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Studies on heterosis in forage sorghum

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Abstract
Nature and magnitude of heterosis was studied for ten quantitative characters viz., 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 in a diallel mating design in forage sorghum. Out of forty five cross combinations, only five hybrids revealed superiority over better parent more than 36% for green fodder yield. Five F_1's hybrids *viz.,* HC-308 x PC-1, HC-308 x HJ-513, HC-260 x PC-1, HC-260 x HJ-513 and HC-260 x HJ 541 more than 36% heterobeltiosis over better parents. These individual crosses can be exploited in heterosis breeding programme for improvement in fodder yield and also suggesting that these attributes were governed by additive genes.

Keywords: *Sorghum bicolor,* heterosis

Introduction

Sorghum (*Sorghum bicolor* L. Moench) also called "Global Grain" is a crop of worldwide important due to its multipurpose use being a food, feed, fodder and fuel crop. The tremendous increase in demand for animal products in 21st century has led to great expansion in the area allocated for fodder crops, especially under sorghum production. Although, sorghum besides use as a grain and energy crop is also widely used for the production of forage and silage for animal feed; its leaves are broader having high palatability and provide green fodder over a longer period of time. But the required quantity of quality green fodder in not available throughout the year (Pahuja *et al.*, 2014) [15]. Sorghum belonging to family Poaceae, is an important *Kharif* seasons crop which is widely grown to meet the green as well as dry fodder requirement of the livestock. It is fast growing, adaptive to vast environmental condition and provides palatable nutritious fodder to the animals. India support 512.05 million of livestock, which includes 37.28 per cent cattle, 21.23 per cent buffalo, 12.71 per cent sheep, 26.40 per cent goat and 2.01 per cent pig. India supports nearly 20 per cent of the world's livestock being the leader in cattle (16%) and buffalo (5.5%) population. Deficiency in feed and fodder has been identified as one of the major component in achieving the desired level of livestock production. The shortage in dry fodder is 21.8 per cent compared with requirement of 560 million tones for the current livestock populations. Identification of good quality sorghum genotypes and development of location specific production technology offer an excellent opportunity to provide fodder for better nutrition to bovine population. Thus, suitable genotype and proper nutrition are very important to get higher fodder yield (Satpal *et al.*, 2015). The area under high forage yielding varieties is negligible in western Uttar Pradesh. Hence, it is essential to develop superior varieties with a significant superiority in term of green fodder yield. However, suitable varieties have not been developed for western U.P. The present study was, therefore, conducted to find out possibility of developing high yielding varieties in forage sorghum under different agro climatic conditions for Uttar Pradesh.

Material and Methods

The present investigation "Selection parameters and gene action for metric traits in forage sorghum (*Sorghum bicolor*)" was undertaken to assess the information on genetic parameters for green fodder yield and its components from a ten diverse parents *i.e*., MP Chari, HC-171, SSG-59-3, HC-308, CSV-15, HC-260, PC-1, HJ-513, HJ-541 and HC-136 using diallel mating design (excluding reciprocals). The experimental material for the present investigation was comprised of ten promising diverse parents and their all possible 45 F_1s, developed through crossing ten parental lines in diallel mating design (excluding reciprocals). All genotypes were evaluated in a complete randomized block design with three replications at Crop Research Center (Chirodi) of Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, during *kharif* season 2017 and 2018. The observations were recorded on ten characters namely, 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. Field plot was well prepared for sowing of the experimental materials 55 genotype (10 parents + 45 F_1's). The experiment was laid out in Randomized Completely Block Design with three replications. Seeds of each of the parental lines and crosses were sown by hand dibbling method in two rows plot by keeping row length 5.0 meter, row to row distance 30 cm and plant to plant 10 cm. Heterosis over mid and better parent suggested by Panse and Sukhatme (1967) [16].

