International Journal of Statistics and Applied Mathematics 2023; SP-8(5): 895-900

International Journal of Statistics and Applied Mathematics

ISSN: 2456-1452
Maths 2023; SP-8(5): 895-900

https://www.mathsjournal.com
Received: 25-06-2023
Accepted: 20-08-2023

Mayank Chaudhary
Department of Genetics & Plant Breeding, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, Uttar Pradesh, India

Rohit Maurya
SMS Horticulture (Vegetable Science) KVK Turki, Muzaffarpur, DRPCAU, Pusa. Samastipur, Bihar., India

Corresponding Author:
Mayank Chaudhary
Department of Genetics & Plant Breeding, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, Uttar Pradesh, India

Heterosis studies for yield and yield components in forage sorghum (*Sorghum bicolor* L. Moench)

Mayank Chaudhary and Rohit Maurya

Abstract
The present was carried out the genetic analysis of breeding material through heterosis among yield and it components in parents and F1's hybrids. Ten diverse parents i.e., UP Chari-1, HC-308, UP Chari-2, HC-171, Pant Chari-8, CSV-17, Pant Chari-6, CSV-84, Pant Chari-5 and Rajasthan Chari-1, germplasm selected from SVPUA&T, Meerut, U.P. Ten parents diallel set excluding reciprocals was made during the season of kharif 2018 by raising the crop at Crop Research Centre of Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut. All the 45 crosses and their ten parents were grown during kharif season 2019. All the 45 F1's hybrids along with ten parents were sown in randomized block design with three replications. Observations were recorded on days to 50% flowering, plant height, leaf breadth, leaf length, stem girth, leaves per plant, leaf area, leaf stem ratio, total soluble solids and green fodder yield. The manifestation of high degree of heterosis over better and mid parent in certain cross combinations revealed the UP Chari-1 x HC-308, UP Chari-2 x CSV-17, UP Chari-2 x Pant Chari-5, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1, suggested that great possibility to produce higher fodder yield varieties/genotype under study. On the basis of overall findings and per se performance the manifestation of high degree of heterosis over better and mid parent in certain cross combinations i.e., UP Chari-1 x HC-308, UP Chari-2 x CSV-17, UP Chari-2 x Pant Chari-5, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1, suggested that great possibility to produce higher fodder yield varieties/genotypes.

Keywords: Sorghum, heterosis

Introduction

Sorghum [*Sorghum bicolor* (L) Moench] is an often-cross-pollinating crop with a genome, about 25 per cent the size of maize or sugarcane and having diploid (2n = 2x = 20) chromosomes. It is a C_4 plant with higher photosynthetic efficiency and higher tolerance to abiotic stress (1) and (2). It is the third most important food grain crop in India, next to rice and wheat. The importance of sorghum as a forage crop is growing in many regions of the world due to its high productivity and ability to utilize efficiently water even under drought conditions. It is highly palatable and digestible than maize and pearl millet as for as the nutritional quality is concerned. It produces a tonnage of dry matter having digestible nutrients (50%), crude protein (8%), fat (2.5%) and nitrogen free extracts (45%). The farmers have a preference for sorghum as it can be utilized for different purposes like fresh fodder, hay and silage and grows well in hot and dry climate. It has quick growth habit, quick recovery or regeneration after cutting or grazing and its ability to provide highly palatable and nutritious fodder for cattle. As green fodder it is one of the cheapest sources of feed for milch, meat and draft animals.

Considering the importance of sorghum as a fodder crop in northern part of India, scientists (Dangi and Paroda, 1978) [21] have reported high amount of heterosis for fodder yield and advocated the possibility of economic exploitation of heterosis through the use of male sterile lines. Hence it is necessary to understand the genetic nature of the parents. General combining ability is average performance of a genotype in cross combinations involving a set of other genotypes. Specific combining ability is average performance of a specific cross combination expressed as deviation from the population mean. Combining ability analysis helps in selection of suitable parents for hybridization, evaluation of inbreds in terms of their genetic value and identification of superior specific cross combinations (Sprague and Tatum, 1942) [2]. Like green revolution, India is contemplating for white revolution which is possible only with adequate supply of nutritious feeds and fodder. It is well known that the animal industry in any country revolves around sufficient quantity of good quality feed and fodder.

The information on the magnitude and nature of prevalent genetic variation is essentially needed to infer about genetic potential of a particular population. The development of the concept of combining ability helps in choosing the parents for hybridization. Combining ability studies are regarded useful to select good combining parents, which on crossing would produce more desirable segregants. Such studies also elucidate nature and magnitude of gene action in an inheritance of yield and its components, which will decide the breeding programme to be followed in segregating generations.

