudasama *et al.* (2022) for green fodder yield per plant.

In the case of dry fodder yield per plant out of 15 hybrids, six and eleven hybrids evinced

TABLE 5A

The overall picture of heterosis level in promising heterotic crosses of sorghum for yield (i.e. green & dry fodder) and its attributes with better parent

S. No.	Hybrids	DF	PH	NOL	SD	LLB	LWB	LSR	GFY	DFY	TSS	CPDF
1.	IS 3265 × Malwan	Moderate	Moderate	High	High	Moderate	Moderate	Low	Low	Low	Low	Moderate
2.	CSV 46F × IS 3338	High	Low	Moderate	Moderate	Low	Moderate	Low	Moderate	High	Moderate	Moderate
3.	CSV 46F × IS 3284	High	High	High	Moderate	High	Low	Low	High	High	Low	Moderate
4.	IS 3338 × IS 3314	Moderate	Low	Moderate	Moderate	Low	Low	Low	Low	Low	High	High
5.	IS 3314 × IS 3284	High	High	High	Moderate	High	High	Moderate	High	High	Moderate	High
6.	IS 3284 × Malwan	High	Low	Moderate	High	Moderate	Low	Low	Low	Low	Low	Moderate

TABLE 5B

The overall picture of heterosis level in promising heterotic crosses of sorghum for yield (i.e. green & dry fodder) and its attributes with standard parent

S. No.	Hybrids	DF	PH	NOL	SD	LLB	LWB	LSR	GFY	DFY	TSS	CPDF
1.	IS 3265 × Malwan	Low	Moderate	High	Moderate	Low	High	Low	High	High	Low	Moderate
2.	CSV 46F × IS 3338	High	Moderate	Moderate	Moderate	Low	Moderate	Low	High	High	Moderate	Low
3.	CSV 46F × IS 3284	High	Low	High	High	Low	Moderate	Low	High	High	Moderate	Moderate
4.	IS 3338 × IS 3314	High	Low	Moderate	High	Low	Low	Low	Moderate	Moderate	High	High
5.	IS 3314 × IS 3284	High	Low	Low	High	Low	Low	Moderate	Low	Low	High	High
6.	IS 3284 × Malwan	Moderate	Low	Moderate	High	Low	Moderate	Low	High	Moderate	Moderate	Moderate

Where,

DF	:	Days to flowering	LSR	:	Leaf : stem ratio
PH	:	Total plant height	GFY	:	Green fodder yield per plant
NOL	:	Number of leaf per plant	DFY	:	Dry fodder yield per plant
SD	:	Stem diameter	TSS	:	Total soluble solids
LLB	:	Leaf length of blade	CPDF	:	Crude protein content in dry fodder
LWB	:	Leaf width of blade			

significant and positive heterosis over the better parent, standard check CSV 46F, respectively. The wide spectrum of heterobeltiosis and standard heterosis was recorded, *i.e.,* -43.33 to 144.10 percent (heterobeltiosis), -15.38 to 179.54 per cent over check CSV 46F. Top three hybrids CSV 46F × IS 3284, IS 3314 × IS 3284 and CSV 46F × IS 3338 registered highly significant and positive heterotic effects in terms of heterobeltiosis (*i.e*., 144.10, 104.36 and 83.06 %) and standard heterosis over check CSV 46F (*i.e*., 144.11, 20.98 and 179.54 %) for dry fodder yield per plant. The wide range of heterobeltiosis and standard heterosis for dry fodder yield was also reported earlier by More *et al*. (2016), Naik *et al.* (2018), Soujanya *et al.* (2018), Patel *et al.* (2018[a]), Patel *et al.* (2018[b]), Patel *et al.* (2020), Rathod *et al.* (2020), Joshi *et al.*(2021) and Chudasama *et al.* (2022).

