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Combining ability studies for yield and quality traits in baby corn (*Zea mays* L.)

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Abstract
Combining ability analysis for baby corn yield and its component traits was performed with four lines (Single cross hybrids), twelve testers (Inbred lines) and the resulting 48 three way cross hybrids using Line × tester analysis. The interaction of Line × tester was highly significant for all the characters studied. Among the lines, HM 4 and AH 7009 were found as the best general combiners with better mean performance for most of the yield contributing traits. Considering the testers, PDM 260-1 and PDM 112-1 were found as the best general combiners with better mean performance for most of the yield contributing traits. Among the crosses, HM 4 × PDM 53, HM 4×PDM 260-1 and was found to be the superior with positive significant SCA effects and better mean performance for most of the traits along with babycorn yield. Similar superior positive significant SCA effects with better mean performance were also observed in HM 4 × PDM 4441 and HM 4×PDM 112-1.

Keywords: Line × tester, baby corn, combining ability, GCA, SCA, three way cross

Introduction
Maize (*Zea mays* L.) is the third most important cereal crop in India after rice and wheat. The crop can be used at any stage of its growth and has very big market potential. Specialty corns (babycorn, sweet corn, popcorn, high oil corn, etc) assume tremendous market potential in India and international markets (Venkatesh *et al*., 2003) [17]. Baby corn (*Zea mays*) refers to whole, entirely edible cobs of immature corn harvested just before fertilization at the silk emergence stage. Baby corn is highly nutritive and its nutritional quality is on par or even superior to some of the seasonal vegetables. Besides protein, vitamins and iron, it is one of the richest source of phosphorus. It is also free from residual effects of pesticides, as the young cobs are wrapped up within the husk and well protected from diseases, insects, fungicides and insecticides (Dass *et al*., 2008). Looking to the scope for cultivation of babycorn in India, the present study was conducted with an objective to identify the heterotic combination for babycorn yield, yield traits; quality traits in three way cross hybrids.

Materials and Methods
The materials in the present investigation comprised of 48 three way crosses derived from 4 lines (Single cross hybrids including one private sector hybrid) and twelve testers (inbred lines) in a line × tester mating design which were evaluated in randomized block design with 3 replications during summer 2016 at Botany garden, Department of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad (Karnataka), India. Each experimental plot consisted of two rows of 3 m length with 60 cm × 20 cm spacing. Plants were de-tassled for baby corn purpose at the time of flowering. Baby corns were harvested after 1-1.5 cm silk emergence. Observations such as days to fifty per cent silking, baby corn length, baby corn girth, number of cobs per plant, husked weight of cob, dehusked weight of cob, husked yield per plant, dehusked yield per plant, husked yield per hectare and dehusked yield per hectare were recorded. Combining ability analysis was carried out as per procedure given by Kempthorne (1957) [11].

Results and Discussion
Analysis of variance for heterosis and combining ability was carried out for yield and yield contributing characters and the mean sum of squares are presented in Table 1. The results revealed that genotypes exhibited highly significant differences among themselves for all the traits studied. The parents exhibited significant differences for all the traits indicating greater

diversity in the parental lines and governed by both additive and non-additive gene action. The crosses exhibited significant differences, indicating varying performance of cross combinations. After partitioning the effects of crosses into lines, testers and line × tester effects, the interaction effects (line × testers) were found to be significant for all the traits under study indicating that hybrids differed significantly in their *sca* effects. Tucak *et al*. (2012) [16] and Atif *et al.* (2012) [2] observed highly significant differences for testers, lines and line x tester interaction.

The general combining ability (*gca)* effects of 4 lines (females) and 12 testers (males) and the specific combining ability (*sca*) effects of 48 hybrids for yield and yield contributing characters were estimated and were presented in Tables 2 and 3 respectively.

