



Combining ability studies in multiple cross derivatives of upland cotton (*Gossypium hirsutum*) for identifying desirable plant types suitable to High Density Planting System

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ABSTRACT

To develop genotypes suitable for High Density Planting System (HDPS), six lines and seven testers that possessed compact plant type characteristics were crossed in Line \times Tester mating design and the resulting 42 crosses along with their parents were evaluated at three different locations during *khari*, 2014 to identify good general and specific combiners for plant type suitable for HDPS with desirable fibre quality. The results revealed significant differences among lines, testers and crosses for most of the traits and preponderance of non-additive gene action. Three lines MC 17-6, MC 16-3, MC 4-3 and two testers NH 630, MC 19-2 exhibited good gca and were found to possess compact plant type characteristics with desirable fibre quality. Among the 42 cross combinations, three crosses MC 9-1 \times NH 630, MC 17-6 \times MC 19-2 and MC 4-3 \times MC 3-2 were identified as best specific combiners. The superior multiple cross derivatives and cross combinations can be used for developing hybrids suitable for high density planting system through heterosis breeding.

Key words: Combining ability, Cotton, High density planting system, Line \times tester analysis, Multiple cross derivatives

Cotton (*Gossypium* spp.) is an important fibre crop and plays a vital role as a cash crop in the commerce of many countries such as USA, China, India, Pakistan, Uzbekistan, Australia and Africa. India ranks first in area with 10.50 Mha and produces 35.1 million bales (1 bale=170 kgs of lint) with a productivity of 568 Kg/ha (www.cotcorp.gov.in). Almost two third of area under cotton cultivation is rain dependent and the cotton productivity got stagnated during the past five years at around 500 kg/ha, which is lower when compared to Australia (1833 kg/ha), China (1633 kg/ha) and Brazil (1522 kg/ha) (www.apps.fas.usda.gov) which could be attributed to the fact that a large area (more than 90 per cent) is being cultivated with *Bt* cotton hybrids at a plant population of 9000 to 12000 plants/ha even under rainfed ecology. World over during the last three decades, breeding efforts were concentrated on development of varieties suitable for HDPS with short sympodial branches

and less number of bolls/plant. On the contrary, hybrids with high vegetative luxuriance were developed and popularized making HDPS ineffective (Tamilselvam *et al.* 2013) in India. In the recent past, HDPS in cotton is commonly followed to obtain higher yields with straight varieties across the world, especially in the major cotton growing countries like USA, Australia, China, Brazil and Uzbekistan due to the development of suitable plant types to accommodate higher plant densities varying from 1 lakh to 2.5 lakh plants/ha using narrow and ultra narrow spacing (Gunasekaran *et al.* 2014). However, in India the recommended plant density for cotton seldom exceeded 55000 plants/ha (Venugopalan *et al.* 2013). High Density Planting System is more relevant in context to India, as cotton is being cultivated under rain fed conditions in about 60% of the area thus resulting in low productivity due to negative effect of low soil moisture on boll formation and retention particularly in shallow soils (Manickam *et al.* 2014a). Cotton breeders mainly focused on the development of hybrids having robust plant type with higher yield, that resulted in lack of short compact plant types (dwarf plant stature, 8-14 bolls/plant with a boll weight 3.0 g, short sympodia and low or zero monopodia) suitable for HDPS. The productivity of cotton in light soils with low moisture retention capacity can be improved by developing compact genotypes with early maturity. Therefore, development of varieties suitable for HDPS is

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the urgent need of the hour, so as to mitigate the hardship of the cotton farmers to some extent.

To develop the varieties amenable for HDPS, it is essential to combine all these traits by identifying and using suitable genotypes in the crossing programme for further exploitation. Knowledge on combining ability is useful for selection of desirable parents for exploitation of heterosis and transgressive expressions and also to elucidate the nature and magnitude of gene action involved in the inheritance of seed cotton yield and its related characters. The choice of parents for hybridization can be made on the basis of combining ability and *per se* performance, though the *per se* performance is important, the parents selected on the basis of *per se* performance may not produce hybrids with desirable traits in the event of the presence of non-additive gene action. In this context, combining ability effects provide sound basis for parental selection (Preetha and Raveendran 2008). Line \times Tester analysis would reveal General Combining Ability (GCA) effects of parents and Specific Combining Ability (SCA) effects of crosses. Studies showed that additive and non-additive genes control the variation in seed cotton yield and its related components (Ashokkumar *et al.* 2010, and Sajjad *et al.* 2016). Additive and non-additive gene action for inheritance of various traits will be governed by general combining ability and specific combining ability respectively (Griffing, 1956, Sprague and Tatum, 1942). Thus the SCA is important for hybrid crop exploitation and GCA is practicable for hybridization and selection programmes (Ali *et al.* 2016 and Jatoi *et al.* 2011). The present study was conducted to estimate the *gca* effects of parents and *sca* effects of their crosses for identification of parents/crosses possessing compact plant