A comparative study of the best heterotic hybrid revealed that CSV 46F × IS 3338, CSV 46F × IS 3284, and IS 3314 × IS 3284 for green fodder yield per plant where, crosses CSV 46F × IS 3284, CSV 46F × IS 3314 and IS 3265 × CSV 46F for dry fodder yield per plant revealed significant positive heterosis over both better parent and standard checks. These hybrids also showed significant and positive heterosis over better parent or combination of standard check for various component characters *viz*., days to flowering, total plant height, number of leaves per plant, stem diameter, leaf length of blade and leaf width of blade (Table 4). The results revealed that the extent of heterosis varied from the cross to cross for all the traits. For any one trait, certain hybrids expressed considerable high heterosis, while it was low in other hybrids, suggesting that the selection of parents has an important bearing on the performance of any hybrid. The superiority of hybrids over better parents indicates the parental combinations ability to throw high levels of transgressive segregation (Fonseca and Patterson, 1968). Such hybrids might be exploited as a basic material for breeding purposes (Table 5a) and (Table 5b).

The analysis of variance revealed significant differences among the parents for all traits. This indicated a sufficient variability in the parents for all the traits. The parental genotype Malwan was rewarded higher green fodder yield per plant and dry fodder yield per plant, also performed considerably good for total plant height and number of leaf per plant. The parent CSV 46F was found superior for leaf: stem ratio and total soluble solids. It stood second for number of leaf per plant and leaf: stem ratio. The parent IS 3338 was found superior for total plant height and leaf length of blade. The parent IS 3314 was earliest, minimum stem diameter and highest crude protein content in dry fodder.

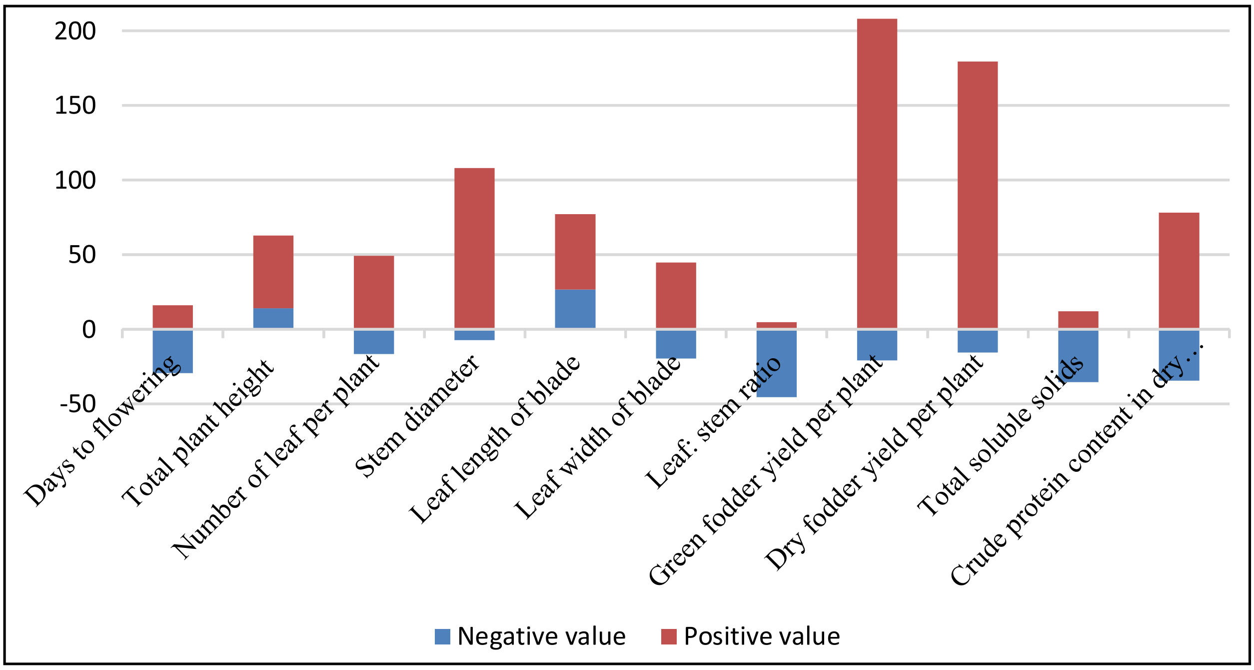

Fig. 1. The extent of heterobeltiosis in forage sorghum.