Before initiating hybridization programme, the selection of suitable parents is one of the most important steps because selection of the parent on the basis of phenotypic performance alone is not a sound procedure since phenotypically superior lines may yield poor hybrids. The lines or parents which produce good progenies on crossing are of immense use to the breeder. This necessitates the testing of parents for their combining ability which in turn will help in identifying the best combiners which may be hybridized either to exploit heterosis or to accumulate desirable genes through selection. For the identification of parents having good potentials to transmit desirable characteristics to their progenies and also to help in sorting out of promising crosses for fodder yield and its related traits, combining ability analysis is powerful tool. The gca is attributed to additive genetic effects which are theoretically fixable. On the other hand, sca attributable to non-additive gene action may be due to dominance, additive x dominance and dominance x dominance or higher order interactions and is unfixable. The presence of non-additive genotypic variance is the primary justification for initiating the hybrid programme **(**Cockerham, 1961) [4]. At the time, it also elucidates the nature of gene action involved in the inheritance of the characters. Sprague and Tatum (1942) [2] proposed the concept of gca and sca as a measure of gene effects. Therefore, the present investigation was undertaken with a view to study the performance of different hybrids, extent of heterosis, combining ability of genotypes (females, males, hybrids and checks together) for thirteen characters through line x tester mating design in fodder sorghum having diverse male sterile lines and pollen fertility restorers.

Materials and Method

The present investigation was conducted during kharif 2018 and 2019 at Crop Research Centre of Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut U.P. The soil of experimental site was sandy loam well drained and had fairly good moisture holding capacity. Ten genotypes of sorghum were studied in this experiment. Ten genotypes consisted five lines namely, UP Chari-1, HC-308, UP Chari-2, HC-171, Pant Chari-8, CSV-17, Pant Chari-6, CSV-84, Pant Chari-5 and Rajasthan Chari-1. These parents were crossed in a line x tester mating design and resultant fourty five hybrids along with their parents were raised in Complete Randomized Block Design with three replications during kharif 2019. Heterosis was assessed over the better parent (Heterobeltiosis), mid parental value (relative heterosis) and standard variety (standard heterosis). Estimations of these three types of heterosis were done for following characters *viz*., days to 50 per-cents flowering, plant height, leaves per plant, leaf breadth, leaf length, leaf area, stem girth, leaf stem ratio, total soluble solids and green fodder. Forty-five hybrids and ten parents were also evaluated to study heterosis analysis.

Results and Discussion

Manifestation of heterosis over better parent Heterosis is amount by which the mean of cross combinations exceed over its better and relative parent. It has been utilized in boosting yield in much self and often cross-pollinated crops, and the main point utilization of hybrid vigour in commercial scale to extent of heterosis and case with which hybrid seed can be produced on a large scale. Different workers have measured the magnitude of heterosis in different ways such as the superiority of F1 over the better parent and mid parent. The extent of heterosis relative parent would be deciding factor in its practical utilization. Heterosis may be high or low depending upon the mean of parent in question. Obviously, there can be possibility of getting a cross with high per se performance but with low heterosis. In case the parental performance is also high. On the contrary, there may be a cross with poor per se performance but high percentage of heterosis. It means that the choice of best cross combination on the basis of high heterosis would not necessarily be one which would give the highest per se performance. The superiority of hybrids particularly over better parent is more useful in determining the feasibility of commercial exploitation of heterosis and also indicating the parental combinations capable of producing the highest level of transgressive segregants. Investigation on degree of heterosis is, however, important as it may be of value in deciding the directions of future breeding programmes.

In the present investigation both heterosis have been worked out. Higher yield is desirable, which is reflected by positive heterosis. Range of heterosis and number of hybrids indicating significant desirable heterosis over mid parent and better parent for per se performance has been given in Table-1.

Thirteen hybrids namely, UP Chari-1 x UP Chari-2, UP Chari-1 x Rajasthan Chari1, HC 308 x UP Chari-2, HC 308 x HC-171, HC 308 x Pant Chari-8, UP Chari-2 x Pant Chari-8, UP Chari-2 x CSV-17, UP Chari-2 x Pant Chari-6, UP Chari-2 x Pant Chari-5, UP Chari-2 x Rajasthan Chari-1, CSV-17 x Pant Chari-5, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1 showed positive and significant heterosis over better parent for desirable late flowering and these cross combinations also exhibited positive and significant heterosis over mid parent for days to flowering while five crosses revealed negative non-significant heterosis over better and mid parent for early flowering. The similar findings were also reported by Premalatha *et al*. (2006) [17], Khapre *et al*. (2007) [11], Prakash *et al*. (2010) [15] and Akabari *et al*. (2012) [2].

In respect of plant height eighteen cross combinations i.e., UP Chari-1 x HC 308, HC 308 x UP Chari-2, HC 308 x HC-171, HC 308 x Pant Chari-8, HC 308 x CSV-17, HC 308 x CSV-84, HC 308 x Pant Chari-5, UP Chari-2 x HC-171, UP Chari-2 x CSV-17, UP Chari-2 x Pant Chari-6, UP Chari-2 x Pant Chari-5, HC-171 x CSV-84, HC-171 x Pant Chari-5, Pant Chari-8 x CSV-17, Pant Chari-8 x CSV-84, CSV-17 x CSV-84, CSV-17 x Rajasthan Chari-1, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1 were found desirable heterosis over better and mid parent for tall stature thereby suggesting possibility to produce taller genotypes/varieties whereas, twelve hybrids had negative and non-significant heterosis over better and mid parent for dwarf stature. Present findings are in agreement with those of Rini *et al*. (2016) [23], Chikuta *et al*. (2017) [24] and Dehinwal *et al*. (2017) [6].