type characteristics along with medium to high yield and desirable quality parameters that make them amenable for HDPS.

MATERIALS AND METHODS

The experimental material used for the present study comprised stable multiple cross derivatives (Table 1) that possessed compact plant type characteristics and were selected through the combined use of metroglyph (Anderson 1957) and SSR marker analyses in a study conducted at Agricultural College, Aswaraopet during *kharif* 2013 for evaluating 52 genotypes obtained from multiple crossing of eight strains of cotton, viz. Renuka, Narasimha, LRA 5166, L 604, MCU 5, DHY 286, ADB 39 and NDL 1588 (Pradeep and Sumalini, 2005). The selected multiple cross derivatives (six lines and seven testers) were crossed in Line \times Tester mating design to produce 42 F₁ cross combinations. All the 42 F₁ hybrids and 13 parents were evaluated along with two checks Suraj and NCS 954 Bt at three different locations, viz. Aswaraopet, Warangal and Adilabad during *kharif* 2014 by adopting a spacing of 60 cm \times 30 cm in a Randomized Block Design replicated thrice. All the agronomic practices were followed uniformly along with required prophylactic measures. The data were recorded on five randomly selected plants in each replication on days to 50% flowering, days to first boll bursting, plant height (cm), number of monopodial branches, earliness index, number of sympodial branches, length of the sympodial branches (cm), leaf area (cm²), number of bolls/plant, boll weight (g), harvest index, 100-seed weight (g), seed cotton yield per plant (g/pl) and ginning outturn (%). The fibre quality parameters 2.5% span length (mm), uniformity

Table. 1 Mean performance of selected multiple cross derivatives of cotton for compact plant type characteristics

Multiple Cross Derivative	DFE	PHT	NM	NS	SL	NB	BW	100-SW	SCY
<i>Lines</i>									
MC 4-3	64	74.27	1.27	19.93	14.89	45.07	1.93	8.37	92.45
MC 5-1	62	76.33	0.93	21.13	16.57	51.20	2.43	9.66	129.89
MC 9-1	61	86.43	0.83	23.20	14.17	47.27	2.50	6.84	123.43
MC 16-3	63	81.50	0.20	17.53	15.59	48.47	3.03	9.83	152.17
MC 17-6	63	72.80	0.60	18.33	12.94	40.40	2.93	8.61	123.81
MC 23-2	60	66.07	0.67	18.07	13.64	44.67	2.33	9.90	103.87
<i>Testers</i>									
NH 630	67	72.13	0.47	17.67	15.63	58.60	1.93	10.04	121.27
MC 3-2	63	88.17	0.80	25.40	15.93	46.93	2.30	8.96	113.17
MC 17-1	63	102.27	1.33	20.00	17.40	79.93	2.90	6.17	237.03
MC 19-2	66	96.43	0.67	23.33	20.81	59.13	2.93	8.00	178.77
MC 22-2	64	82.87	1.13	22.67	16.70	70.87	2.40	8.82	175.31
MC 11-1	63	110.37	1.20	22.87	18.50	66.87	3.20	8.60	219.19
MC 17-2	65	94.80	0.20	19.47	16.58	39.27	4.43	6.03	167.57

DFE – Days to 50% flowering, PHT – Plant height (cm), NM – Number of monopodial branches, NS – Number of sympodial branches, SL – Length of the sympodial branches (cm), NB – Number of bolls per plant, BW – Boll weight (g), 100-Seed weight (g), SCY – Seed cotton yield (g/pl).

ratio were measured by using HVI (ICC Mode) instrument and bundle strength ($\text{g } 10^{-3} \text{ texture}^{-1}$) by Presley strength tester, whereas micronaire value ($\mu\text{g/inch}$) was measured with spacer technique at Regional Quality Evaluation Unit, CIRCOT, Lam Farm, Guntur, Andhra Pradesh. The line \times tester analysis was carried out for determining the combining ability effects according to the method outlined by Kempthorne (1957).