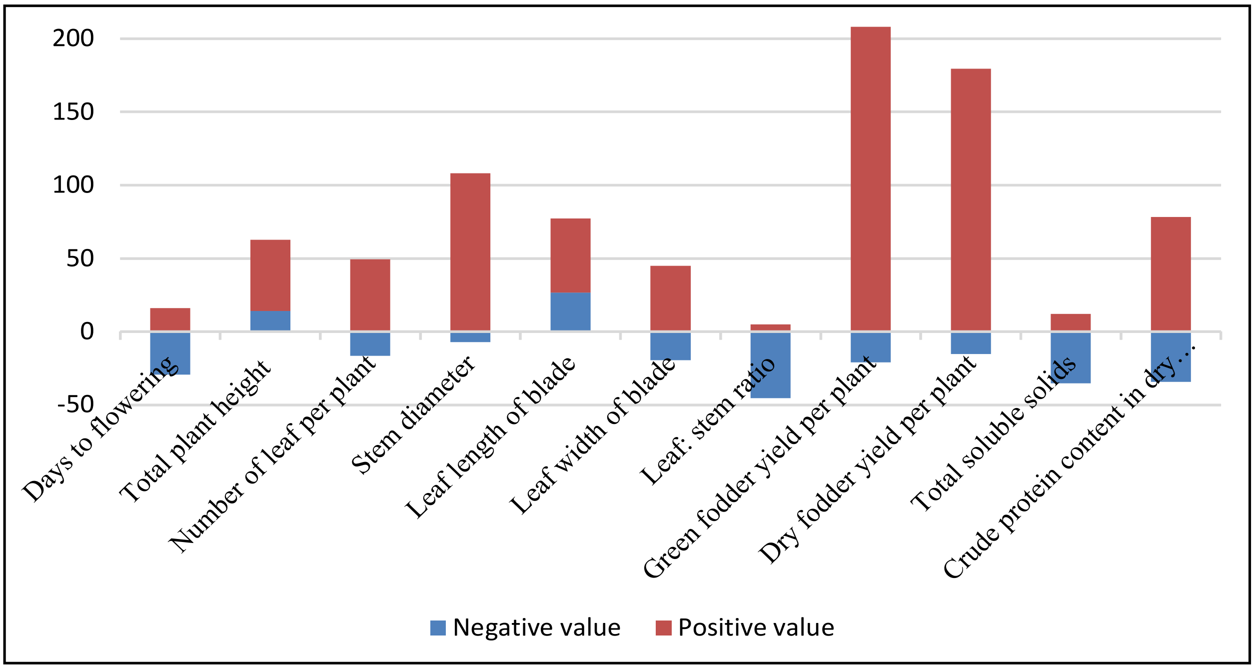

Fig. 2. The extent of standard heterosis over check CSV 46F.

CONCLUSION

The analysis of variance revealed significant differences due to genotypes for all the traits under study. This supports that the parents and their hybrids under investigation possessed a sufficiently high genetic variability. The mean performance of parents revealed that the parent Malwan was top ranking for green fodder yield per plant and dry fodder yield per plant. The parent IS 3314 was found earliest, with minimum stem diameter and highest crude protein content in dry fodder. A comparative study of best heterotic hybrid, CSV 46F × IS 3338, CSV 46F × IS 3284 and IS 3265 × Malwan for green fodder yield per plant and dry fodder yield per plant manifested significant positive heterosis over both better parent and standard check.

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