Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
www.phytojournal.com
JPP 2020; 9(5): 1339-1348
Received: 12-07-2020
Accepted: 14-08-2020

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Combining ability and heterosis analysis in forage sorghum (*Sorghum bicolor* L. Moench) for yield and yield components

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Abstract
The aim of this study was to estimate the general combining ability (GCA) of the parents and specific combining ability (SCA) to estimate heterosis in F 1 hybrids of sorghum [*Sorghum bicolor* (L.) Moench] with respect to yield and its components using ten hybrids considered for the development of high yielding and better quality cultivars of forage sorghum. Analysis of variance revealed significant differences among genotypes, parents and hybrids for all the traits on pooled basis. The hybrids and their parents were evaluated to assess the combining ability and gene action governing the quantitative traits. High heritability coupled with high genetic advance as percent of mean was observed for the traits *viz.*, plant height, leaves per plant, leaf area, stem girth, leaf stem ratio and green fodder yield. The SCA variance was found to be more important to gca variance for green and dry fodder yield per plant, plant height, stem diameter, leaf width, leaf: stem ratio, shoot fly dead heart percentage, quality characters and days to flowering, which favored a hybrid breeding programme. The mean degree of dominance $(\sigma^2 g/\sigma^2 s)^{1/2}$ was estimated greater than unity for days to 50% flowering, leaf area, stem girth, leaf stem ratio and green fodder yield over dominance for these characters. This cross found to be superior in terms of days to 50 percent flowering, plant height, number of grains per panicle and grain yield per plant. It was followed by UP Chari-1 x HC-308, UP Chari-1 x Rajasthan Chari-1, HC-308 x UP Chari-2, HC-308 x HC-171, HC-308 x CSV-17, HC-171 x CSV-84 and Pant Chari-5 x Rajasthan Chari-1. 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.

Keywords: Sorghum, combining ability, 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%) (Azam *et al*., 2010) [3]. 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 (Dara Singh and Sukhchain, 2010) [6]. 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) [5] 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) [20].

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 (Siddiqui and Baig, 2001) [18].

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) [20] 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. Fourty five hybrids and ten parents were also evaluated to study the combining ability and heterosis analysis. The combining ability analysis was carried out as per the method suggested by Kempthorne [1].

Results and Discussion

Analysis of variance for combining ability

Analysis of variance for combining ability was carried out for all the ten attributes are given in Table 1. General and specific combining ability were found highly significant and positive for all the ten characters namely, days to 50 % flowering (141.59 and 6.36), plant height (3495.14 and 324.84), leaves per plant (14.91 and 1.54), leaf breadth (0.97 and 0.78), leaf length (59.98 and 18.35), leaf area (6896.18 and 571.90), stem girth (13.89 and 0.96), leaf stem ratio (0.84 and 0.73), total soluble solids (1.29 and 0.94) and green fodder yield (35643.00 and 1107.29). The values of general combining ability variances were found higher than the specific combining ability variance for all the characters.

Estimates of variance σ^2s was found higher than σ^2g for all the traits *i.e.*, days to 50% flowering, plant height, leaves per plant, leaf breadth, leaf length, leaf area, stem girth, leaf stem ratio, total soluble solids and green fodder yield per plant. Ratio between estimated variance owing σ^2g/σ^2s was less than unity for the attributes namely, plant height (0.91), leaves per plant (0.87), leaf breadth (0.51), leaf length (0.28) and total soluble solids (0.71), whereas it was more than one unity for the characters *viz.*, days to 50% flowering (2.03), leaf area (1.02), stem girth (1.31), leaf stem ratio (1.12) and green fodder yield (2.70). The mean degree of dominance $(\sigma^2g/\sigma^2s)^{0.5}$ recorded greater than unity fordays to 50% flowering (1.43), leaf area (1.01), stem girth (1.15), leaf stem ratio (1.06) and green fodder yield (1.64), which indicating that the involvement of over dominance for these attributes, while less than unity for plant height (0.95), leaves per plant (0.93), leaf breadth (0.72), leaf length (0.53) and total soluble solids (0.84), indicated the involvement of partial dominance for these traits . Similar results were also reported by Rajguru *et al*. (2005) [17] and Premalatha *et al*. (2006) [16].

Table 1: Analysis of variance for combining ability of fodder yield and its components in forage sorghum (*Sorghum bicolor* L. Moench)

Source of variation	df	Days to 50% flowering	Plant height (cm)	Leaves per plant	Leaf breadth (cm)	Leaf length (cm)	Leaf area (cm^2)	Stem girth (mm)	Leaf stem ratio	Total soluble solids (%)	Green fodder yield (g/plant)
GCA	9	141.59**	3495.14**	14.91**	0.97**	59.98**	6896.18**	13.89**	0.84**	1.29**	35643.00**
SCA	45	6.36**	324.84**	1.54**	0.78**	18.35**	571.90**	0.96**	0.73**	0.94**	1107.29**
Error	108	0.58	5.25	0.13	0.02	0.86	6.26	0.09	0.08	0.12	9.00

Estimation variance due to

Source of variation	Days to 50% flowering	Plant height (cm)	Leaves per plant	Leaf breadth (cm)	Leaf length (cm)	Leaf area (cm^2)	Stem girth (mm)	Leaf stem ratio	Total soluble solids (%)	Green fodder yield (g/plant)
$\sigma^2 g$	11.75	290.82	1.23	0.08	4.93	574.16	1.15	0.09	0.11	2969.50
$\sigma^2 g$	15.78	319.60	1.42	0.15	17.49	585.64	1.87	0.10	0.15	3098.29
$\sigma^2 g/\sigma^2 s$	2.03	0.91	0.87	0.51	0.28	1.02	1.31	1.12	0.71	2.70
$\sigma^2 g/\sigma^2 s)^{0.5}$	1.43	0.95	0.93	0.72	0.53	1.01	1.15	1.06	0.84	1.64

*, ** significant at 5% and 1% level, respectively

General combining ability and Manifestation of heterosis

Days to 50% flowering

Genotype UP Chari-1 (-4.29) was showed significant and negative general combining ability effects and emaeged as good general combiner in order to merit for early flowering. Varieties *i.e.*, UP Chari-2 (5.13), HC-171 (2.05), CSV-17 (1.47), Pant Chari-5 (6.48) and Rajasthan Chari-1 (1.64) exhibited significant and positive gca effects and they were expressed as good general combiners for late flowering (Table 2).