Results and Discussion

In the present investigation, the degree of heterosis was measured as mean superiority of F_1s over their respective better parents. Heterosis may be high or low depending upon the mean of the parents. 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 also. The *per se* performance being the realized value, and the heterotic response being an estimate, the former should be given preference with high percentage of heterosis while making selection of cross combination. Analyzing the crosses for manifestation of hybrid vigour over better parent and mid parent (table-1), none of the crosses showed vigour for all the characters in the present investigation. Heterosis over better parent for days to 50% flowering ranged from -9.22 (HC-171 x HJ-513) to 10.27 (HC-308 x HJ-513). Hybrids MP Chari x CSV-15, MP Chari x HC-260, HC -171 x SSG-59-3, SSG-59-3 x HJ-513, HC-308 x HC-260, HC-308 x PC-1, HC-308 x HJ-513, HC-260 x HJ-513 and HC-260 x HJ-541 exhibited positive and significant heterosis over better parent for late flowering, whereas crosses MP Chari x PC-1, HC-171 x HJ-513, HC-260 x HC-136 and PC-1 x HJ-541 showed negative significant heterosis over better parent for early flowering. The similar findings were also reported by Kulkarni *et al.* (2006) [12] and Mohan *et al.* (2007) [14]. Heterobeltiosis for plant height values ranged from -16.84 (HJ-513 x HJ-541) to 21.25 (HC-260 x HJ-541). Hybrids MP Chari x SSG-59-3, SSG-59-3 x HC-260, HC-308 x HC-260, HC-308 x PC-1, HC-308 x HJ-513, HC-260 x PC-1, HC-260 x HJ-513, HC-260 x HJ-541 showed positive significant heterosis over better parent for tall stature. Hybrids MP Chari x CSV-15, MP Chari x PC-1, MP Chari x HJ-541, MP Chari x HC-136, CSV-15 x HC-260, CSV-15 x HJ-513, CSV-15 x HJ-541, HJ-513 x HJ-541 and HJ-541 x HC-136 revealed negative significant heterosis over better parent for dwarf stature. Present findings are in agreement with those of Chaudhary *et al.* (2006) [3] and Rani *et al.* (2007) [18]. Heterosis over better parent values ranged from -21.12 (CSV-15 x HJ-541) to 21.86 (HC-260 x HJ-541). Thirteen cross combinations exhibited namely, HC -171 x SSG-59-3, HC-171 x HC-308, SSG-59-3 x HC-260, HC-308 x CSV-15, HC-308 x HC-260, HC-308 x PC-1, HC-308 x HJ-513, CSV-15 x HC-260, CSV-15 x HJ-513, CSV-15 x HC-136, HC-260 x PC-1, HC-260 x HJ-513 and HC-260 x HJ-541 observed positive significant heterosis over better parent for leaf breadth and, eleven hybrids revealed negative significant heterosis over better parent, indicated poor performance for leaf breadth. The corroborative findings were also reported by Chaudhary *et al.* (2006) [3], Borole *et al.* (2008) [2] and Patel and Patel (2010) [17]. Heterobeltiosis over the better parental ranged from -10.90 (HC-171 x HJ-541) to 14.45 (HC-308 x HJ-513). Nine hybrids *i.e*., MP Chari x SSG-59-3, HC-171 x HJ-513, HC-308 x HC-260, HC-308 x PC-1, HC-308 x HJ-513, CSV-15 x HJ-513, HC-260 x PC-1, HC-260 x HJ-513, HC-260 x HJ-541 noted positive significant heterosis in order to merit over better parent for leaf length. Nine crosses exhibited negative significant heterosis over better parent, indicated poor performance for this trait. These results are in agreement with the finding of Deepalakshmi *et al.* (2007) [5] and Yadav and Pahuja (2007) [23]. Heterosis over better parent for hybrids over their better parental values varied from -16.65 (CSV-15 x HC-260) to 13.91 (HC-308 x PC-1). Cross combinations namely, MP Chari x HC-171, MP Chari x SSG-59-3, MP Chari x CSV-15, MP Chari x HJ-513, SSG-59-3 x HC-308, HC-308 x PC-1, HC-260 x PC-1, HC-260 x HJ-513 and HC-260 x HJ-541 revealed positive significant heterosis over better parent for stem girth and only seventeen hybrids showed negative significant heterosis over better parent. Present results are in agreement with the finding of Kamdi *et al.* (2009) [9] and Kanbar *et al.* (2011) [10]. Heterobeltiosis for leaves per plant over better parental values ranged from -21.33 (MP Chari x HJ-541) to 22.03 (HC-260 x PC-1). Ten hybrids showed positive significant heterosis over better parental values out of forty five crosses like MP Chari x SSG-59-3, SSG-59-3 x HC-308, SSG-59-3 x CSV-15, SSG-59-3 x HC-260, HC-308 x HC-260, HC-308 x PC-1, HC-308 x HJ-513, HC-260 x PC-1, HC-260 x HJ-513 and HC-260 x HJ-541 were found to be promising for more leaves per plant, whereas seventeen cross combinations exhibited significant negative heterosis over better parent, which indicated poor performance for this trait. The corroborative findings to total results were reported by Akabari *et al.