RESULTS AND DISCUSSION

Analysis of variance for combining ability

Analysis of variance revealed presence of significant differences among the locations, genotypes, parents, parents vs. crosses and crosses for all the characters studied (Table 2). Significant differences for locations were recorded for all the characters under study except for days to 50% flowering, earliness index, length of the sympodial branches, uniformity ratio and bundle strength. Partitioning of crosses into lines,

testers and line \times tester also showed that the variances were significant for all the characters. The interaction effects of (parents vs. crosses) \times locations were significant for all the characters except for days to 50 % flowering, earliness index, number of sympodial branches, leaf area, boll weight and seed cotton yield, ginning out turn and quality parameters while interaction of parents \times locations showed significant variation for the characters plant height, number of monopodia, days to first boll bursting, number of sympodial branches, length of the sympodial branches, leaf area, number of bolls/plant, boll weight, 100 seed weight, seed cotton yield and ginning out turn.

Further partitioning of variance due to crosses \times locations revealed that the interaction of lines \times locations had significant differences for days to 50% flowering, days to first boll bursting, length of sympodial branches, number of bolls/plant and seed cotton yield. Interaction effects of lines \times testers \times locations were significant for all the characters except for earliness index, number of

Table 2 Pooled analysis of variance for combining ability (L \times T) for yield, its components and quality parameters in multiple cross derivatives of cotton

Source of variation	df	Days to 50 % flowering	Days to first boll bursting	Plant height (cm)	Number of monopodial branches	Earliness index	Number of sympodial branches	Length of the sympodial branches (cm)
Replications	2	0.099	0.051	2.162	0.198	7.190	1.469	0.933
Environments	2	6.554	110.948**	598.306**	3.983**	15.392	15.497**	4.596
Replications \times Locations	4	9.051	6.575*	2.854	0.203*	0.130	0.393	2.281
Genotypes	54	67.119**	21.201**	277.208**	0.678**	143.296**	26.723**	16.497**
Parents	12	109.526**	39.503**	415.633**	1.686**	163.403**	14.458**	8.498**
Parent vs Crosses	1	66.486**	0.147	58.603*	1.567**	15.389	6.375	11.095
Crosses	41	54.723**	16.358**	242.025**	0.361**	140.531**	30.810**	18.970**
Lines	5	75.992*	28.498*	359.333	0.907*	263.330	100.766**	46.016*
Testers	7	171.616**	41.505**	623.603**	0.229	177.230	27.222	10.360
Line \times Tester	30	27.799**	9.305**	146.158**	0.297**	112.724**	19.868**	16.184**
Environments \times Genotypes	108	18.535**	12.454**	58.367**	0.218**	0.686	4.292**	9.210**
Parents \times Locations	24	1.197	5.003**	23.067**	0.517**	0.273	3.998**	10.355**
(Parent vs Cross) \times Locations	2	4.635	35.418**	38.061*	0.685**	1.499	4.545	10.211*
Crosses \times Locations	82	23.949**	14.074**	69.194**	0.119**	0.787	4.372**	8.851**
Line \times Locations	10	67.833**	28.247*	62.676	0.134	0.910	6.308	21.850**
Tester \times Locations	12	27.066	10.446	106.850	0.147	0.532	3.200	5.118
Line \times Tester \times Locations	60	16.611**	12.438**	62.749**	0.111*	0.817	4.284**	7.431**
Error	324	4.042	2.246	12.291	0.075	8.086	2.093	2.883
	<i>df</i>	<i>Leaf area (cm²)</i>	<i>Number of bolls per plant</i>	<i>Boll weight (g)</i>	<i>Harvest index</i>	<i>100 – Seed weight (g)</i>	<i>Seed cotton yield (g/plant)</i>	<i>Ginning out turn (%)</i>
Replications	2	1348.99	1.788	0.006	0.003	0.147	0.281	0.089
Environments	2	3997752.00**	230.887**	0.251**	0.100**	12.936**	315.722**	25.438**
Replications \times Locations	4	8024.56	3.189	0.048	0.001	0.231	10.739	2.520