Among the lines, AH 5021 (-1.40) and AH 7009 (-0.65) recorded significant negative *gca* effects for days to 50 per cent silking, and among testers, PDM 112-1, PDM 260-1 and PDM 260 recorded the significant negative gca values of -2.62, -2.62 and -1.37 respectively indicating that they were good general combiners for earliness regarding days to 50 per cent silking. In respect of days to 50 per cent silking 13 hybrids recorded significant negative *sca* effects, among which, AH 7009 × PDM 105 recorded lowest significant negative *sca effect* (-5.26). The results obtained are in conformity with the findings of Rajitha *et al*. (2014) [13], Kumari *et al.* (2017) [12].

In respect of baby corn length, tester, PDM 260 (0.57) recorded significant positive *gca* effects Four hybrids recorded significant positive *sca* effects, *viz.*, AH 7009×PDM 260-1 (0.92), PINNACLE×PDM 260-2 (0.91), AH 7009×PDM 162-2 (1.37) and HM 4×PDM 24-3 (2.84). Character in present investigation is also in consonance with the findings of Dhasarathan *et al.* (2015) [7] and Rodrigues and da Silva (2002) [15] and Kumari *et al.* (2017) [12], Camacho *et al*. (2015) [4].

The GCA effects for line AH 7009 and tester PDM 24-3 and were found to be highest and positively significant for baby corn girth suggesting their potential utility for achieving the different standards of babycorn girth. The crosses HM 4 × HKI 323 and Pinnacle × PDM 260-2 reflected good SCA effect for cob girth. Kumari *et al.* (2017) [12] and Dhasarathan *et al.* (2015) [7], Camacho *et al*. (2015) [4] reported similar findings for cob girth.

Lines AH 5021(3.65) and Pinnacle (1.82) and testers PDM 112-1 (2.75), HKI 323 (1.44) and HKI 1105 (3.18) were good general combiners for husked weight of cob suggesting their usefulness in developing hybrids and subsequently new inbreds with high babycorn yield. The 13 crosses exhibited positive and significant sca effects for husked weight of cob, among which AH 5021 × HKI 323 and AH 7009 × PDM 260-1 recorded the highest *perse* yield. Dhasarathan *et al.* (2012) [12] reported the similar findings.

The estimates of *gca* for dehusked weight of cob showed that the testers, PDM 260 (1.20), PDM 260-1 (1.06) and HKI 1105 (0.823) have exhibited positive and significant *gca* effects Hence, these could be used extensively in hybrid breeding program for improvement of babycorn weight. The crosses which exhibited significant desirable *sca* effects were AH 5021 × HKI 323, Pinnacle × HKI 1105, AH 7009 × PDM 260-1, AH 7009 × PDM 260-2 and AH 5021 × PDM 260 for dehusked weight of cob. Dhasarathan *et al.* (2015) [7] also found positive and significant gca effects for the trait.

The estimates of *gca* showed that among the testers, PDM 112-1 and PDM 260-1, among the lines, HM 4 recorded positive and significant *gca* effects for number of cobs per plant. Hence, they have been identified as best general combiner for the respective trait. HM 4 × PDM 53, AH 7009 × HKI 323, HM 4 × PDM 4441, HM 4 × PDM 260-1 and AH 7009 × PDD 260 crosses recorded positive and significant s*ca* effects for dehusked weight of cob. The findings are in line with Kumari *et al.* (2017) [12], Ahmed *et al*. (2016) [1] and Dhasarathan *et al.* (2015) [7] and Bhat (2016) [3].

Line AH 5021 and testers PDM 112-1 and PDM 260-1 possessed positive and significant GCA effects for husked yield per plant and husked yield per hectare. Among the hybrids 9 recorded significant and positive sca for husked yield per plant and husked yield per hectare. These results are in conformity with findings of Kumari *et al.* (2017) [12] and Izhar and Chakraborty (2013) [10].