* (2012) [1] and Tariq *et al.* (2012) [22]. Heterosis over better parent values ranged from -22.82 (CSV-15 x HJ-541) to 24.31 (HC-308 x HC-260). Cross combinations namely MP Chari x HC-171, MP Chari x PC-1, MP Chari x HC-136, HC -171 x SSG-59-3, HC-171 x HJ-513, SSG-59-3 x CSV-15, HC-308 x HC-260, HC-308 x PC-1, HC-308 x HJ-513, CSV-15 x PC-1, CSV-15 x HJ-513, HC-260 x PC-1, HC-260 x HJ-513 and HC-260 x HJ-541 exhibited significant positive heterosis over better parent for more leaf area, whereas six crosses were found negative significant heterosis over better parent for this character. Such type of findings were also reported by Goyal *et al.* (2013) [6] and Kale and Desai (2016) [8]. Heterobeltiosis for leaf stem ratio values varied from -37.21 (HC-260 x HC-136) to 38.78 (HC-260 x HJ-513). Thirteen hybrids revealed positive significant heterosis over better parent which are as follows: MP Chari x HJ-513, MP Chari x HJ-541, HC-171 x HJ-513, HC-171 x HJ-541, HC-171 x HC-136, SSG-59-3 x HC-260, SSG-59-3 x HJ-513, HC-308 x HC-260, HC-308 x PC-1, HC-308 x HJ-513, CSV-15 x HJ-541, HC-260 x PC-1 and HC-260 x HJ-513. Similar findings and suggestions were given by Khandelwal *et al.* (2006) [11], Deepalakshmi *et al.* (2007) [5] and Patel and Patel (2010) [17]. Heterosis over better parent for hybrids over their better parental values ranged from -21.61 (HJ-513 x HJ-541) to 15.38 (HC-260 x HJ-541). Cross combinations *i.e*., MP Chari x SSG-59-3, HC-308 x HC-260, HC-308 x PC-1, HC-308 x HJ-513, HC-260 x PC-1, HC-260 x HJ-513 and HC-260 x HJ-541 revealed positive significant heterosis over better parent for total soluble solids, while ten crosses showed negative significant heterosis over better parent for this character. Similar findings were also reported by earlier researchers namely Kanbar *et al.* (2011) [10], Jain and Patel (2016) [7] and Kumar and Shrotria (2016) [13]. Maximum magnitude of heterosis and *per se* performance was exhibited highly significant and positive desirable heterosis over mid and better parent manifested in cross combinations *i.e.* HC -171 x SSG-59-3 for days to 50% flowering, leaf breadth, leaf area and green fodder yield; HC- 171 x HC-260 for green fodder yield; HC-171 x PC-1 for leaf length, leaf area, leaf stem ratio and green fodder yield; SSG-59-3 x CSV-15 for leaves per plant, leaf area and green fodder yield; SSG-59-3 x HC-260 for plant height, leaf breadth, leaves per plant, leaf stem ratio and green fodder yield; SSG-59-3 x PC-1 for green fodder yield; SSG-59-3 x HJ-513 for days to 50% flowering, leaf stem ratio and green fodder yield; HC-308 x HC-260 for days to 50% flowering, plant height, leaf breadth, leaf length, leaves per plant, leaf area, leaf stem ratio, total soluble solids and green fodder yield; HC-308 x PC-1 for 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; HC-308 x HJ-513 for 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; HC-308 x HJ-541 for green fodder yield; HC-260 x PC-1 for plant height, leaf breadth, leaf length, stem girth, leaves per plant, leaf area, leaf stem ratio, total soluble solids and green fodder yield; HC-260 x HJ-513 for 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; HC-260 x HJ-541 for days to 50% flowering, plant height, leaf breadth, leaf length, stem girth, leaves per plant, leaf area, total soluble solids and green fodder yield; PC-1 x HC-136 for green fodder yield and HJ-541 x HC-136 for green fodder yield. These results are in general agreement with the finding of Rini *et al.* (2016) [19], Chikuta *et al.* (2017) [4], Rocha *et al.* (2018) and Soujanya *et al.* (2018) [21]. On the basis of overall results and *per se* performance the manifestation of high degree of heterosis over better and mid parent in certain F_1's hybrids *viz.*, HC-308 x PC-1, HC-308 x HJ-513, HC-260 x PC-1, HC-260 x HJ-513 and HC-260 x HJ 541 identified that great possibility of developing hybrid for commercial cultivation. Considering the predominance of non additive gene action for yield and yield contributing traits manifesting high magnitude of hybrid vigor, heterosis breeding may be useful for improving yield in forage sorghum. As pointed out earlier, the possibility of exploiting hybrid vigour depends upon the extent and the cost of hybrid seed production. It is easier to produce hybrid seed of forage sorghum economically as each pollination would produce sufficient quantity of seed and therefore, the hybrid vigour can be easily be exploited for the commercial purposes in sorghum crop.