For more leaves per plant, F1 hybrids *viz*., UP Chari-1 x HC 308, UP Chari-1 x UP Chari-2, UP Chari-1 x CSV-17, UP Chari-1 x CSV-84, UP Chari-1 x Pant Chari-5, HC 308 x HC-171, HC 308 x Pant Chari-8, HC 308 x CSV-84, HC 308 x Pant Chari-5, UP Chari-2 x HC-171, UP Chari-2 x Pant Chari-8, UP Chari-2 x CSV-17, UP Chari-2 x Pant Chari-6, UP Chari-2 x Pant Chari-5, CSV-17 x Pant Chari-5, CSV-84 x Pant Chari-5, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1 observed positive significant heterosis over better and mid parent, suggested thereby that it is possible to produce more leaves per plant in forage sorghum while, twelve crosses recorded negative and non-significant heterosis over better and mid parent for this trait. The corroborative findings were also reported by Aaref *et al*. (2016) [1].

The crosses like UP Chari-1 x HC 308, HC 308 x HC-171, HC 308 x Pant Chari-8, UP Chari-2 x Pant Chari-8, UP Chari-2 x CSV-84, UP Chari-2 x Pant Chari-5, Pant Chari6 x Rajasthan Chari-1, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1 noted positive and significant heterosis in order to merit over better and mid parent for leaf breadth while eleven cross combinations recorded negative non-significant heterosis over better and mid parent, out of forty five hybrids for this attribute. These results are in agreement with the finding of Ingle *et al*. (2018) [8], Parmar *et al*. (2019) [14].

F1s hybrids i.e., UP Chari-1 x HC 308, HC 308 x UP Chari-2, HC 308 x HC-171, HC 308 x Pant Chari-8, UP Chari-2 x Pant Chari-8, UP Chari-2 x CSV-17, UP Chari-2 x Pant Chari-5, HC-171 x CSV-84, CSV-17 x CSV-84, CSV-17 x Pant Chari-5, Pant Chari6 x CSV-84, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1 revealed positive significant heterosis over better and mid parent for leaf length while, fifteen hybrids recorded negative and non-significant heterosis over better and mid parent for this character. This study confirmed with those of Jain and Patel (2013) [9], Akabari and Parmar (2014) [2], Mohammed *et al*. (2014) [25].

In leaf area, out of forty five cross combinations only sixteen hybrids showed significant and positive heterosis over better and mid parent. The best sixteen crosses for this trait were UP Chari-1 x HC 308, UP Chari-1 x UP Chari-2, UP Chari-1 x Pant Chari8, HC 308 x UP Chari-2, HC 308 x HC-171, HC 308 x Pant Chari-8, HC 308 x CSV-17, HC 308 x Pant Chari-6, HC 308 x Rajasthan Chari-1, UP Chari-2 x CSV-17, UP Chari-2 x Pant Chari-6, UP Chari-2 x CSV-84, UP Chari-2 x Pant Chari-5, HC-171 x Pant Chari-8, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1. Only thirteen cross combinations exhibited non-significant and negative heterosis over better parent for this character. Similar findings and suggestions were given by Chikuta *et al*. (2017) [24], Pal *et al*. (2017) [13] and Ingle *et al*. (2018) [8].

Positive and significant heterosis over better and mid parent for stem girth was shown by nine hybrids in order of merit were UP Chari-1 x HC 308, UP Chari-1 x HC171, HC 308 x HC-171, HC 308 x Pant Chari-8, HC 308 x Pant Chari-5, UP Chari-2 x CSV-17, UP Chari-2 x Pant Chari-5, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1, whereas eighteen crosses observed negative non significant heterosis over better parent for this character. Similar findings were also reported by earlier researchers namely Parmar *et al*. (2019) [14].

Through twenty seven cross combinations manifested positive significant heterosis superiority over better and mid parent for leaf stem ratio which are follows: UP Chari-1 x HC 308, UP Chari-1 x UP Chari-2, UP Chari-1 x Pant Chari-8, UP Chari-1 x CSV-17, UP Chari-1 x Pant Chari-6, UP Chari-1 x CSV-84, UP Chari-1 x Rajasthan Chari-1, HC 308 x UP Chari-2, HC 308 x HC-171, HC 308 x Pant Chari-8, HC 308 x Pant Chari-5, UP Chari-2 x Pant Chari-8, UP Chari-2 x CSV-17, UP Chari-2 x Pant Chari-6, UP Chari-2 x CSV-84, UP Chari-2 x Pant Chari-5, HC-171 x Pant Chari-8, HC-171 x CSV-17, Pant Chari-8 x Pant Chari-6, Pant Chari-8 x CSV-84, CSV-17 x Pant Chari-5, Pant Chari-6 x CSV-84, Pant Chari-6 x Pant Chari-5, Pant Chari-6 x Rajasthan Chari-1, CSV-84 x Pant Chari-5, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1 while, only five crosses noted negative and non-significant heterosis over better and mid parent for this character. These findings are similar in agreement with earlier reported by Khapre *et al*. (2007) [11], Jain and Patel (2013) [9], Aaref *et al*. (2016) [1].