For dehusked yield per plant and dehusked yield per hectare, which are of high economic importance, lines AH 7009 (64.014) and HM 4 (66.908) came out to be best general combiners with mean babycorn yields of 17245 and 2052 Kg per hectare and were found to be 44 and 71 percent superior over the commercial babycorn single cross hybrid check CPB 472 which recorded a mean babycorn yield of 1198 Kg per hectare. Among testers HKI 323 recorded highest perse babycorn yield (1431 Kg/ha) which was 19 percent superior to check CPB 472 (1198 Kg/ha). But, even though the yield levels of PDM 112-1, HKI 163 and PDM 260-1were lower than check they found to be best general combiners as they possessed significant gca values in desirable direction for most of the yield influencing characters. Among the hybrids HM 4×PDM 53, HM 4×PDM 260-1, HM 4×PDM 4441 and HM 4×PDM 112-1 recorded the mean babycorn yields of 1448, 1436, 1320 and 1316 Kg per hectare and 21, 10, 10 and 10 per cent superior respectively over check CPB 472 significant positive sca effect values for most of the traits studied. Similar findings were also reported by Ramachandrappa *et al.* (2004) [14] and Ahmed *et al.* (2016) [1].

Table 2: Estimates of general combining ability (GCA) effects of parents, perse babycorn yield (Kg/ha) and percent superiority/ inferiority over check

Lines												
	DFS	**CL**	**CG**	**HWC**	**DHWC**	**NCPP**	**HYPP**	**DHYPP**	**HYPH**	**DHYPH**	***Perse* babycorn yield (Kg/ha)**	**Percent improvement over Check CPB 472**
HM 4	0.54**	-0.34**	-0.04**	-2.74**	0.08	0.06*	-1.53	0.80*	-127.39	66.91**	2052	71
AH 7009	-0.65**	-0.26*	0.06**	-2.73**	0.41	0.03	-2.51*	0.77*	-208.92*	64.01*	1725	44
AH 5021	-1.40**	-0.10	-0.04**	3.65**	-0.71**	0.00	4.67**	-0.92*	389.46**	-76.40*	1164	-3
PINNACLE	1.51	0.71	0.02	1.82**	0.21	-0.10	-0.64	-0.66	-53.15	-54.52	967	-19
SE (gi)	0.17	0.13	0.01	0.03	0.38	0.21	1.03	0.38	86.01	31.52		
CD 5%	0.35	0.26	0.03	0.06	0.76	0.41	2.05	0.75	170.78	62.57		
CD 1%	0.46	0.34	0.04	0.08	1.01	0.55	2.71	0.99	226.15	82.86		
SEd (gi-gj)	0.25	0.18	0.02	0.04	0.54	0.29	1.46	0.53	121.64	44.57		
Testers												
	DFS	CL	CG	HWC	DHWC	NCPP	HYPP	DHYPP	HYPH	DHYPH	***Perse* babycorn**	**Percent improvement**