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

S. No.	Characters	Day of 50% flowering		Plant height (cm)		Leaf breadth		Leaf length (cm)		Stem girth (mm)	
	Crosses	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP
1	MP Chari x HC-171	2.84	3.88	-1.96	- 3.88	-4.38**	- 5.54**	2.80	4.26	5.95**	9.47**
2	MP Chari x SSG- 59-3	-2.82	- 0.33	5.23**	5.35**	-1.26	- 3.22	4.19**	4.88**	4.32**	4.88**
3	MP Chari x HC-308	-1.95	- 0.33	1.31	3.05	-4.14**	- 4.94**	-0.68	- 3.28	1.68	2.90
4	MP Chari x CSV-15	4.34**	4.81**	-13.69**	-14.12**	-7.82**	- 8.80**	0.18	1.53	-13.10**	-15.04**
5	MP Chari x HC-260	4.39**	4.79**	3.97	04.93	-2.19	- 3.47	-6.58**	-7.79**	-9.89**	-8.55**
6	MP Chari x PC-1	-8.00**	-9.13**	-7.44**	-7.55**	0.94	0.98	3.77	5.07*	-2.14	- 3.95
7	MP Chari x HJ-513	1.00	1.47	0.54	3.96	-5.98**	-5.11**	-2.50	-2.98	4.17**	4.88**
8	MP Chari x HJ-541	1.57	4.47	-13.53**	- 12.85**	-2.12	- 3.91	-4.29	- 3.99	-1.79	-0.60
9	MP Chari x HC-136	-0.53	- 4.81	-13.85**	-14.09**	-0.81	-3.80	0.67	1.02	1.79	2.40
10	HC-171 x SSG- 59-3	4.98**	4.26**	-1.25	-0.24	4.35**	4.89**	-3.94	-1.94	-0.79	- 1.97
11	HC-171 x HC-308	-1.65	-0.37	-3.53	- 3.49	4.15**	4.93**	-8.31**	-8.02**	-10.56**	-14.76**
12	HC-171 x CSV-15	2.83	4.33	-0.37	- 2.59	-3.11	-3.71	-0.13	- 2.63	-10.11**	-14.75**
13	HC-171 x HC-260	-0.98	- 4.36	-0.85	-1.16	3.29	2.56	-5.95	-2.82	-12.16**	-15.03**
14	HC-171 x PC-1	0.29	0.43	-1.69	-1.02	1.69	3.76	-2.55	-2.39	-6.17**	-5.48**
15	HC-171 x HJ-513	-9.22**	-9.32**	-2.91	-0.40	-4.84**	- 4.87**	5.94**	7.26**	-6.34**	-7.60**
16	HC-171 x HJ-541	-3.96	-2.20	-9.65	- 3.44	-0.27	-0.09	-10.90**	-7.25**	-3.66	-1.62
17	HC-171 x HC-136	0.06	3.42	1.60	3.87	-2.71	-2.36	0.89	2.67	-1.32	-0.57
18	SSG-59-3 x HC-308	2.03	2.98	-3.22	-3.22	0.00	0.76	-1.70	- 3.86	4.25**	4.95**
19	SSG-59-3 x CSV-15	-3.61	-3.09	2.83	2.83	-19.61**	-15.05**	1.49	2.18	-6.29**	- 4.71**
20	SSG-59-3 x HC-260	-2.53	- 3.89	11.43**	15.16**	4.69**	4.98**	-0.14	- 1.11	-1.35	- 0.94
21	SSG-59-3 x PC-1	-1.66	- 4.58	-2.51	- 0.14	-1.54	-1.01	2.06	4.02	-13.42**	-15.00**
22	SSG-59-3 x HJ-513	4.41**	4.62**	-1.67	- 1.88	-8.96**	-8.99**	-0.13	- 3.19	-1.47	- 0.32
23	SSG-59-3 x HJ-541	-1.20	-0.81	-7.76	- 3.69	-3.98	-1.43	-7.42**	-11.71**	1.25	3.99
24	SSG-59-3 x HC-136	2.75	4.94	-1.95	-0.20	-2.01	- 0.07	-3.98	-3.67	-7.08**	-5.38**
25	HC-308 x CSV-15	-3.42	-1.78	-1.19	- 4.99	11.72**	14.92**	-10.12**	-14.42**	-6.87**	- 4.68**
26	HC-308 x HC-260	8.30**	8.24**	11.63**	11.09**	10.68**	10.21**	13.69**	12.37**	-1.08	- 0.55
27	HC-308 x PC-1	9.84**	9.49**	12.28**	10.71**	10.69**	20.00**	12.34**	11.33**	13.91**	14.96**
28	HC-308 x HJ-513	10.27**	14.38**	20.21**	2 0.50**	10.07**	14.47**	14.45**	12.22**	11.17**	11.29**
29	HC-308 x HJ-541	-1.59	-1.07	-10.82	-4.97	-2.52	-0.68	-6.28**	-6.80**	-2.23	-2.04
30	HC-308 x HC-136	-3.80	-0.86	-1.55	-4.85	-2.15	-0.82	-6.47**	-7.47**	-0.95	-2.73
31	CSV-15 x HC-260	0.65	4.61	-9.85**	-10.73**	14.89**	15.55**	-0.22	-0.36	-16.65**	-16.96**
32	CSV-15 x PC-1	-3.44	-0.86	0.13	4.80	-15.76**	-16.94**	2.25	4.91	-2.96	-0.98
33	CSV -15 x HJ-513	-2.01	- 4.71	-9.90**	-8.90**	10.00**	11.50**	11.01**	15.46**	-13.56**	-14.97**