(Continued)

Table 2 (Concluded)

	<i>df</i>	<i>Leaf area (cm²)</i>	<i>Number of bolls per plant</i>	<i>Boll weight (g)</i>	<i>Harvest index</i>	<i>100 – Seed weight (g)</i>	<i>Seed cotton yield (g/plant)</i>	<i>Ginning out turn (%)</i>
Genotypes	54	558496.80**	33.133**	1.083**	0.007**	9.973**	341.443**	60.794**
Parents	12	328506.70**	12.994**	0.869**	0.002**	8.325**	204.271**	42.332**
Parent vs Crosses	1	2484466.00**	22.935*	6.639**	0.002	198.521**	2953.254**	34.791**
Crosses	41	578836.10**	39.277**	1.010**	0.008**	5.856**	317.888**	66.832**
Lines	5	780842.10**	102.068*	1.569	0.007	1.009	336.650	165.457*
Testers	7	365915.40**	18.338	1.494	0.005	10.598	278.496	58.129
Line x Tester	30	557752.60**	32.999**	0.820**	0.009**	5.715**	322.639**	52.134**
Environments × Genotypes	108	259304.10**	11.346**	0.171**	0.002**	0.595**	121.336**	21.185**
Parents × Locations	24	171003.80**	17.087**	0.107**	0.002**	0.868**	114.902**	17.250**
(Parent vs Cross) × Locations	2	142951.60	9.601**	0.041	0.008**	1.811**	45.764	3.422
Crosses × Locations	82	287985.90**	19.935**	0.192**	0.001	0.486**	125.062**	22.770**
Line × Locations	10	291323.10	16.078*	0.202	0.002	0.608	279.113**	17.721
Tester × Locations	12	584941.80**	6.583**	0.442**	0.001	0.555	244.910**	15.240
Line × Tester × Locations	60	228038.50**	3.534	0.141**	0.001	0.451**	75.417**	25.117**
Error	324	64951.86	3.534	0.040	0.001	0.212	26.630	3.679

	<i>df</i>	<i>2.5% span length (mm)</i>	<i>Uniformity ratio</i>	<i>Bundle strength (g 10⁻³ texture)</i>	<i>Micronaire value (µg/inch)</i>
Replications	2	0.302	0.565	0.199	0.056
Environments	2	22.087**	2.095	2.111	0.178**
Replications × Locations	4	0.113	0.181	1.319	0.011
Genotypes	54	8.183**	7.353**	14.662**	1.438**
Parents	12	7.336**	12.600**	19.296**	1.261**
Parent vs Crosses	1	0.384	0.553	48.944**	1.217**
Crosses	41	8.621**	5.984**	12.469**	1.495**
Lines	5	6.919	18.284**	24.118**	2.718**
Testers	7	4.853	17.277**	36.451**	7.095**
Line × Tester	30	9.657**	1.675	5.731**	0.171**
Environments × Genotypes	108	0.761	0.401	1.217	0.007
Parents × Locations	24	0.243	0.432	0.112	0.006
(Parent vs Cross) × Locations	2	0.846	0.003	0.326	0.008
Crosses × Locations	82	0.885	0.401	1.562	0.008
Line × Locations	10	1.293	0.397	1.419	0.006
Tester × Locations	12	1.323	0.241	1.743	0.015*
Line × Tester × Locations	60	0.730	0.434	1.550	0.006
Error	324	1.123	2.598	1.687	0.024

*Significant at 5% level; **Significant at 1% level

bolls/plant, harvest index and quality parameters which indicated the presence of sufficient genetic divergence among the material under study and there is an ample scope for identifying promising parents and hybrid combinations for productive traits and plant type with compact traits and good fibre quality.