											yield (Kg/ha)	over Check CPB 472
HKI 323	0.54	0.08	0.05*	1.44*	-0.02	0.02	2.65	0.10	220.95	8.68	1431	19
PDM 4441	-0.04	-0.24	0.07 **	0.02	0.18	0.06	1.86	0.83	155.11	69.02	1143	-5
HKI 1105	-0.21	0.44	-0.05*	3.18**	0.82*	-0.10	0.71	0.05	58.90	-4.25	867	-28
PDM 260-2	0.46	-0.37	-0.04	-3.01**	-0.75*	-0.07	-5.82**	1.49*	-484.79**	124.34*	761	-36
PDM 53	-0.54	0.30	-0.03	0.73	0.50	0.03	2.30	1.09	191.65	90.76	750	-37
PDM 112-1	-2.62**	-0.47*	-0.04	2.75**	-0.38	0.20**	9.32**	1.51*	776.73**	125.48*	743	-38
PDM 24-3	2.21**	0.00	0.14**	-2.41**	-0.02	0.00	-3.38	0.04	-281.32	3.63	689	-42
PDM 162-2	1.37**	0.01	-0.05*	1.15	-0.313	-0.12*	-1.82	1.56*	-151.77	130.07*	686	-43
HKI 163	3.12**	-0.09	-0.04	-1.51*	-0.83*	-0.07	-3.85*	1.73**	-321.25*	143.89**	675	-44
PDM 260	-1.37**	0.57*	0.00	-0.44	1.20**	-0.05	-2.20	0.75	-183.48	61.95	608	-49
PDM 105	-0.29	-0.59*	-0.10**	-2.10**	-1.45**	-0.05	-4.38*	2.34**	-365.41*	194.99*	475	-60
PDM 260-1	-2.62**	0.36	0.08**	0.21	1.06**	0.16 **	4.62*	2.86**	384.69*	238.04**	394	-67
SE (gi)	0.30	0.22	0.02	0.05	0.66	0.36	1.79	0.66	148.98	54.59		
CD 5%	0.60	0.45	0.05	0.11	1.32	0.72	3.55	1.30	295.81	108.38		
CD 1%	0.79	0.59	0.06	0.14	1.74	0.95	4.70	1.72	391.70	143.52		
SEd (gi-gj)	0.43	0.32	0.03	0.08	0.94	0.51	2.53	0.93	210.69	77.20		

Mean yield of check (CPB 472) - 1197.770 Kg/ha

DFS - Days to 50% silking, CL - Cob length, CG - Cob girth, NCPP - No of babycorns per plant, HWC - Husked weight of babycorn (g), DHWC - Dehusked weight of babycorn (g), HYPP - Husked yield per plant (g), DHYPP - Dehusked yield per plant (g), HYPH - Husked yield per hectare (Kg), DHYPP - Dehusked yield per hectare (Kg).

Table 2: Estimates of specific combining ability (SCA) effects of crosses, *perse* babycorn yield (Kg/ha) and percent superiority/ inferiority over check