34	CSV-15 x HJ-541	-5.01	-1.88	-3.13	- 4.73	-21.12**	-24.81**	-8.80**	-9.56**	-12.07**	-14.98**
35	CSV-15 x HC-136	-1.05	-4.70	-0.08	- 0.16	12.75**	14.84**	-1.69	-2.71	-3.51	-1.91
36	HC-260 x PC-1	-0.86	-0.39	13.25**	20.97**	13.00**	21.27**	5.81**	6.82**	6.43**	4.81**
37	HC-260 x HJ-513	7.68**	8.25**	11.62**	11.81**	10.38**	14.37**	7.66**	8.43**	5.03**	6.10**
38	HC-260 x HJ-541	9.52**	8.99**	21.25**	18.21**	21.86**	20.47**	11.88**	15.33**	4.08**	4.87**
39	HC-260 x HC-136	-7.81**	-7.16**	-3.98	- 4.91	3.76	3.67	-3.37	-3.88	-0.49	-0.41
40	PC-1 x HJ-513	-4.29	- 4.81	-1.43	-0.55	-0.19	- 3.73	2.57	4.02	-5.23**	- 6.28**
41	PC-1 x HJ-541	-8.53**	-8.09**	-16.05**	-17.49**	-2.52	- 3.59	-3.54	-1.51	-7.99**	-7.42**
42	PC-1 x HC-136	-3.74	- 2.24	-7.06	-2.50	0.27	2.94	-2.66	-1.11	-6.83**	-6.46**
43	HJ-513x HJ-541	-3.35	-3.01	-16.84**	-18.69**	-9.56**	-10.23**	-1.04	-2.33	-3.41	-4.59
44	HJ-513 x HC-136	1.22	2.27	-3.16	- 2.45	-9.13**	-9.24**	-2.05	-2.19	-0.88	-2.33
45	HJ-541 x HC-136	-5.21	-2.82	-12.56**	-13.65**	-0.27	- 0.27	-10.65**	-11.42**	-1.83	-0.49
	SE	3.43	3.12	6.25	5.11	0.42	0.36	2.92	2.58	1.00	0.87