Significant increase or decreases in performance of F_1's hybrids over better parent (heterobeltiosis) and mid parent (relative heterosis) in respect of all the ten traits under study are being presented in Table 4. Heterobeltiosis for days to 50% flowering ranged from -3.41 (UP Chari-1 x Pant Chari-5) to 26.94 (UP Chari-2 x Pant Chari-5). Cross combinations *viz.*, UP Chari-1 x UP Chari-2 (10.59), UP Chari-1 x Rajasthan Chari-1 (10.85), HC 308 x UP Chari-2 (13.70), HC 308 x HC-171 (13.23), HC 308 x Pant Chari-8 (11.18), UP Chari-2 x Pant Chari-8 (17.35), UP Chari-2 x CSV-17 (18.22), UP Chari-2 x Pant Chari-6 (13.70), UP Chari-2 x Pant Chari-5 (26.94), UP Chari-2 x Rajasthan Chari-1 (15.07), CSV-17 x Pant Chari-5 (10.64), CSV-84 x Rajasthan Chari-1 (12.88) and Pant Chari-5 x Rajasthan Chari-1 (17.95) exhibited positive and significant heterosis over better parent for late flowering while five crosses showed negative non significant heterosis over better parent for early flowering. Similar findings were also reported by Khatri and Lodhi (1997) [11]

Relative heterosis varied from -5.19 (UP Chari-1 x Pant Chari-5) to 26.99 (UP Chari-2 x Pant Chari-5). Out of forty five F_1's hybrids, only thirteen hybrids namely, UP Chari-1 x UP Chari-2 (15.39), UP Chari-1 x Rajasthan Chari-1 (10.13), HC 308 x UP Chari-2 (14.62), HC 308 x HC-171 (14.95), HC 308 x Pant Chari-8 (11.56), UP Chari-2 x Pant Chari-8 (18.44), UP Chari-2 x CSV-17 (18.28), UP Chari-2 x Pant Chari-6 (13.75), UP Chari-2 x Pant Chari-5 (26.99), UP Chari-2 x Rajasthan Chari-1 (16.35), CSV-17 x Pant Chari-5 (10.27), CSV-84 x Rajasthan Chari-1 (13.38) and Pant Chari-5 x Rajasthan Chari-1 (18.35) revealed positive and significant heterosis over mid parent for late flowering, whereas five crosses was observed negative non significant heterosis over mid parent for early flowering in order to merit.

Plant height

Among the parental lines, genotypes *viz.*, Pant Chari-6 (-17.60), CSV-84 (-22.27) and Rajasthan Chari-1 (-6.04) had significient and negative GCA effect and were appeared as good general combiners for dwarfness, whereas varieties namely, UP Chari-1 (14.85), HC-308 (8.92), UP Chari-2 (9.07), HC-171 (8.47), Pant Chari-8 (15.27), CSV-17 (24.33) and Pant Chari-5 (6.48) revealed significant and positive general combining ability effects and were found to be good general combiners for tall plant (Table 2).

Heterobeltiosis for plant height values ranged from -9.63 (HC-171 x CSV-17) to 23.09 (HC-171 x CSV-84). The cross combinations *i.e.*, UP Chari-1 x HC 308 (16.46), HC 308 x UP Chari-2 (15.40), HC 308 x HC-171 (13.53), HC 308 x Pant Chari-8 (13.38), HC 308 x CSV-17 (11.39), HC 308 x CSV-84 (15.34), HC 308 x Pant Chari-5 (17.11), UP Chari-2 x HC-171 (12.23), UP Chari-2 x CSV-17 (15.76), UP Chari-2 x Pant Chari-6 (11.39), UP Chari-2 x Pant Chari-5 (11.52), HC-171 x CSV-84 (23.09), HC-171 x Pant Chari-5 (14.36), Pant Chari-8 x CSV-17 (12.60), Pant Chari-8 x CSV-84 (21.07), CSV-17 x CSV-84 (11.54), CSV-17 x Rajasthan Chari-1 (10.01), CSV-84 x Rajasthan Chari-1 (15.91) and Pant Chari-5 x Rajasthan Chari-1 (10.47) showed positive and significant heterosis over better parent for tall stature and twelve hybrids had negative and non significant heterosis over better parent for dwarf stature (Table 4). Relative heterosis varied from -9.34 (HC-171 x CSV-17) to 30.68 (HC-171 x CSV-84). Cross combinations *viz.*, UP Chari-1 x HC 308 (16.56), HC 308 x UP Chari-2 (16.13), HC 308 x HC-171 (13.29), HC 308 x Pant Chari-8 (14.04), HC 308 x CSV-17 (18.39), HC 308 x CSV-84 (16.48), HC 308 x Pant Chari-5 (17.49), UP Chari-2 x HC-171 (12.78), UP Chari-2 x CSV-17 (16.76), UP Chari-2 x Pant Chari-6 (12.27), UP Chari-2 x Pant Chari-5 (12.27), HC-171 x CSV-84 (30.68), HC-171 x Pant Chari-5 (13.68), Pant Chari-8 x CSV-17 (13.98), Pant Chari-8 x CSV-84 (25.41), CSV-17 x CSV-84 (17.81), CSV-17 x Rajasthan Chari-1 (11.63), CSV-84 x Rajasthan Chari-1 (17.06) and Pant Chari-5 x Rajasthan Chari-1 (10.10) noted positive significant heterosis over mid parent for tall stature, whereas twelve crosses recorded negative non significant heterosis over mid parent for dwarf stature (Table 4).

Leaves per plant

In case of leaves per plant, parents like UP Chari-2 (0.98), CSV-17 (1.55), Pant Chari-6 (1.19), CSV-84 (11.45) and Pant Chari-5 (1.58) recorded significant and positive general combining ability effects and were considered to be good general combiner for leaves per plant. Genotype Rajasthan Chari-1 (-0.72) exhibited non significant and negative general combining ability effects and was identify that poor general combiner for leaves per plant (Table 2). Heterobeltiosis values ranged from -9.26 (CSV-17 x Rajasthan Chari-1) to 37.44 (HC 308 x Pant Chari-5). Eighteen hybrids namely, 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 parent for leaves per plant while, twelve crosses showed negative and non significant heterosis over better parent for this character (Table 4).

Relative heterisis varied from -10.28 (CSV-17 x Rajasthan Chari-1) to 42.19 (HC 308 x Pant Chari-5). Out of forty five

F_1's hybrids, only eighteen cross combinations *i.e.*, 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 exhibited positive significant heterosis over mid parent for leaves per plant, whereas twelve crosses were found negative and non significant heterosis over better parent for this trait (Table 4).