Heterosis response of total soluble solids ten crosses i.e., UP Chari-1 x HC 308, HC 308 x HC-171, HC 308 x Pant Chari-8, HC 308 x CSV-17, HC 308 x Pant Chari-6, UP Chari-2 x HC-171, HC-171 x CSV-84, CSV-17 x Pant Chari-6 and Pant Chari-6 x Rajasthan Chari-1 revealed positive and significant over better and mid parent for total soluble solids. Twenty hybrids showed negative and non-significant heterosis over better and mid parent for this character.

Maximum magnitude of heterosis and per se performance showed highly significant and positive desirable heterosis over mid and better parent manifested in crosses *viz*., UP Chari-1 x HC-308 for plant height, leaves per plant, leaf breadth, leaf length, leaf area, stem girth, leaf stem ratio, total soluble solids and green fodder yield; UP Chari-1 x HC-171 for stem girth and green fodder yield; UP Chari-1 x CSV-17 for leaves per plant, leaf stem ratio and green fodder yield; UP Chari-1 x Pant Chari-6 for leaf stem ratio and green fodder yield; Pant Chari-5 x Rajasthan Chari-1for days to 50% flowering, leaf stem ratio and green fodder yield; UP Chari-2 x CSV-17 for days to 50% flowering, plant height, leaves per plant, leaf length, leaf area, stem girth, leaf stem ratio and green fodder yield; UP Chari-2 x Pant Chari-5 for days to 50% flowering, plant height, leaves per plant, leaf breadth, leaf length, leaf area, stem girth, leaf stem ratio and green fodder yield; Pant Chari-8 x CSV-84 for plant height, leaf stem ratio and green fodder yield; Pant Chari-8 x Pant Chari-5 for green fodder yield; Pant Chari-6 x Pant Chari-5 for leaf stem ratio and green fodder yield; CSV-84 x Rajasthan Chari-1 for days to 50% flowering, plant height, leaves per plant, leaf breadth, leaf length, leaf area, stem girth, leaf stem ratio and green fodder yield and Pant Chari-5 x Rajasthan Chari-1 for days to 50% flowering, plant height, leaves per plant, leaf breadth, leaf length, leaf area, stem girth, leaf stem ratio and green fodder yield. These results are in general agreement with the finding of Pal *et al*. (2017) [13], Ingle *et al*. (2018) [8], Soujanya *et al*. (2018) [26], Parmar *et al*. (2019) [14].

Table 1: Estimates of heterosis (%) over better parent and mid parent of yield and its components in forage sorghum (*Sorghum bicolor* L. Moench)