* Significant at 5% probablity level, ** Significant 1% probablity level

S. No.	Characters	Leaves per plant		Leaf area (cm^2)		Leaf stem ratio		Total soluble solids (%)		Green fodder yield (g) per plant	
	Crosses	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP
1	MP Chari x HC-171	-8.90**	-9.64**	5.97**	12.48**	-4.40	-1.69	-15.20**	-16.07**	-7.27	- 7.53
2	MP Chari x SSG- 59-3	6.28**	10.95**	-3.81	- 1.51	-1.43	-2.62	6.90**	6.87**	-3.64	- 3.90
3	MP Chari x HC-308	-2.21	- 1.25	-2.06	- 5.81	-18.92**	-18.63**	-4.88**	-5.35**	7.43	8.37
4	MP Chari x CSV-15	-5.45**	- 4.77**	-4.47**	- 9.93**	-5.81	- 6.52	-3.13	-4.60	-3.15	-1.71
5	MP Chari x HC-260	-9.45**	- 10.74**	-1.22	-1.57	-26.74**	-26.97**	4.40	5.32	3.34	4.31
6	MP Chari x PC-1	-0.80	-1.90	9.75**	10.18**	-17.95**	-18.42**	-6.65	- 7.81	-3.15	- 4.16
7	MP Chari x HJ-513	-1.99	- 3.08	-9.39**	-9.88**	18.37**	19.00**	-1.77	- 2.65	1.98	1.01
8	MP Chari x HJ-541	-21.33**	-27.47**	0.51	0.65	15.56**	16.17**	-1.68	-1.32	1.72	1.78
9	MP Chari x HC-136	1.45	2.51	11.30**	12.93**	-23.26**	-23.91**	2.35	3.04	-1.34	-1.96
10	HC-171 x SSG- 59-3	-1.13	- 2.42	4.07**	4.72**	-11.43**	-15.10**	-7.60	-8.56	14.17**	15.07**
11	HC-171 x HC-308	0.15	0.60	2.26	3.20	-13.51**	-14.95**	-9.94**	-9.06**	1.44	2.00
12	HC-171 x CSV-15	-1.57	-0.20	-9.22**	- 9.87**	-7.69	- 8.00	-7.96	-8.31	2.21	4.69
13	HC-171 x HC-260	-2.43	- 1.90	1.53	2.87	-8.77	-9.35	3.39	4.30	36.89**	36.91**
14	HC-171 x PC-1	2.02	2.23	3.60	3.61	-17.95**	-18.69**	-2.90	- 1.29	34.18**	34.31**
15	HC-171 x HJ-513	-17.24**	-16.40**	9.76**	10.51**	16.33**	17.36**	-3.87	-4.14	31.06*	34.74**
16	HC-171 x HJ-541	-6.48**	- 5.67**	-1.66	-1.83	22.22**	23.08**	-13.57**	-17.03**	1.11	5.44
17	HC-171 x HC-136	-8.03**	-9.66**	2.41	2.50	11.63**	13.64**	-3.09	-3.81	4.50	5.23
18	SSG-59-3 x HC-308	4.56**	4.45**	-2.52	-0.06	-3.41	-2.78	-3.66	- 3.64	2.66	3.36
19	SSG-59-3 x CSV-15	5.15**	6.04**	21.12**	22.00**	-2.29	- 3.45	-7.14	- 8.60	44.51**	44.72**
20	SSG-59-3 x HC-260	5.05**	5.56**	1.20	2.90	25.71**	26.96**	0.49	2.21	33.09**	36.42**
21	SSG-59-3 x PC-1	-1.28	- 2.46	0.93	1.29	-10.26**	-11.41	-6.01	- 7.16	28.22**	35.02**
22	SSG-59-3 x HJ-513	-5.41**	-5.61**	-3.13	-2.50	10.20**	11.76**	-13.26	-15.14	31.87**	35.31**