Leaf breadth

Out of ten genotypes, only one parent UP Chari-1 (0.93) was observed significant and positive general combining ability effects and possessed as good general combiners for leaf breadth, while the genotypes UP Chari-2 (-0.25), Pant Chari-8 (-0.17) and Pant Chari-5 (-0.06) noted non significant and negative general combining ability effects for this trait (Table 2). Heterobeltiosis ranged from -8.75 (HC 171 x CSV-84) to 22.83 (HC 308 x HC-171). The hybrids *viz*., 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 Chari-6 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 parent for this character and eleven cross combinations exhibited negative non significant heterosis over better parent, out of forty five crosses for leaf breadth (Table 4).

Relative heterosis varied from -9.22 (HC 171 x CSV-84) to 24.20 (HC 308 x HC-171). F_1's hybrids namely, 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 Chari-6 x Rajasthan Chari-1, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1 observed positive significant heterosis over better parent for leaf breadth whereas eleven crosses had negative and non significant heterosis over mid parent for this character (Table 4).

Leaf length

Significant and desirable general combining ability effects were marked for leaf length in the varieties *viz.*, UP Chari-1 (1.66), HC-308 (3.51), UP Chari-2 (3.18), HC-171 (1.72), Pant Chari-8 (3.55), CSV-84 (1.35), Pant Chari-5 (1.57) and Rajasthan Chari-1 (1.22) and appeared good general combiners, whereas parent Pant Chari-6 (-0.74) reported non-significant and negative general combining ability effects, reflecting as poor general combiners for this character (Table 2).

Heterobeltiosis for cross combinations over their better parent values varied from -9.84 (Pant Chari-8 x Rajasthan Chari-1) to 20.53 (UP Chari-2 x Pant Chari-8). Crosses *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 Chari-6 x CSV-84, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1 revealed positive significant heterosis over better parent for leaf length while, fifteen hybrids recorded negative and non significant heterosis over better parent for this attributes. Relative heterosis ranged from -11.97 (Pant Chari-8 x Rajasthan Chari-1) to 25.26 (UP Chari-2 x Pant Chari-8). Thirteen 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, 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 Chari-6 x CSV-84, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1 noted positive and significant heterosis over mid parent for this character. Out of forty five crosses, only fifteen hybrids exhibited negative non significant heterosis over mid parent for leaf length (Table 4).

Leaf area

Positive and significant general combining ability effects was recorded for genotypes *i.e.*, UP Chari-1 (5.46), HC-308 (26.94), UP Chari-2 (41.22), HC-171 (28.81), Pant Chari-8 (40.78), CSV-17 (3.77), Pant Chari-6 (4.26), CSV-84 (10.36) and Pant Chari-5 (5.23) and proved as good general combiners for this attribute. Only one genotype Rajasthan Chari-1 (-0.62) had non-significant and negative gca effects for leaf area (Table 2). The variance components $\sigma^2 g$ and $\sigma^2 s$ estimated more than unity for days to 50% flowering, plant height, leaves per plant, leaf length, leaf area, stem girth and green fodder yield, which indicates the involvement of the additive gene action in this attribute and rest trait had less than unity, indicated that involvement of non additive gene action.

The proportion of $\sigma^2 g/\sigma^2 s$ being less than unity for plant height, leaves per plant, leaf breadth, leaf length and total soluble solids, indicating more involvement of non additive type of gene action for these characters, whereas the ratio of $\sigma^2 g/\sigma^2 s$ being more than unity for days to 50% flowering, leaf area, stem girth, leaf stem ratio and green fodder yield, which indicated that involvement of additive type of gene action for these character. The similar findings are in conformity with Aaref *et al.* (2016) [1]; Dehinwal *et al.* (2017) [7]. The mean degree of dominance **(**$\sigma^2 g/\sigma^2 s$) $^{1/2}$ was estimated greater than unity for days to 50% flowering, leaf area, stem girth, leaf stem ratio and green fodder yield, indicated the involvement of over dominance for this trait, whereas it was less than unity for plant height, leaves per plant, leaf breadth, leaf length and total soluble solids, indicating that the involvement of partial dominance for these attributes. In earlier studies role of non additive genetic variance were reported by Parmar *et al.* (2019) [12].

Stem girth

Genotypes *viz.*, UP Chari-1 (0.94), UP Chari-2 (2.00), CSV-17 (1.08) and Pant Chari-5 (1.87) showed significant and positive general combining ability effects and considered as good general combiner for stem girth. Varieties namely, HC-171 (-0.53), Pant Chari-8 (-0.62), CSV-84 (-0.31) and Rajasthan Chari-1 (-0.03) showed non-significant and negative gca effects for this character (Table 2).

Heterobeltiosis for leaf area over better parents values ranged from -7.64 (Pant Chari-8 x Pant Chari-5) to 28.01 (HC 308 x Pant Chari-8). Sixteen crosses were found positive and significant heterosis over better parent values out of forty five F_1's hybrids which are namely, UP Chari-1 x HC 308, UP Chari-1 x UP Chari-2, UP Chari-1 x Pant Chari-8, 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 for more leaf area. Only thirteen cross combination observed non significant and negative heterosis over better parent for this character. Relative heterosis varied from -9.21 (Pant Chari-8 x Pant Chari-5) to 32.09 (HC 308 x Pant Chari-8). Out of forty five crosses, only sixteen hybrids *viz.*, UP Chari-1 x HC 308, UP Chari-1 x UP Chari-2, UP Chari-1 x Pant Chari-8, 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 revealed significant positive heterosis over mid parent for more leaves per plant, while thirteen hybrids exhibited non significant negative heterosis over mid parent for this trait (Table 4).