S. No.	Parents	Days to 50% flowering		Plant height (cm)		Leaves per plant		Leaf breadth (cm)	
		BP	MP	BP	MP	BP	MP	BP	MP
1	UP Chari-1 x HC 308	7.39	8.36	16.46**	16.56**	10.78**	10.21**	12.27**	12.75**
2	UP Chari-1 x UP Chari-2	10.59**	15.39**	-1.46	-0.62	13.11**	15.36**	-3.95	-0.12
3	UP Chari-1 x HC-171	3.23	5.36	2.46	8.86	-1.62	-1.09	9.12	3.65
4	UP Chari-1 x Pant Chari-8	6.27	7.09	0.58	7.71	1.53	5.01	-0.95	-0.36
5	UP Chari-1 x CSV-17	4.02	4.43	6.30	7.92	17.03**	17.77**	-3.50	-7.34
6	UP Chari-1 x Pant Chari-6	5.36	5.72	4.78	6.23	1.89	1.37	-3.65	-8.31
7	UP Chari-1 x CSV-84	7.00	7.99	1.51	3.04	10.38**	12.70**	-0.98	-0.50
8	UP Chari-1 x Pant Chari-5	-3.41	-5.19	-3.00	-2.15	23.50**	27.89**	-3.66	-7.20
9	UP Chari-1 x Rajasthan Chari-1	10.85**	10.13**	-8.68	-3.26	-8.74	-2.05	4.19	1.17
10	HC 308 x UP Chari-2	13.70**	14.62**	15.40**	16.13**	2.51	1.23	2.75	3.92
11	HC 308 x HC-171	13.23**	14.95**	13.53**	13.29**	19.05**	19.73**	22.83**	24.20**
12	HC 308 x Pant Chari-8	11.18**	11.56**	13.38**	14.04**	12.56**	13.90**	13.67**	16.80**
13	HC 308 x CSV-17	6.02	6.35	11.39**	18.39**	-9.17	-2.80	1.10	7.36
14	HC 308 x Pant Chari-6	-1.95	-2.70	7.96	8.27	-6.13	-3.16	5.50	1.23
15	HC 308 x CSV-84	1.65	2.20	15.34**	16.48**	27.64**	28.57**	0.09	6.24
16	HC 308 x Pant Chari-5	8.17	8.89	17.11**	17.49**	37.44**	42.19**	7.71	2.33
17	HC 308 x Rajasthan Chari-1	1.17	1.19	-7.97	-2.49	0.55	0.84	7.80	1.71
18	UP Chari-2 x HC-171	6.85	6.21	12.23**	12.78**	11.89**	13.55**	6.14	1.70
19	UP Chari-2 x Pant Chari-8	17.35**	18.44**	8.62	9.25	13.53**	14.04**	20.34**	23.76**
20	UP Chari-2 x CSV-17	18.22**	18.28**	15.76**	16.76**	22.71**	27.33**	3.84	5.34
21	UP Chari-2 x Pant Chari-6	13.70**	13.75**	11.39**	12.27**	33.73**	33.01**	1.59	8.39
22	UP Chari-2 x CSV-84	1.83	3.46	6.82	7.38	8.50	4.09	11.41**	12.48**
23	UP Chari-2 x Pant Chari-5	26.94**	26.99**	11.52**	12.27**	16.99**	17.30**	10.52**	11.29**
24	UP Chari-2 x Rajasthan Chari-1	15.07**	16.35**	-6.75	-7.99	-6.01	-4.50	2.09	2.98
25	HC-171 x Pant Chari-8	5.65	4.17	-8.83	-5.83	-1.20	-7.61	7.94	4.45
26	HC-171 x CSV-17	-0.40	-0.60	-9.63	-9.34	-3.10	-3.86	-7.81	-1.35
27	HC-171 x Pant Chari-6	2.82	2.20	2.84	2.88	1.89	8.82	-6.23	1.22
28	HC-171 x CSV-84	0.41	0.61	23.09**	30.68**	1.76	2.33	-8.75	-9.22
29	HC-171 x Pant Chari-5	7.26	7.62	14.36**	13.68**	1.89	6.54	3.79	2.60
30	HC-171 x Rajasthan Chari-1	8.87	8.47	7.75	8.89	-1.81	-3.79	-0.67	-0.82
31	Pant Chari-8 x CSV-17	2.41	2.19	12.60**	13.98**	-8.73	-1.65	2.23	4.15
32	Pant Chari-8 x Pant Chari-6	1.18	1.45	2.24	5.57	0.26	4.19	2.01	7.71
33	Pant Chari-8 x CSV-84	1.65	1.80	21.07**	25.41**	3.06	1.79	1.56	4.71
34	Pant Chari-8 x Pant Chari-5	6.67	6.68	7.62	0.89	1.22	2.78	3.30	3.36
35	Pant Chari-8 x Rajasthan Chari-1	-0.78	-2.50	1.33	3.77	1.67	1.13	9.01	3.44
36	CSV-17 x Pant Chari-6	-2.22	-2.35	-9.02	-5.68	2.18	1.59	3.53	4.51
37	CSV-17 x CSV-84	4.94	4.66	11.54**	17.81**	2.18	2.86	1.56	1.72
38	CSV-17 x Pant Chari-5	10.64**	10.27**	-9.63	-6.75	30.57**	39.14**	-1.86	-1.50
39	CSV-17 x Rajasthan Chari-1	2.01	3.97	10.01**	11.63**	-9.26	-10.28	0.31	0.10
40	Pant Chari-6 x CSV-84	3.70	4.00	2.87	1.16	-6.32	-7.68	5.73	6.56
41	Pant Chari-6 x Pant Chari-5	3.45	4.42	-0.66	1.69	0.47	2.73	1.03	0.26
42	Pant Chari-6 x Rajasthan Chari-1	0.49	0.57	-1.33	-6.31	-2.23	-9.73	11.83**	12.42**
43	CSV-84 x Pant Chari-5	8.64	13.47	-4.22	-0.63	14.55**	16.96**	4.12	4.66
44	CSV-84 x Rajasthan Chari-1	12.88**	13.38**	15.91**	17.06**	15.70**	16.76**	10.73**	10.99**
45	Pant Chari-5 x Rajasthan Chari-1	17.95**	18.35**	10.47**	10.10**	17.33**	18.43**	12.37**	13.61**
	SE	**1.28**	**1.03**	**3.74**	**3.03**	**0.48**	**0.43**	**0.21**	**0.19**