23	SSG-59-3 x HJ-541	-15.22**	-17.93**	-3.83	-3.49	-6.67	-7.00	-8.34**	- 9.53**	3.93	4.79
24	SSG-59-3 x HC-136	-2.61	- 0.66	-1.06	-0.36	-1.63	-2.56	-0.65	- 0.25	2.90	3.50
25	HC-308 x CSV-15	-8.00**	-9.19**	-17.11**	- 18.81**	-24.32**	-26.67**	-3.52	- 3.42	3.44	4.72
26	HC-308 x HC-260	8.67**	9.56**	24.31**	30.29**	24.43**	25.66**	14.98**	15.23**	45.17**	46.88**
27	HC-308 x PC-1	9.48**	10.27**	22.83**	25.77**	25.00**	26.63**	11.39**	12.91**	36.23**	45.25**
28	HC-308 x HJ-513	5.29**	6.94**	10.17**	14.44**	16.33**	17.65**	11.88**	12.96**	42.43**	48.02**
29	HC-308 x HJ-541	-3.07	- 3.51	-1.99	-0.93	-4.44	- 4.88	-13.37**	-15.01**	40.02**	49.04**
30	HC-308 x HC-136	-0.14	- 2.35	-1.78	-0.01	-11.63**	-15.00**	-1.18	- 1.60	2.00	3.20
31	CSV-15 x HC-260	-11.02**	-15.83**	-1.12	- 2.04	-3.04	- 2.56	-11.27**	-14.19**	1.50	2.56
32	CSV-15 x PC-1	-0.79	- 0.80	13.87**	15.44**	-25.64**	-26.45**	-7.55	-8.85	2.85	3.82
33	CSV -15 x HJ-513	-8.53**	- 9 09**	10.04**	14.98**	-2.49	-2.78	1.14	3.49	1.71	2.87
34	CSV-15 x HJ-541	-17.72**	-18.53**	-22.82**	-24.41**	28.89**	28.88**	-1.01	- 0.41	2.89	3.95
35	CSV-15 x HC-136	-12.97**	-14.14**	-2.23	- 3.88	-2.93	- 3.03	-2.75	-3.01	2.91	3.85
36	HC-260 x PC-1	22.03**	32.12**	23.26**	24.00**	33.33**	35.45**	8.80**	9.19**	35.62**	40.80**
37	HC-260 x HJ-513	21.82**	23.54**	19.41**	18.43**	38.78**	39.69**	10.97**	10.52**	40.88**	44.91**
38	HC-260 x HJ-541	20.88**	20.43**	20.81**	22.42**	2.89	3.92	15.38**	17.42**	41.52**	41.54**
39	HC-260 x HC-136	-7.05**	- 8.49**	0.82	3.24	-37.21**	-38.47**	-6.00	-7.54	3.93	3.80
40	PC-1 x HJ-513	-2.06	-3.77	0.79	4.34	-14.29**	-14.55**	-8.94***	-9.64**	1.79	2.09
41	PC-1 x HJ-541	-5.04**	-6.90**	-1.21	- 2.68	-2.22	-3.76	-1.05	-1.11	1.08	1.30
42	PC-1 x HC-136	-1.62	- 2.04	0.25	1.32	-9.30	-.88	-12.55**	-13.53**	24.44**	25.28**
43	HJ-513x HJ-541	-21.16**	-23.36**	-0.79	-0.92	-2.04	- 2.13	-21.61**	-21.89**	2.29	2.32
44	HJ-513 x HC-136	-2.36	-2.59	-8.29**	-9.09**	-3.20	-3.35	-2.39	-3.55	1.89	2.36
45	HJ-541 x HC-136	-2.55	-3.86	-3.39	-1.64	-2.44	-2.27	-2.56	-3.61	23.84**	24.84**
	SE	0.79	0.68	8.88	7.97	0.02	0.02	0.49	0.42	16.23	14.57

* Significant at 5% probability level, ** Significant 1% probability level

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