Table 2: Estimates of GCA effect and *Per se* performance of parents for fodder yield and its components in forage sorghum (*Sorghum bicolor* L. Moench)

Parents	Days to 50% flowering	Plant height (cm)	Leaves per plant	Leaf breadth (cm)	Leaf length (cm)	Leaf area (cm^2)	Stem girth (mm)	Leaf stem ratio	Green fodder yield (g/plant)
UP Chari-1	-4.29**	14.85**	0.35	0.93**	1.66**	5.46**	0.94**	2.09**	69.40**
HC-308	-0.33	8.92**	0.46	0.45	3.51**	26.94**	0.11	1.07**	79.61**
UP Chari-2	5.13**	9.07**	0.98**	-0.25	3.18**	41.22**	2.00**	-0.04	-6.34
HC-171	2.05**	8.47**	0.21	0.37	1.72**	28.81**	-0.53	1.01**	39.88**
Pant Chari-8	-0.19	15.27**	0.97	-0.17	3.55**	40.78**	-0.62	-0.03	-5.55
CSV-17	1.47**	24.33**	1.55**	0.04	0.59	3.77**	1.08**	-0.01	5.61
Pant Chari-6	-0.02	-17.60**	1.19**	0.04	-0.74	4.26**	0.87	2.06**	57.12**
CSV-84	-0.22	-22.27**	11.45**	0.09	1.35**	10.36**	-0.31	-0.05	74.19**
Pant Chari-5	6.48**	22.36**	1.58**	-0.06	1.57**	5.23**	1.87**	-0.04	80.25**
Rajasthan Chari-1	1.64**	-6.04**	-0.72	0.04	1.22**	-0.62	-0.03	-0.06	48.97**
SE (gi)	0.20	0.62	0.09	0.04	0.25	0.68	0.08	0.02	0.82
SE (gi-gj)	0.31	2.64	0.17	0.06	0.37	1.02	0.33	0.03	1.22

Leaf stem ratio

The parents *i.e.*, Pant Chari-1 (2.09), HC-308 (1.07), HC-171 (1.01) and Pant Chari-6 (2 .06) were identified as good general combiners for leaf stem ratio by exhibiting significant and positive gca effects. Varieties namely, UP Chari-2 (-0.04), Pant Chari-8 (-0.03), CSV-17 (-0.01), CSV-84 (-0.05), Pant Chari-5 (-0.04) and Rajasthan Chari-1 (-0.06) observed non significant and negative general combining ability effects for this trait (Table 2). Heterobeltiosis for leaf stem ratio values varied from -3.26 (CSV-17 x CSV-84) to 57.08 (HC-171 x Pant Chari-8). Twenty seven hybrids revealed positive and significant heterosis over better parent which are as 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 parent for leaf stem ratio (Table 4).

Green fodder yield

Out of ten parental lines, only seven varieties *i.e.*, UP Chari-1 (69.40), HC-308 (79.61), HC-171 (39.88), Pant Chari-6 (57.12), CSV-84 (74.19), Pant Chari-5 (80.25), Rajasthan Chari-1 (48.97) revealed significant and positive gca effects and were identified as good general combiners for green fodder yield. Two genotypes namely, UP Chari-2 and Pant Chari-8 were found non-significant and negative general combining ability effects and considered as poor general combiners for green fodder yield (Table 2). Heterobeltiosis for green fodder yield values varied from -19.15 (HC-308 x UP Chari-2) to 41.27 (CSV-84 x Rajasthan Chari-1). Out of forty five F_1's hybrids, only sixteen crosses namely, UP Chari-1 x HC 308, UP Chari-1 x HC-171, UP Chari-1 x CSV-17, UP Chari-1 x Pant Chari-6, UP Chari-1 x Rajasthan Chari-1, 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 CSV-17, UP Chari-2 x Pant Chari-5, Pant Chari-8 x CSV-84, Pant Chari-8 x Pant Chari-5, Pant Chari-6 x Pant Chari-5, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1 observed positive and significant heterosis over better parent, indicating best specific cominers for *per se* performance. Cross combinations *i.e.*, UP Chari-1 x UP Chari-2 and HC-308 x UP Chari-2 were found significant and negative heterosis over better parent for this attribute (Table 4).

Relative heterosis ranged from -19.15 (HC-308 x UP Chari-2) to 41.27 (CSV-84 x Rajasthan Chari-1). F_1's Hybrids *viz.*, UP Chari-1 x HC 308, UP Chari-1 x HC-171, UP Chari-1 x CSV-17, UP Chari-1 x Pant Chari-6, UP Chari-1 x Rajasthan Chari-1, 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 CSV-17, UP Chari-2 x Pant Chari-5, Pant Chari-8 x CSV-84, Pant Chari-8 x Pant Chari-5, Pant Chari-6 x Pant Chari-5, CSV-84 x Rajasthan Chari-1 and Pant Chari-5 x Rajasthan Chari-1 revealed significant and positive heterosis over mid parent for this character, whereas two crosses showed significant and negative heterosis over mid parent for green fodder yield (Table 4). The similar findings were also reported by Prakash *et al.* (2010) [14]; Patel and Patel (2011); Akabari *et al.* (2012) [2].

Specific combining ability effects

The estimates of specific combining ability effects (SCA) in F_1s hybrids for ten traits are presented in Table 3. The criteria for findings out the desirable and significant specific combiners were the same as for sca effects.

Days to 50% flowering

Specific combining ability effect ranged from -3.50 (UP Chari-2 x CSV-84) to 6.86 (UP Chari-1 x HC-308). Cross combinations were recorded positive and significant specific combining ability effects for the attributes namely, UP Chari-1 x HC 308 (6.86), UP Chari-1 x Pant Chari-6 (1.23), UP Chari-1 x Rajasthan Chari-1 (4.56), HC 308 x UP Chari-2

(2.28), HC 308 x HC-171 (5.80), HC 308 x CSV-17 (5.62), HC 308 x Pant Chari-2 (2.28), UP Chari-2 x Pant Chari-8 (4.81), UP Chari-2 x Pant Chari-6 (1.98), UP Chari-2 x Pant Chari-5 (5.14), UP Chari-2 x Rajasthan Chari-1 (1.31), HC-171 x CSV-84 (6.43), HC-171 x Rajasthan Chari-1 (4.23), CSV-17 x CSV-84 (3.51), Pant Chari-6 x CSV-84 (1.06) and Pant Chari-5 x Rajasthan Chari-1 (6.70) and were proved as best specific combiners for late flowering whereas, fourteen crosses *i.e*., UP Chari-1 x HC-171 (-3.08), UP Chari-1 x CSV-17 (-2.66), UP Chari-1 x Pant Chari-5 (-2.61), HC 308 x Pant Chari-8 (-1.66), HC 308 x Pant Chari-6 (-1.82), UP Chari-2 x CSV-84 (-3.50), HC-171 x Pant Chari-5 (-1.94), Pant Chari-8 x Pant Chari-5 (-1.80), Pant Chari-8 x Rajasthan Chari-1 (-3.30), CSV-17 x Pant Chari-6 (-1.69), CSV-17 x Rajasthan Chari-1 (-1.69), Pant Chari-6 x Pant Chari-5 (-2.63), CSV-84 x Pant Chari-5 (-1.44) and CSV-84 x Rajasthan Chari-1 (-1.27) showed negative and significant specific combining ability effects and were appeared poor specific combiners for early flowering.