Combining ability variances and gene action

The estimates of GCA and SCA variances in pooled analysis are presented in Table 3. General combining ability is associated with additive gene action, whereas specific combining ability is associated with dominance and epistasis (non-additive gene action). In the present study,

it was found that SCA variances were higher than GCA variances in pooled analysis for all the characters indicating the preponderance of non-additive gene action for all the characters under study. The presence of non-additive gene action for various characters in cotton were also reported by Sajjad *et al.* (2016), Sawarkar *et al.* (2015), Patil *et al.* (2014), Deshmukh *et al.* (2014), Deosarkar *et al.* (2014), Shakeel *et al.* (2012), Basal *et al.* (2011), Ashokkumar *et al.* (2010), Saravanan *et al.* (2010), Preetha and Raveendran (2008), Karademir *et al.* (2009), Ahuja and Dhayal (2007), Reshmi *et al.* (2007), Ilyas *et al.* (2007), Panhwar (2007), Khan *et al.* (2005), Manickam and Gururajan (2004), whereas additive gene action was reported by Sawarkar *et al.* (2015), Alkuddsi *et al.* (2013), Shakeel *et al.* (2011), Ali *et al.* (2011), Nadeem and Azhar (2004). The preponderance

Table. 3 Estimates of general and specific combining ability variances and proportionate gene action in multiple cross derivatives of cotton for 18 characters.

Character	Location	Source of variation		
		σ^2_{gca}	σ^2_{sca}	$\frac{\sigma^2_{gca}}{\sigma^2_{sca}}$
Days to 50% flowering	Aswaraopet	0.376	4.265	0.088
	Warangal	0.242	50.099	0.005
	Adilabad	0.137	7.308	0.019
	Pooled	0.175	0.638	0.274
Days to first boll bursting	Aswaraopet	0.135	0.902	0.150
	Warangal	0.088	1.071	0.082
	Adilabad	-0.039	7.01	-0.006
	Pooled	0.042	-0.334	-0.126
Plant height (cm)	Aswaraopet	0.486	14.180	0.034
	Warangal	1.21	13.34	0.091
	Adilabad	0.202	50.74	0.004
	Pooled	0.559	9.757	0.057
Number of monopodial branches	Aswaraopet	0.0001	0.0084	0.012
	Warangal	0.0008	0.059	0.014
	Adilabad	0.0005	0.029	0.017
	Pooled	0.0003	0.009	0.033
Earliness index	Aswaraopet	0.154	10.766	0.014
	Warangal	0.152	10.347	0.015
	Adilabad	0.180	8.920	0.020
	Pooled	0.162	12.45	0.013
Number of sympodial branches	Aswaraopet	0.073	1.571	0.046
	Warangal	0.051	3.57	0.014
	Adilabad	0.069	2.246	0.031
	Pooled	0.064	1.730	0.037
Length of the sympodial branches	Aswaraopet	0.123	3.206	0.038
	Warangal	-0.029	2.605	-0.011
	Adilabad	0.004	1.653	0.002
	Pooled	0.016	0.776	0.021

Contnd.

Table. 3 (Concluded)

Character	Location	Source of variation		
		σ^2_{gca}	σ^2_{sca}	$\frac{\sigma^2_{gca}}{\sigma^2_{sca}}$
Leaf area	Aswaraopet	55.352	87701.629	0.001
	Warangal	1031.89	115630.26	0.009
	Adilabad	854.762	79659.47	0.011
	Pooled	-52.01	36494.39	-0.001
Number of bolls/plant	Aswaraopet	0.075	4.665	0.016
	Warangal	0.09	4.01	0.022
	Adilabad	0.051	3.155	0.016
	Pooled	0.037	2.543	0.015
Boll weight	Aswaraopet	0.003	0.103	0.029
	Warangal	0.0007	0.126	0.006
	Adilabad	0.001	0.097	0.010
	Pooled	0.001	0.073	0.014
Harvest index	Aswaraopet	0.000	0.0008	0.000
	Warangal	0.000	0.001	0.000
	Adilabad	0.000	0.001	0.000
	Pooled	0.000	0.001	0.000
100 - Seed weight	Aswaraopet	0.001	0.919	0.001
	Warangal	0.002	0.441	0.005
	Adilabad	0.003	0.635	0.005
	Pooled	0.001	0.569	0.002
Seed cotton yield	Aswaraopet	0.627	34.810	0.018
	Warangal	0.890	58.266	0.015
	Adilabad	0.137	37.959	0.004
	Pooled	-0.060	23.627	-0.003
Ginning out turn	Aswaraopet	0.047	9.532	0.005
	Warangal	0.022	9.063	0.002
	Adilabad	0.106	11.847	0.009
	Pooled	0.086	3.440	0.025
2.5% span length	Aswaraopet	0.002	1.016	0.002
	Warangal	-0.009	0.799	-0.011
	Adilabad	-0.002	0.768	-0.003
	Pooled	-0.0061	0.988	-0.006
Uniformity ratio	Aswaraopet	0.025	0.266	0.094
	Warangal	0.026	-0.955	-0.027
	Adilabad	0.023	-1.061	-0.022
	Pooled	0.025	0.141	0.177
Bundle strength	Aswaraopet	0.034	0.777	0.044
	Warangal	0.038	0.222	0.171
	Adilabad	0.04	0.25	0.160
	Pooled	0.039	0.502	0.078
Micronaire value	Aswaraopet	0.007	0.015	0.467
	Warangal	0.007	0.015	0.467
	Adilabad	0.009	0.008	1.125
	Pooled	0.008	0.018	0.444