	DFS	CL	CG	HWC	DHWC	NCPP	HYPP	DHYPP	HYPH	DHYPH	*Perse* babycorn yield (Kg/ha)	Percent improvement over Check CPB 472
HM 4×PDM 53	-2.21**	0.45	0.08	0.875	0.86	0.30**	9.04*	4.15**	753.58*	345.80*	1448	21
HM 4×PDM 260-1	-0.79	-0.59	-0.04	0.05	-0.07	0.24*	6.03	2.25	502.39	187.08	1436	20
HM 4×PDM 4441	-1.37*	0.56	-0.01	0.90	0.12	0.28*	8.37*	2.88*	697.32*	239.77*	1320	10
HM 4×PDM 112-1	-2.12**	0.62	0.11*	-2.01	1.26	0.07	-1.14	2.15	-95.11	179.38	1316	10
AH 5021×HKI 323	-0.35	0.79	0.05	6.80**	3.02**	0.12	12.41**	4.94**	1033.90**	412.08**	1289	8
AH 7009×PDM 112-1	-0.93	0.00	-0.18**	-4.74**	1.03	0.04	-5.93	1.74	-494.17	144.98	1279	7
PINNACLE×HKI 1105	-4.18**	0.82	-0.02	-10.12**	2.84**	0.13	-7.85*	4.47**	653.89*	372.68**	1258	5
AH 7009×PDM 260-1	2.40**	0.92*	0.20**	4.91**	1.83*	-0.26*	-0.99	-0.56	-82.69	-46.92	1199	0
PINNACLE×PDM 260-1	0.24	-0.73	-0.07	-6.45**	-0.26	0.10	-4.87	0.74	405.85	62.01	1190	-1
HM 4×PDM 260	-0.71	-0.19	-0.05	3.48*	0.95	-0.02	4.162	1.10	346.95	91.83	1165	-3
AH 5021×PDM 53	-4.26**	-0.38	0.04	3.89**	1.27	0.10	8.06*	2.46	671.52*	204.66	1163	-3
AH 7009×PDM 260-2	-0.01	0.12	-0.04	-3.39*	1.69*	0.10	-1.09	3.14*	-90.87	261.99*	1146	-4
AH 7009×PDM 24-3	2.57**	-1.43**	0.09*	-6.9**	0.19	0.10	-6.399	1.38	-533.23	114.60	1127	-6
PINNACLE×PDM 24-3	0.40	-0.72	-0.05	5.18**	0.79	0.10	9.60**	1.87	799.89*	155.62	1049	-12
AH 7009×HKI 323	-3.10**	-1.33**	-0.12*	-1.29	-1.75*	0.28*	5.691	0.24	474.42	20.17	1037	-13
AH 7009×PDM 260	-2.85**	-0.18	-0.05	-0.849	-2.26**	0.22*	4.93	-0.56	410.88	-46.91	1023	-15
AH 5021×PDM 112-1	1.82**	-0.43	0.13**	4.18**	0.13	0.00	7.11*	0.11	592.78*	8.69	1002	-16
AH 7009×PDM 105	-5.26**	-1.20**	0.06	1.01	0.71	0.09	4.047	1.85	337.30	154.33	968	-19
AH 5021×PDM 260	0.90	0.62	0.133**	0.88	1.58*	-0.15	-4.094	0.33	-341.26	27.09	957	-20
PINNACLE×PDM 4441	-0.68	-0.06	0.17**	6.30**	-0.89	0.07	9.91**	-0.40	825.95*	-33.28	926	-23
AH 7009×PDM 4441	1.49*	0.45	-0.04	-2.56	0.29	-0.22 *	-8.74*	-1.93	-727.10*	-160.67	917	-23
HM 4×HKI 163	0.13	0.39	0.04	-3.15*	-0.42	0.14	-0.498	0.56	-41.50	46.57	914	-24
AH 5021×PDM 260-1	-1.85**	0.40	-0.09	1.49	-1.50*	-0.09	-0.165	-2.43	-13.85	202.17	904	-25
AH 5021×PDM 4441	0.57	-0.95*	-0.12**	-4.64**	0.49	-0.12	-9.54**	-0.55	-795.27**	45.81	891	-26
AH 7009×PDM 53	5.65**	0.52	0.09	-1.73	0.27	-0.26*	-9.24*	-2.59	-770.09*	-215.75	883	-26
PINNACLE×PDM 260	2.65**	-0.25	-0.03	-3.51**	-0.27	-0.05	-4.99	-0.87	416.56	-72.01	880	-27
PINNACLE×PDM 260-2	0.15	0.91*	0.24**	11.41**	1.09	0.03	13.57**	1.28	1131.14*	-106.78	872	-27
HM 4×HKI 1105	1.79**	-2.07**	-0.13**	-0.55	-0.53	-0.10	-3.19	-1.68	266.10	139.75	867	-28
PINNACLE×PDM 162-2	0.24	-0.43	0.10*	-8.17**	0.41	0.08	-6.96	1.27	579.66	-105.84	866	-28
AH 7009×PDM 162-2	-2.26**	1.37**	0.03	2.84*	-0.52	0.02	3.936	-0.21	327.92	-17.14	861	-28
AH 7009×HKI 1105	2.32**	0.84	0.12**	12.73**	-2.31**	0.07	17.37**	-1.97	1447.38*	-163.71	840	-30
AH 7009×HKI 163	-0.01	-0.09	-0.16**	0.007	0.83	-0.17	-3.58	-0.54	-298.86	-44.99	819	-32
HM 4×PDM 162-2	2.21**	-0.78	-0.20**	2.4	0.64	-0.15	-1.55	-0.74	129.04	-61.98	819	-32
AH 5021×PDM 24-3	-2.68**	-0.70	-0.21**	-2.73*	-1.08	0.07	-1.72	-0.65	-143.56	53.99	818	-32
PINNACLE×HKI 163	-1.514 *	-0.28	0.04	1.62	0.83	-0.04	0.711	0.68	59.26	-56.884	803	-33
HM 4×PDM 24-3	-0.29	2.84**	0.17**	4.47**	0.10	-0.26*	-1.48	-2.60	123.10	216.24	799	-33
AH 5021×HKI 1105	0.07	0.41	0.02	-2.06	0.00	-0.10	-6.33	-0.83	-527.39	69.22	794	-34
PINNACLE×PDM 105	-0.10	0.87	0.07	7.04**	1.06	-0.05	6.075	0.91	506.19	-75.572	770	-36
HM 4×HKI 323	2.71**	-0.11	0.24**	-2.68*	-0.49	-0.28*	-10.80**	-3.24*	900.37**	269.90*	750	-37
PINNACLE×HKI 323	0.74	0.65	-0.18**	-2.83*	-0.78	-0.12	-7.29*	-1.95	607.94*	-162.35	736	-39
AH 5021×PDM 162-2	-0.18	-0.17	0.07	2.93*	-0.53	0.05	4.57	-0.32	380.78	26.73	711	-41
HM 4×PDM 260-2	-2.54**	-1.04*	-0.11*	-3.29*	-1.66*	0.00	-3.822	-2.34	318.51	194.65	692	-42
PINNACLE×PDM 112-1	1.24*	-0.19	-0.06	2.571	-2.43**	-0.10	-0.041	-3.99**	-3.50	-333.04**	682	-43