Plant height

Estimates of specific combining ability effect varied from -24.98 (HC-171 x Pant Chari-8) to 45.36 (Pant Chari-5 x Rajasthan Chari-1). The F_1's hybrids *viz.*, UP Chari-1 x HC 308, UP Chari-1 x HC-171, UP Chari-1 x CSV-17, 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 CSV-17, HC 308 x Pant Chari-6, UP Chari-2 x CSV-17, UP Chari-2 x Pant Chari-6, HC-171 x CSV-84, HC-171 x Rajasthan Chari-1, Pant Chari-8 x CSV-17, Pant Chari-8 x CSV-84, CSV-17 x CSV-84, Pant Chari-6 x Pant Chari-5 and Pant Chari-5 x Rajasthan Chari-1 observed significant positive specific combining ability effects and were considered as best specific combiners for tall plant, whereas nine crosses namely, UP Chari-1 x UP Chari-2, HC 308 x Pant Chari-5, UP Chari-2 x HC-171, HC-171 x Pant Chari-8, HC-171 x CSV-17, CSV-17 x Pant Chari-6, CSV-17 x Pant Chari-5, Pant Chari-6 x Rajasthan Chari-1 and CSV-84 x Rajasthan Chari-1 noted significant and negative specific combining ability effects for dwarf plant. Harer and Sapat (1982) [9] stated that the *per se* performance of the parents with the nature of combining ability provide the criteria for the choice of parents for hybridization. On this basis, those parents which performed well for both *per se* performance and gea effects can be considered as good parents.

Table 3: Estimation of SCA effect and *per se* performance of crosses for yield component in sorghum (*Sorghum bicolor* L. Moench)

S. No.	Parents	Days to 50% flowering		Plant height (cm)		Leaves per plant		Leaf breadth (cm)		Leaf length (cm)	
		SCA Effect	Mean	SCA Effect	Mean	SCA Effect	Mean	SCA Effect	Mean	SCA Effect	Mean
1	UP Chari-1 x HC 308	6.86**	92.00	35.68**	236.79	3.53**	14.03	1.23**	6.59	9.02**	74.07
2	UP Chari-1 x UP Chari-2	-0.60	80.73	-10.58**	223.90	-0.47	10.60	-0.32	5.35	-3.04**	64.37
3	UP Chari-1 x HC-171	-3.08**	85.33	23.09**	275.11	-0.13	12.13	0.43	6.71	2.59**	73.89
4	UP Chari-1 x Pant Chari-8	0.06	90.33	3.72	262.53	0.25	13.27	-0.16	5.58	0.36	67.40
5	UP Chari-1 x CSV-17	-2.66**	86.33	16.33**	284.21	-0.93	12.67	-0.40	5.55	2.45**	73.63
6	UP Chari-1 x Pant Chari-6	1.23**	91.67	7.22	268.37	1.16**	14.40	-0.51**	5.44	-2.18**	67.67
7	UP Chari-1 x CSV-84	-0.58	86.67	-1.25	220.03	0.33	10.93	-0.05	5.95	1.04**	72.98
8	UP Chari-1 x Pant Chari-5	-2.61**	94.33	-4.49	216.70	-1.14**	9.33	-0.27	5.58	0.39	69.41
9	UP Chari-1 x Rajasthan Chari-1	4.56**	96.67	37.73**	229.77	4.20**	11.13	1.68**	6.63	8.92**	72.73
10	HC 308 x UP Chari-2	2.28**	83.00	12.74**	270.99	1.76**	12.93	0.42	7.07	5.73**	74.99
11	HC 308 x HC-171	5.80**	80.00	32.33**	273.45	3.30**	12.07	1.56**	5.70	9.60**	63.55
12	HC 308 x Pant Chari-8	-1.66**	84.00	10.44**	293.03	-1.52**	11.60	0.81**	7.53	-4.43**	64.46
13	HC 308 x CSV-17	5.62**	88.00	22.87**	268.77	2.16**	13.87	0.91**	7.35	7.76**	76.79
14	HC 308 x Pant Chari-6	-1.82**	84.00	21.10**	306.01	-0.08	13.27	-0.07	6.87	0.71	72.40
15	HC 308 x CSV-84	-0.30	82.33	-5.08	239.96	-1.11**	9.60	0.27	7.26	0.93	74.72
16	HC 308 x Pant Chari-5	0.34	92.67	-12.31**	232.65	-2.28**	8.30	-0.12	6.71	0.58	71.45
17	HC 308 x Rajasthan Chari-1	-0.82	86.67	-0.41	260.87	0.56	12.00	-0.24	6.70	0.23	73.89
18	UP Chari-2 x HC-171	-1.00	78.00	-10.24**	247.56	-0.07	10.87	0.37	6.93	1.61**	68.07
19	UP Chari-2 x Pant Chari-8	4.81**	85.67	3.76	268.35	1.58**	13.27	0.64**	6.67	9.46**	71.65
20	UP Chari-2 x CSV-17	-0.58	79.00	12.20**	285.85	-0.47	11.80	0.43	6.67	-1.96**	64.37
21	UP Chari-2 x Pant Chari-6	1.98**	83.00	18.84**	285.76	-2.54**	9.37	-0.04	6.20	-1.62**	63.38
22	UP Chari-2 x CSV-84	-3.50**	74.33	4.29	231.35	0.06	9.33	0.20	6.49	4.77**	71.87
23	UP Chari-2 x Pant Chari-5	5.14**	92.67	3.70	230.67	-0.68	8.47	-0.35	5.79	0.10	64.28
24	UP Chari-2 x Rajasthan Chari-1	1.31**	84.00	-8.63	234.65	-0.10	9.90	0.26	6.50	0.17	67.15
25	HC-171 x Pant Chari-8	0.40	87.33	-24.98**	257.15	-1.15**	11.73	0.16	6.80	4.09**	70.19
26	HC-171 x CSV-17	-0.32	82.33	-17.07**	274.12	-0.20	13.27	-0.04	6.81	3.44**	73.67
27	HC-171 x Pant Chari-6	0.90	85.00	5.61	290.07	1.30**	14.40	0.07	6.93	-0.75	68.16
28	HC-171 x CSV-84	6.43**	81.33	27.65**	216.94	3.20**	10.27	0.96**	6.74	9.21**	61.79
29	HC-171 x Pant Chari-5	-1.94**	88.67	-2.95	241.55	0.53	10.87	0.36	7.11	4.09**	72.17
30	HC-171 x Rajasthan Chari-1	4.23**	90.00	43.09**	303.91	-0.20	11.00	-0.04	6.82	-4.34**	66.53
31	Pant Chari-8x CSV-17	0.48	85.00	25.36**	323.35	-0.28	13.93	-0.04	6.28	-5.45**	60.52
32	Pant Chari-8x Pant Chari-6	0.04	86.00	-3.10	288.17	0.31	14.17	0.11	6.43	6.53**	71.16
33	Pant Chari-8x CSV-84	-0.44	82.33	41.92**	293.31	1.45**	12.67	-0.07	6.30	-2.90**	63.83
34	Pant Chari-8x Pant Chari-5	-1.80**	90.67	-7.35	243.95	0.51	11.60	0.04	6.25	-0.15	63.66
35	Pant Chari-8 x Rajasthan Chari-1	-3.30**	84.33	-0.05	267.57	-0.02	11.93	-0.53**	5.79	-2.75**	63.85
36	CSV-17 x Pant Chari-6	-1.69**	83.00	-24.35**	275.97	0.49	14.93	0.12	6.65	0.33	69.10
37	CSV-17 x CSV-84	3.51**	85.00	38.21**	298.66	3.13**	14.93	-0.06	6.52	-4.33**	66.53
38	CSV-17 x Pant Chari-5	-0.19	91.00	-16.58**	243.78	-1.08**	10.60	-0.08	6.35	-7.42**	60.52
39	CSV-17 x Rajasthan Chari-1	-1.69**	84.67	-3.74	272.95	-1.73**	10.80	-0.13	6.40	0.41	71.15
40	Pant Chari-6 x CSV-84	1.06**	84.00	-8.14	245.58	-2.45**	9.00	0.19	6.77	-5.71**	63.83
41	Pant Chari-6 x Pant Chari-5	-2.63**	90.00	26.37**	280.00	2.75**	14.07	-0.02	6.40	-3.74**	62.87
42	Pant Chari-6 x Rajasthan Chari-1	-0.80	87.00	-20.04**	249.91	-1.04**	11.13	0.59**	7.12	2.08**	71.49
43	CSV-84 x Pant Chari-5	-1.44**	88.00	-3.48	210.28	0.56	9.24	0.26	6.73	3.06**	71.77
44	CSV-84 x Rajasthan Chari-1	-1.27**	83.33	-18.49**	211.59	0.40	9.93	-0.13	6.45	4.12**	75.63