of non-additive gene action in the inheritance of all the traits showing the possibility of exploitation of heterosis for developing plant types suitable for HDPS.

General and specific combining ability effects

The contribution of lines was high for the trait number of sympodial branches (Table 4) and contribution of testers was high for days to 50% flowering (50.33%), uniformity ratio (42.26%), bundle strength (42.78%) and micronaire value (69.47%), whereas the contribution of line \times tester interaction was high for days to first boll bursting (41.15%), plant height (44.29%), number of monopodia (61.16%), earliness index (58.69%), length of the sympodia (62.42%), leaf area (74.30%), number of bolls/plant (51.47%), boll weight (59.39%), harvest index (80.74%), 100-seed weight (71.42%), seed cotton yield (75.44%), ginning outturn (57.08%) and 2.5% span length (81.99 %).

The estimates of general combining ability for six lines and seven testers and specific combining ability effects for 42 hybrids for different characters under study over three environments (pooled) has been presented in the Tables 5 and 6.

Among the six lines, the line, viz. MC 17-6 exhibited significant *gca* effects for number of sympodial branches (1.700**), leaf area (165.193**), number of bolls/plant (1.300**), harvest index (0.011*), seed cotton yield (4.124**) besides being a good general combiner for quality parameters namely 2.5% span length (0.411**), uniformity ratio (0.738**) and bundle strength (0.515**), while the line MC 16-3 had shown significant *gca* effects for the traits

Table. 4 Proportional contribution of lines, testers and their interactions to total variance

Character	Contribution		
	Line (%)	Tester (%)	Lines \times Tester (%)
Days to 50% flowering	16.50	50.33	33.17
Days to first boll bursting	20.34	38.50	41.15
Plant height	18.10	37.70	44.29
No. of monopodial branches	29.97	8.56	61.16
Earliness index	22.86	18.45	58.69
Number of sympodial branches	39.88	12.92	4.72
Length of the sympodial branches	29.58	7.99	62.42
Leaf area	16.45	9.25	74.30
Number bolls/plant	31.69	6.83	61.47
Boll weight	18.95	21.65	59.39
Harvest index	9.68	9.58	80.74
100 - Seed weight	2.10	26.17	71.42
Seed cotton yield	12.65	11.91	75.44
Ginning out turn	30.18	12.73	57.08
2.5% span length	9.79	8.22	81.99
Uniformity ratio	37.26	42.26	20.47
Bundle strength	23.60	42.78	33.64
Micronaire value	22.16	69.47	8.37