S. No.	Parents	Leaf area (cm^2)		Stem girth (mm)		Leaf stem ratio		Total soluble solids (%)	
		BP	MP	BP	MP	BP	MP	BP	MP
1	UP Chari-1 x HC 308	12.64**	13.80**	11.88**	12.13**	19.37**	20.01**	17.53**	17.77**
2	UP Chari-1 x UP Chari-2	14.54**	14.51**	4.71	5.64	41.87**	46.22**	-7.35	-2.44
3	UP Chari-1 x HC-171	2.51	5.27	20.05**	28.86**	8.12	5.22	4.31	0.49
4	UP Chari-1 x Pant Chari-8	19.81**	19.64**	-6.98	-3.85	30.62**	30.91**	-7.35	-4.19
5	UP Chari-1 x CSV-17	1.25	2.98	4.10	3.13	41.87**	44.39**	-1.50	-2.81
6	UP Chari-1 x Pant Chari-6	-2.88	-2.84	-3.10	-6.67	41.25**	35.62**	0.73	0.28
7	UP Chari-1 x CSV-84	0.41	2.68	-1.56	-0.81	20.00**	17.97**	-7.95	-6.72
8	UP Chari-1 x Pant Chari-5	1.43	1.01	-1.00	-0.75	1.25	3.93	-9.33	-6.37
9	UP Chari-1 x Rajasthan Chari-1	-1.34	-0.83	-1.07	-0.01	19.37**	16.74**	-1.48	-2.38
10	HC 308 x UP Chari-2	21.50**	29.34**	1.75	1.45	19.91**	25.61**	3.41	3.06
11	HC 308 x HC-171	24.07**	22.76**	16.30**	18.52**	10.99**	11.00**	16.72**	16.83**
12	HC 308 x Pant Chari-8	28.01**	32.09**	18.75**	18.77**	17.12**	17.60**	11.82**	12.49**
13	HC 308 x CSV-17	18.61**	19.09**	-6.50	-2.42	1.80	4.72	14.26**	19.29**
14	HC 308 x Pant Chari-6	15.66**	17.51**	-0.68	-3.51	6.82	6.05	12.04**	17.58**
15	HC 308 x CSV-84	-4.34	-8.68	-6.28	-2.57	5.41	9.29	-1.14	-7.69
16	HC 308 x Pant Chari-5	6.40	4.97	12.70**	15.41**	34.41**	41.11**	-8.32	-1.62

17	HC 308 x Rajasthan Chari-1	13.20**	15.22**	1.61	3.77	7.12	6.98	-4.52	-2.90
18	UP Chari-2 x HC-171	-2.03	-1.43	-2.03	-3.63	1.24	4.64	15.35**	16.64**
19	UP Chari-2 x Pant Chari-8	4.03	5.46	6.43	4.44	37.10**	39.34**	0.04	8.64
20	UP Chari-2 x CSV-17	18.29**	21.24**	11.51**	12.81**	12.33**	12.92**	0.23	3.27
21	UP Chari-2 x Pant Chari-6	18.71**	19.67**	-1.20	-4.56	18.12**	19.59**	1.14	3.09
22	UP Chari-2 x CSV-84	10.75**	11.77**	-1.64	-1.61	12.90**	17.65**	-8.62	-2.57
23	UP Chari-2 x Pant Chari-5	14.32**	15.24**	27.28**	31.20**	12.00**	12.34**	1.28	3.35
24	UP Chari-2 x Rajasthan Chari-1	1.23	1.22	-1.43	-3.10	6.45	7.32	17.70**	18.95**
25	HC-171 x Pant Chari-8	21.60**	25.56**	-2.02	-0.02	57.08**	63.76**	-2.45	-0.87
26	HC-171 x CSV-17	-4.42	-1.60	5.95	2.40	17.98**	20.00**	4.23	0.39
27	HC-171 x Pant Chari-6	6.04	1.43	7.26	0.83	1.39	2.26	-9.91	-14.47
28	HC-171 x CSV-84	-5.94	-1.34	4.77	5.36	-2.35	-4.11	11.15**	17.88**
29	HC-171 x Pant Chari-5	1.79	8.46	4.67	8.09	-1.61	-3.80	0.88	0.82
30	HC-171 x Rajasthan Chari-1	3.56	1.30	-4.67	-2.38	8.99	8.00	-2.60	-0.02
31	Pant Chari-8 x CSV-17	-1.61	-0.07	7.17	2.94	-1.12	1.00	3.60	2.61
32	Pant Chari-8 x Pant Chari-6	5.41	6.62	-0.62	-1.02	16.67**	14.58**	1.97	2.37
33	Pant Chari-8 x CSV-84	-1.57	-4.61	4.77	7.49	10.99**	12.82**	-4.86	-2.89
34	Pant Chari-8 x Pant Chari-5	-7.64	-9.21	1.74	1.35	1.45	8.53	1.41	5.16
35	Pant Chari-8 x Rajasthan Chari-1	1.14	1.70	2.14	2.20	6.84	1.74	4.38	5.46
36	CSV-17 x Pant Chari-6	0.48	1.17	-2.26	-2.12	6.06	3.76	16.16**	17.08**
37	CSV-17 x CSV-84	-5.15	-3.82	2.40	5.71	-3.26	-7.69	-8.47	-0.69
38	CSV-17 x Pant Chari-5	-5.16	-1.19	4.61	-0.79	20.47**	22.58**	4.73	7.70
39	CSV-17 x Rajasthan Chari-1	-4.90	-3.76	4.97	1.19	-2.09	-8.84	-8.26	-1.40
40	Pant Chari-6 x CSV-84	-5.24	-2.33	3.09	4.82	20.45**	21.11**	1.67	4.07
41	Pant Chari-6 x Pant Chari-5	1.28	1.21	2.87	1.15	46.21**	59.35**	-3.68	-1.52
42	Pant Chari-6 x Rajasthan Chari-1	0.26	0.73	-9.51	-13.77	35.61**	41.92**	16.48**	15.25**
43	CSV-84 x Pant Chari-5	0.23	0.05	-7.77	-7.69	26.09**	29.05**	-6.90	-2.63
44	CSV-84 x Rajasthan Chari-1	11.92**	10.63**	10.63**	11.19**	13.11**	14.17**	-3.44	-2.44
45	Pant Chari-5 x Rajasthan Chari-1	12.64**	13.27**	17.36**	18.95**	11.14**	11.62**	-7.30	-2.08
	SE	3.34	3.00	0.35	0.33	0.01	0.01	0.15	0.13