AH 5021 × HKI 163	1.40*	-0.01	0.08	1.527	-1.24	0.07	3.37	-0.70	281.10	58.46	666	-44
AH 5021×PDM 105	2.15**	0.39	-0.01	-7.56**	-1.01	0.19	-5.00	-0.26	-416.98	22.00	651	-46
PINNACLE×PDM 53	0.82	-0.59	-0.21**	-3.04*	-2.39**	-0.14	-7.86*	-4.02**	655.03 *	-334.71**	646	-46
HM 4×PDM 105	3.21**	-0.07	-0.11*	-0.48	-0.76	-0.22	-5.11	-2.49	426.52	207.90	608	-49
AH 5021×PDM 260-2	2.40**	0.01	-0.09	-4.73**	-1.13	-0.13	-8.66*	-2.09	-721.75*	174.13	569	-52
SE (sij)	0.60	0.45	0.05	0.11	1.33	0.72	3.58	1.31	297.96	109.17	M Mean yield of check (CPB 472) - 1198.00 Kg/ha	
CD 5%	1.20	0.89	0.09	0.22	2.63	1.43	7.10	2.60	591.61	216.76		
CD 1%	1.59	1.18	0.12	0.29	3.48	1.90	9.40	3.44	783.40	287.04		
SEd (sij-skl)	0.85	0.63	0.07	0.15	1.87	1.02	5.06	1.85	421.38	154.39		

Conclusion

The estimates of GCA effects exhibited that the parent HM 4 and AH 7009 among the lines and PDM 260-1 and PDM 112-1 among the testers were the best general combiners for most studied characters. So, these parents viz., could be used extensively in hybrid breeding program to increase baby corn yield. Among the cross combinations, HM 4 × PDM 53, HM 4×PDM 260-1 and HM 4 × PDM 4441 and HM 4×PDM 112-1 showed significant sca effects in desirable direction for most of the traits studied with highest mean babycorn yield. These hybrids were associated with the high effect of the general combining ability of the HM 4 parent with one of the highest effects of the estimated specific combining ability, since PDM 53 and PDM 4441 inbreds showed lower general combining ability. In this case, the participation of a specific combining ability is significant for hybrid yield, contributing almost to the general combining ability from both parents, regarding the dominance and epistasis effects (Gardner, 1963). Therefore, it is possible to analyze these hybrids that showed high performance for most of the yield and quality traits in multi location trials to evaluate their yield stability.

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