45	Pant Chari-5 x Rajasthan Chari-1	6.70**	95.00	45.36**	235.35	2.79**	11.20	0.69**	6.31	4.27**	68.85
	SE (sij)	0.70		2.11		0.33		0.14		0.85	
	SE (sij-sik)	1.03		3.10		0.48		0.21		1.26	

S. No.	Parents	Leaf area (cm^2)		Stem girth (mm)		Leaf stem ratio		Total soluble solids (%)		Green fodder yield (g/plant)	
		SCA Effect	Mean	SCA Effect	Mean	SCA Effect	Mean	SCA Effect	Mean	SCA Effect	Mean
1	UP Chari-1 x HC 308	30.67**	378.16	5.11**	17.89	0.02	0.48	0.77**	7.78	49.88**	552.55
2	UP Chari-1 x UP Chari-2	-6.09	273.24	1.02**	15.70	-0.05	0.31	-0.20	7.19	25.14**	481.86
3	UP Chari-1 x HC-171	16.45**	365.80	-1.33**	14.82	0.02	0.44	0.41	8.21	-18.87	434.31
4	UP Chari-1 x Pant Chari-8	-23.38**	256.39	-0.74	15.33	0.00	0.37	-0.26	7.69	22.96**	490.47
5	UP Chari-1 x CSV-17	10.66**	334.97	0.62	18.38	-0.08	0.31	0.02	8.36	-12.35	455.10
6	UP Chari-1 x Pant Chari-6	-14.03**	310.77	-0.94	16.61	-0.14	0.31	0.20	7.70	-0.54	435.40
7	UP Chari-1 x CSV-84	7.91	338.81	-0.15	16.22	0.08	0.43	-0.13	7.33	-19.48	547.77
8	UP Chari-1 x Pant Chari-5	-0.17	315.15	-0.07	18.48	0.01	0.37	-0.30	7.03	4.20	532.11
9	UP Chari-1 x Rajasthan Chari-1	89.47**	318.69	4.99**	16.65	0.89**	0.43	0.66**	7.20	62.29**	446.37
10	HC 308 x UP Chari-2	81.77**	382.58	1.33**	16.55	-0.01	0.33	0.52**	8.70	27.73**	369.21
11	HC 308 x HC-171	75.91**	294.93	5.00**	14.70	0.72**	0.37	0.99**	8.00	72.36**	321.03
12	HC 308 x Pant Chari-8	-21.63**	279.62	-0.59	16.03	-0.04	0.31	0.22	8.57	36.15**	443.88
13	HC 308 x CSV-17	69.67**	316.13	5.39**	17.92	0.61**	0.38	0.63**	8.10	59.28**	466.95
14	HC 308 x Pant Chari-6	-18.70**	327.59	0.88	18.98	0.04	0.47	-0.49	7.40	34.63**	410.79
15	HC 308 x CSV-84	-19.68**	332.70	-0.46	16.46	0.07	0.39	-0.29	7.56	-10.98	496.49
16	HC 308 x Pant Chari-5	26.76**	363.56	-0.98	18.13	0.09	0.42	-0.01	7.71	5.62	519.14
17	HC 308 x Rajasthan Chari-1	-12.49**	337.15	0.65	17.85	-0.01	0.31	-0.21	8.03	-1.46	382.84
18	UP Chari-2 x HC-171	-17.63**	285.05	-0.47	14.11	-0.02	0.26	-0.61**	7.26	22.20**	325.25
19	UP Chari-2 x Pant Chari-8	4.70	237.79	1.89**	16.39	0.04	0.28	0.28	8.30	31.87**	393.65
20	UP Chari-2 x CSV-17	-7.33	270.31	-0.77	15.43	0.03	0.29	0.07	8.48	37.17**	324.55
21	UP Chari-2 x Pant Chari-6	13.98**	292.11	-0.55	15.44	0.06	0.39	-0.05	7.51	-7.09	323.12
22	UP Chari-2 x CSV-84	19.44**	303.66	-0.31	14.50	0.01	0.23	-0.25	7.28	11.59	473.11
23	UP Chari-2 x Pant Chari-5	-38.35**	230.29	-1.89**	15.10	0.03	0.23	-0.04	7.36	17.53	485.10
24	UP Chari-2 x Rajasthan Chari-1	8.49	289.97	-0.51	14.57	0.02	0.22	0.84	8.76	24.78**	313.58
25	HC-171 x Pant Chari-8	-8.95	294.17	-0.25	15.72	0.11	0.41	-0.06	8.37	21.48**	336.75
26	HC-171 x CSV-17	11.00**	358.66	0.35	18.03	0.04	0.35	0.23	9.05	13.95	372.13
27	HC-171 x Pant Chari-6	4.42	352.58	0.26	17.72	0.09	0.38	-0.25	7.73	0.77	327.43
28	HC-171 x CSV-84	31.32**	352.93	5.72**	17.00	0.74**	0.23	0.82**	7.62	83.10**	541.08
29	HC-171 x Pant Chari-5	29.83**	368.50	3.27**	21.73	-0.03	0.25	0.18	7.99	27.50**	491.53
30	HC-171 x Rajasthan Chari-1	37.07**	388.58	-0.51	16.05	0.51**	0.27	0.02	8.35	-17.95	316.86