Table 2: Ranking of crosses showing highly significant heterosis over better parents for seed yield per plant alone with *Per se* performance F1 in sorghum

Crosses	Heterosis (%)	SCA effect	GCA effect		*Per se*	Other character exhibiting significant heterosis in desirable direction
			P1	P2	F_1	
CSV-84 x Rajasthan Chari-1	41.27**	30.87**	74.19**	48.97**	479.76	Days to 50% flowering, plant height, leaves per plant, leaf breadth, leaf length, leaf area, stem girth, leaf stem ratio, green fodder yield
Pant Chari-5 x Rajasthan Chari-1	32.10**	97.82**	80.25**	48.97**	552.77	Days to 50% flowering, plant height, leaves per plant, leaf breadth, leaf length, leaf area, stem girth, leaf stem ratio, green fodder yield
UP Chari-2 x CSV-17	31.67**	37.17**	-6.34	5.61	324.55	Days to 50% flowering, plant height, leaves per plant, leaf length, leaf area, stem girth, leaf stem ratio, green fodder yield
HC 308 x Pant Chari-8	29.23**	72.36**	79.61**	-5.55	321.03	Days to 50% flowering, plant height, leaves per plant, leaf breadth, leaf length, leaf area, stem girth, leaf stem ratio, total soluble solids, green fodder yield
Pant Chari-6 x Pant Chari-5	23.52**	-5.64	57.12**	80.25**	441.15	leaf stem ratio, green fodder yield
UP Chari-1 x HC-171	22.24**	-18.87	69.40**	39.88**	434.31	stem girth, green fodder yield
UP Chari-1 x Pant Chari-6	22.05**	-0.54	69.40**	57.12**	435.40	leaf stem ratio, green fodder yield
UP Chari-1 x HC 308	21.07**	49.88**	69.40**	79.61**	552.55	plant height, leaves per plant, leaf breadth, leaf length, leaf area, stem girth, leaf stem ratio, total soluble solids, green fodder yield
HC 308 x HC-171	21.0**	27.73**	79.61**	39.88**	369.21	Days to 50% flowering, plant height, leaves per plant, leaf breadth, leaf length, leaf area, stem girth, leaf stem ratio, total soluble solids, green fodder yield
UP Chari-2 x Pant Chari-5	20.40**	17.53	-6.34	80.25**	485.10	Days to 50% flowering, plant height, leaves per plant, leaf breadth, leaf length, leaf area, stem girth, leaf stem ratio, green fodder yield
UP Chari-1 x Rajasthan Chari-1	20.08**	62.29**	69.40**	48.97**	446.37	Days to 50% flowering, leaf stem ratio, green fodder yield
HC 308 x CSV-17	18.91**	36.15**	79.61**	5.61	443.88	plant height, leaf area, total soluble solids, green fodder yield
UP Chari-1 x CSV-17	18.52**	-12.35	69.40**	5.61	455.10	leaves per plant, leaf stem ratio, green fodder yield
HC 308 x Pant Chari-6	14.09**	59.28**	79.61**	57.12**	466.95	leaf area, total soluble solids, green fodder yield
Pant Chari-8 x Pant Chari-5	13.43**	-9.65	-5.55	80.25**	468.71	green fodder yield
Pant Chari-8 x CSV-84	13.27**	-3.37	-5.55	74.19**	468.94	plant height, leaf stem ratio, green fodder yield

Conclusions

The present study revealed that hybrids that exhibited heterosis for green fodder yield were not heterotic for all the traits. On the basis of overall findings and per se performance the manifestation of high degree of heterosis over better and mid parent in certain five F1s Hybrids i.e., UP Chari-1 x HC-308, UP Chari-2 x CSV-17, UP Chari-2 x Pant Chari-5, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1 suggested that great possibility to produce higher fodder yield varieties. Therefore, the hybrid vigour can be easily being exploited for the commercial purposes in forage sorghum crop. However, attributes such as to produces male sterile lines are needed for better exploitation of hybrid vigour.