31	Pant Chari-8x CSV-17	11.03**	289.10	0.20	17.79	-0.03	0.24	0.14	9.11	6.88	379.39
32	Pant Chari-8x Pant Chari-6	24.12**	302.69	-0.29	17.08	0.03	0.37	0.01	8.14	-4.48	336.52
33	Pant Chari-8x CSV-84	-4.23	280.43	0.80	17.00	-0.01	0.22	-0.19	7.90	-3.37	468.94
34	Pant Chari-8x Pant Chari-5	-18.48**	250.60	-0.05	18.33	0.04	0.23	0.23	8.19	-9.65	468.71
35	Pant Chari-8 x Rajasthan Chari-1	8.33	290.25	0.00	16.47	0.07	0.22	0.18	8.67	21.31**	327.84
36	CSV-17 x Pant Chari-6	6.11	329.23	-0.34	18.73	0.06	0.41	-0.60**	7.92	-12.70	328.23
37	CSV-17 x CSV-84	-6.50	322.71	0.81	18.71	-0.03	0.22	0.17	8.65	0.97	473.22
38	CSV-17 x Pant Chari-5	0.13	313.76	-0.27	19.81	0.06	0.32	0.65**	9.00	19.37	497.67
39	CSV-17 x Rajasthan Chari-1	-11.85**	314.62	0.04	18.21	-0.02	0.22	-0.21	8.67	24.90**	324.19
40	Pant Chari-6 x CSV-84	-7.30	322.41	0.84	18.52	0.04	0.35	0.46	8.10	-4.24	436.50
41	Pant Chari-6 x Pant Chari-5	1.78	315.90	0.30	20.17	-0.09	0.24	-0.19	7.32	-5.64	441.15
42	Pant Chari-6 x Rajasthan Chari-1	-3.12	323.85	-0.67	17.29	-0.03	0.28	1.03	9.07	9.30	326.87
43	CSV-84 x Pant Chari-5	2.20	322.41	-1.61	17.07	-0.05	0.17	-0.05	7.42	25.81**	552.29
44	CSV-84 x Rajasthan Chari-1	0.63	333.69	-0.06	16.73	-0.03	0.18	-0.14	7.85	30.87**	479.76
45	Pant Chari-5 x Rajasthan Chari-1	32.98**	314.49	1.52**	20.48	-0.01	0.21	0.83**	7.54	97.82**	552.77
	SE (sij)	2.31		0.27		0.01		0.10		2.76	
	SE (sij-sik)	3.39		0.39		0.01		0.15		4.06	

Leaves per plant

Specific combining ability effect ranged from -2.54 (UP Chari-2 x Pant Chari-6) to 4.20 (UP Chari-1 x Rajasthan Chari-1). Cross combinations *i.e.*, UP Chari-1 x HC 308 (3.53), UP Chari-1 x Pant Chari-6 (1.16), UP Chari-1 x Rajasthan Chari-1 (4.20), HC 308 x UP Chari-2 (1.76), HC 308 x HC-171 (3.30), HC 308 x CSV-17 (2.16), UP Chari-2 x Pant Chari-8 (1.58), HC-171 x Pant Chari-6 (1.30), HC-171 x CSV-84 (3.20), Pant Chari-8 x CSV-84 (1.45), CSV-17 x CSV-84 (3.13), Pant Chari-6 x Pant Chari-5 (2.75) and Pant Chari-5 x Rajasthan Chari-1 (2.79) revealed significant positive specific combining ability effects and were emerged best specific combiners for more leaves per plant, while hybrids UP Chari-1 x Pant Chari-5, HC 308 x Pant Chari-8, HC 308 x CSV-84, HC 308 x Pant Chari-5, UP Chari-2 x Pant Chari-6, HC-171 x Pant Chari-8, CSV-17 x Pant Chari-5, CSV-17 x Rajasthan Chari-1, Pant Chari-6 x CSV-84 and Pant Chari-6 x Rajasthan Chari-1 exhibited significant and negative specific combining ability effects for leaves per plant.

Leaf breadth

The value of specific combining ability effects ranged from -0.53 (Pant Chari-8 x Rajasthan Chari-1) to 1.68 (UP Chari-1 x Rajasthan Chari-1). The best cross combinations in order of merit were UP Chari-1 x HC 308, UP Chari-1 x Rajasthan Chari-1, HC 308 x HC-171, HC 308 x Pant Chari-8, HC 308 x CSV-17, UP Chari-2 x Pant Chari-8, HC-171 x CSV-84 and Pant Chari-5 x Rajasthan Chari-1 found positive and significant effects for this characters and appeared best specific combiners for leaf breadth.

Leaf length

Estimates of specific combining ability effects varied from -7.42 (CSV-17 x Pant Chari-5) to 9.60 (HC-308 x HC-171). Crosses *i.e.*, UP Chari-1 x HC 308, UP Chari-1 x HC-171, UP Chari-1 x CSV-17, 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 CSV-17, UP Chari-2 x HC-171, UP Chari-2 x Pant Chari-8, UP Chari-2 x CSV-84, HC-171 x Pant Chari-8, HC-171 x CSV-17, HC-171 x CSV-84, HC-171 x Pant Chari-5, Pant Chari-8 x Pant Chari-6, 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 revealed positive and significant specific combining ability effects and were identified best specific combiners for leaf length, whereas hybrids UP Chari-1 x UP Chari-2, UP Chari-1 x Pant Chari-6, HC 308 x Pant Chari-8, UP Chari-2 x CSV-17, UP Chari-2 x Pant Chari-6, HC-171 x Rajasthan Chari-1, Pant Chari-8 x CSV-17, Pant Chari-8 x CSV-84, Pant Chari-8 x Rajasthan Chari-1, CSV-17 x CSV-84, CSV-17 x Rajasthan Chari-1 and Pant Chari-6 x CSV-84 noted negative and significant specific combining ability effects for this character.

Leaf area

The specific combining ability effect ranged from -38.35 (UP Chari-2 x Pant Chari-5) to 89.47 (UP Chari-1 x Rajasthan Chari-1). The best seventeen F_1's hybrids *viz.*, UP Chari-1 x HC 308, UP Chari-1 x HC-171, UP Chari-1 x CSV-17, UP Chari-1 x Rajasthan Chari-1, HC 308 x UP Chari-2, HC 308 x HC-171, HC 308 x CSV-17, HC 308 x Pant Chari-5, UP Chari-2 x Pant Chari-6, UP Chari-2 x CSV-84, HC-171 x CSV-17, HC-171 x CSV-84, HC-171 x Pant Chari-5, HC-171 x Rajasthan Chari-1, Pant Chari-8 x CSV-17, Pant Chari-8 x Pant Chari-6, and Pant Chari-5 x Rajasthan Chari-1 recorded significiant and positive sca effects and identified best specific combiners for more leaf area while, ten crosses were found significant and negative specific combining ability effects for this trait.

Stem girth

Value of specific combining ability effects ranged from -1.89 (UP Chari-2 x Pant Chari-5) to 5.72 (HC-171 x CSV-84). The F_1's hybrids namely, UP Chari-1 x HC 308, UP Chari-1 x UP Chari-2, UP Chari-1 x Rajasthan Chari-1, HC 308 x UP Chari-2, HC 308 x HC-171, HC 308 x CSV-17, UP Chari-2 x Pant Chari-8, HC-171 x CSV-84, HC-171 x Pant Chari-5 and Pant Chari-5 x Rajasthan Chari-1 had significant positive sca effects and were emerged best specific combiners for leaf stem girth, whereas only two crosses like UP Chari-1 x HC-171 and UP Chari-2 x Pant Chari-5 showed significant negative specific combining ability effects and were found poor specific combiners for this attributes.

Leaf stem ratio

Estimates of specific combining ability effect varied from -0.09 (Pant Chari-6 x Pant Chari-5) to 0.89 (UP Chari-1 x Rajasthan Chari-1). The cross combinations *viz.*, UP Chari-1 x Rajasthan Chari-1, HC 308 x HC-171, HC 308 x CSV-17, HC-171 x CSV-84 and HC-171 x Rajasthan Chari-1 revealed significant and positive sca effects for leaf stem ratio while seventeen cross combinations exhibited non significant negative specific combining ability effects for this characters.

Green fodder yield

The value of specific combining ability effects ranged from -18.87 (UP Chari-1 x HC-171) to 97.82 (Pantn Chari-5 x Rajasthan Chari-1). Crosses namely, UP Chari-1 x HC 308 (49.88), UP Chari-1 x UP Chari-2 (25.14), UP Chari-1 x Pant Chari-8 (22.96), UP Chari-1 x Rajasthan Chari-1 (62.29), HC 308 x UP Chari-2 (27.73), HC 308 x HC-171 (72.36), HC 308 x Pant Chari-8 (36.15), HC 308 x CSV-17 (59.28), HC 308 x Pant Chari-6 (34.63), UP Chari-2 x HC-171 (22.20), UP Chari-2 x Pant Chari-8 (31.87), UP Chari-2 x CSV-17 (37.17), UP Chari-2 x Rajasthan Chari-1 (24.78), HC-171 x Pant Chari-8 (21.48), HC-171 x CSV-84 (83.10), HC-171 x Pant Chari-5 (27.50), Pant Chari-8 x Rajasthan Chari-1 (21.31), CSV-17 x Rajasthan Chari-1 (24.90), CSV-84 x Pant Chari-5 (25.81), CSV-84 x Rajasthan Chari-1 (30.87) and Pant Chari-5 x Rajasthan Chari-1 (97.82) were recorded significant and positive sca effects and were found to be best specific combiners in order to merit for high green fodder yield. Out of forty five cross combinations, thirteen hybrids showed non-significant and negative specific combining ability effects for this attributes and identified poor green fodder yield. High heritability coupled with high genetic advance as percent of mean was observed for the characters *i.e.*, plant height, leaves per plant, leaf area, stem girth, leaf stem ratio and green fodder yield, suggesting that the genes governing these characters may have additive effect. High heritability coupled with high genetic advance for these characters have also been reported earlier by Yadav *et al.* (2007) [21]; Singh *et al.* (2017) [19].

Table 4: 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

Conclusions
The present study revealed that hybrids that exhibited heterosis for green fodder yield were not heterotic for all the traits. Among the lines, UP Chari-1 performed well for most of the characters studied. overall gca effects and *per se* performance among the lines, UP Chari-1 and Pant Chari-5 were identified as good general combiners for maximum 7 traits including green fodder yield, HC-171 for 6 characters and HC-308 for 5 attributes., suggested that these parents may be used in the hybridization programme aimed devolvement of superior genotypes/varieties in forage sorghum. The results indicated that exploitation of the heterosis or hybrid vigour might be one of the promising methods to effect crop improvement in sorghum for fodder purpose. The result also indicated that the heterosis for green fodder yield can be exploited commercially.

Acknowledgements
We are grateful to the authorities of the Sardar Vallabbhai Patel University of Agriculture & Technology, Meerut, U.P., India for all support in execution of this experiment. We also acknowledge the technical support from. Moreover, we would like to express our great respect for the editors and anonymous reviewers to improve the manuscript quality.

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