References

1. Aaref KAO, Ahmad MSH, Hovny MRA, Youns OA. Combining ability and heterosis for some agronomic characters in grain sorghum (*Sorghum bicolor* (L.) Moench). Middle East J Agri Res. 2016;5(2):258-271.
2. Akabari VR, Parmar HP, Niranjana M, Nakarnani DB. Heterosis and combining ability for green fodder yield and its contributing traits in forage sorghum [*Sorghum bicolor* (L.) Moench]. Forage Res. 2012;38(3):156-16.
3. Azam M, Waraich EA, Pervaiz A, Nawaz F. Response of a newly developed fodder sorghum (*Sorghum bicolor* (L.) Monech) variety (F-9917) to NPK application. Pak J. Life Soc. Sci. 2010;8(2):117-120.
4. Cockerham CC. Implication of genetic variance in hybrid breeding programme. Crop Sci. 1961;1:47-52.
5. Singh D, Sukhchain. Combining ability analysis in multi-cut sorghum [*Sorghum bicolor* (L.) Moench]. Range Mgmt. & Agroforestry. 2010;31(2):125-127.
6. Dehinwal AK, Pahuja SK, Shafiqurrahaman M. Genetic improvement through standard heterosis for fodder yield in single cut of forage sorghum (*Sorghum bicolor* L. Moench). Biosciences biotechnology Research Asia. 2017;14(1):391-400.
7. Harer PN, Bapat DR. Linex tester analysis of combining ability in grain sorghum. J Maharashtra Agric.Univ. 1982;7:230-232.
8. Ingle KP, Gahukar SJ, Khelurkar VC, Ghorade RB, Kalpande VV, Jadhav PV, *et al*. Heterosis and combining ability for grain yield trait in rabi sorghum (*Sorghum bicolor* L. Moench) using line x tester mating design. International Journal of Current Microbiology and Applied Sciences. 2018;6:1925-1934.
9. Jain SK, Patel PR. Heterosis studies for yield and its attributing traits in sorghum [*Sorghum bicolor* (L.) Moench]. Forage Research. 2013;39(3):114-117.
10. Kempthorne O. An Introduction to Genetic Statistics. John Wiley and Sons. Inc., New York; c1957.
11. Khapre PR, Pole SP, Borgaonkar SB. Heterosis studies in rabi sorghum. International Journal of Plant Sciences Muzaffarnagar. 2007;2(2):187-191.
12. Khatri RS, Lodhi CP. Genetics of hydrocyanic acid in forage sorghum. Int. Sorghum & Millets Newsltr. 1997;38:30-31.
13. Pal K, Singh SK, Kumar B, Singh C. Studies on combining ability and heterosis in forage sorghum (*Sorghum bicolor* L. Moench). Biochem, Cell. Arch. 2017;17(1):79-96.
14. Parmar NR, Patel MP, Patel PR, Patel NB. Study of heterosis for yield and yield attributes characters in forage sorghum (*Sorghum bicolor* L. Moench). Forage Res. 2019;44(4):247-250.
15. Prakash R, Ganesamurthy K, Nirmalakumari A, Nagarajan P. Heterosis for fodder yield in sorghum (*Sorghum bicolor* L. Moench). Electronic J Plant Breeding. 2010;1(3):319-327.
16. Prasuna Rani Chintala. Study on heterosis and combining ability for yield components in grain sorghum (*Sorghum bicolor* L. Moench). Doctoral dissertation. Department of Genetics and Plant Breeding. College of agriculture, Acharya N. G. Ranga Agricultural University, Ragendranagar, Hyderabad-500030; c2012.
17. Premalatha N, Kumaravadivel N, Veerabadhiran P. Heterosis and combining ability for grain yield and its components in sorghum [*Sorghum bicolor* (L.) Moench]. Indian J Genet. 2006;66(2):123-126.
18. Rathod DP, Gami RA, Chauhan RM, Kugashiya KG, Patel RN. Study of per se performance and heterosis for forage yield and its attributing traits netic analysis in forage sorghum (*Sorghum bicolor* (L.) Moench). Forage research. 2020;45(4):258-263.
19. Rajguru AB, Kashid NV, Kamble MS, Rasal PN, Gosavi AB. Heterotic response for grain yield and yield components of rabi sorghum [*Sorghum bicolor* (L.) Moench]. J Maharashtra Agric. Univ. 2005;30:292-295.
20. Saujanya T, Shashikala T, Umakanth AV. Studies on character association and path analysis for fodder yield and its components in sweet sorghum (*Sorghum bicolor* (L.) Moench) International journal of pure & Applied Bioscience. 2018;6(3):602-607.
21. Dangi OP, Paroda RS. Studies on stability parameters in forage sorghum [India]. Forage Research (India). 1978.
22. Sprague GF, Tatum LA. General vs. specific combining ability in single crosses of corn 1. Agronomy journal. 1942 Oct;34(10):923-32.
23. Rini BI, Dorff TB, Elson P, Rodriguez CS, Shepard D, Wood L, *et al*. Active surveillance in metastatic renal-cell carcinoma: a prospective, phase 2 trial. The Lancet Oncology. 2016 Sep 1;17(9):1317-24.
24. Chikuta O, Du Plessis L, Saayman M. Nature-based travel motivations for people with disabilities. African Journal of Hospitality, Tourism and Leisure. 2017;6(1):1-6.
25. Mohammed MI, Desmulliez MP. Autonomous capillary microfluidic system with embedded optics for improved troponin I cardiac biomarker detection. Biosensors and Bioelectronics. 2014 Nov 15;61:478-84.
26. Soujanya P, Kulkarni BS, Kumar R, Munikrishnappa PM, Shivapriya M, Harshavardhan M. Evaluation of rose (*Rosa hybrida* L.) varieties for growth, yield and quality under eastern dry zone of Karnataka. Journal of Pharmacognosy and Phytochemistry. 2018;7(5):165-8.