like length of the sympodial branches (-1.18**) in addition to ginning out turn (1.82**), bundle strength (0.44**) and micronaire value (0.41**). The line MC 4-3 had shown significant *gca* effects for the characteristics, viz., earliness index (3.41**), number of sympodial branches (1.28**), number of bolls/plant (1.82**), 2.5% span length (0.39**), bundle strength (0.750**) and uniformity ratio (0.46**). Significant *gca* effects in desirable direction for the traits plant height (-4.21**), earliness index (3.31**), number of bolls/plant (0.82), boll weight (0.15**) and 100-seed weight (0.54**) along with quality parameters like 2.5% span length (0.57**) and micronaire value (0.26**) were exhibited by the tester NH 630. The tester MC 19-2 was found to be a good general combiner for plant height (-4.14**), days to 50% flowering (-1.43*), length of the sympodial branches (-0.85*), seed cotton yield/plant (3.44*), ginning out turn (1.77**) and uniformity ratio (0.47**) (Table 5). Among the 42 crosses studied, only three had exhibited significant *sca* effects for compact plant characteristics along with some desirable quality parameters. The cross combination MC 9-1 \times NH 630 had shown significant *sca* effects in respect of plant height (-8.24**), days to 50% flowering (-4.29**), number of sympodia (2.38**), leaf area (574.04**), number of bolls/plant (3.70**), boll weight (0.61**), harvest index (0.04**), 100-seed weight (0.67*), seed cotton yield (11.09**) and uniformity ratio (0.44*) while the cross MC 17-6 \times MC 19-2 exhibited significant *sca* effects for plant height (-5.22*), sympodial branches (3.82**), boll weight (0.51**), 100-seed weight (0.84**), seed cotton yield (9.14*), number of sympodial branches (-2.20*), ginning out turn (3.86**), 2.5% span length (1.82**) and uniformity ratio (0.66**). Significant *sca* effects in desired direction for number of monopodial branches (-0.32*), earliness index (6.34**), number of bolls/plant (2.16*), harvest index (0.03*), 100-seed weight (0.97**) and seed cotton yield (10.26**) were exhibited by MC 4-3 \times MC 3-2 besides, a good specific combiner for uniformity ratio (0.75**) and micronaire value (0.23**) (Table. 6). Significant negative *gca* and *sca* effects for days to 50% flowering, days to first boll bursting, plant height, number of monopodia, length of the sympodia were also reported by earlier workers, viz. Sawarkar *et al.* (2015) and Deosarkar *et al.* (2014), Alkuddsi *et al.* (2013), Deosarkar *et al.* (2014), Preetha and Raveendran (2008) while the significant positive *gca* and *sca* effects for the traits like earliness index, number of sympodia, leaf area, number of bolls/plant, boll weight, seed cotton yield per plant, ginning outturn, 2.5% span length, uniformity ratio, bundle strength and micronaire value were also reported by Azhar *et al.* (2007), Patil *et al.* (2015), Ali *et al.* (2011), Nadeem and Azar (2004), Ahmad *et al.* (2001) and Deosarkar *et al.* (2014).

Based on the *pre se* performance and *gca* effects, the parents, viz. MC 17-6, MC 4-3, NH 630 and MC 19-2 were found to be good general combiners for most of the compact plant characteristics along with the seed cotton yield, hence they could be further evaluated at increased plant densities and transformed with *Bt* genes for further

Table 5 General combining effects (GCA) of the parents for yield, yield contributing traits and quality parameters in cotton over three environments (pooled)

Parents	DFF	DFFB	PHT	NM	EI	NS	LS	LA	NBP
<i>Lines</i>									
MC 4-3	-0.450	-0.489	1.704	0.170**	3.772**	1.284**	1.238**	-87.832	1.822**
MC 5-1	-0.656	-0.363	-0.613	-0.010	-2.951**	-0.402	0.242	-70.350	-0.544
MC 9-1	-1.164*	0.447	-2.298*	-0.140*	-0.147	-1.706**	-0.448	-96.797	-1.470**
MC 16-3	1.662**	-0.871	4.004**	-0.069	-0.369	-0.458	-1.180**	-20.753	-0.433
MC 17-6	0.995	0.796	-1.322	-0.065	-0.039	1.700**	-0.404	165.193*	1.300**
MC 23-2	-0.386	0.479	-1.475	0.113	-0.265	-0.419	0.552	110.538	-0.665
SE (Lines)	0.55	0.44	0.96	0.06	0.10	0.26	0.38	64.16	0.40
<i>Testers</i>									
NH 630	-1.023	-0.840	-4.210**	-0.005	3.416**	-0.078	0.317	48.707	0.817
MC 3-2	0.457	-0.340	1.829	-0.048	0.969	0.343	0.102	50.907	-0.524
MC 17-1	3.272**	1.681**	4.397**	-0.031	0.511	1.331**	-0.077	98.359	0.448
MC 19-2	-1.431*	-0.080	-4.141**	0.052	-1.399	0.052	-0.846*	-80.507	0.049
MC 22-2	-2.282**	-1.005	0.384	0.010	-1.633*	-0.349**	0.368	-72.212	0.266
MC 11-1	-0.283	0.237	3.114**	0.106	-0.426	-0.933**	0.363	-104.172	-0.893
MC 17-2	1.290*	0.346	-1.373	-0.083	-1.437	-0.366	-0.228	58.918	-0.162
SE (Testers)	0.60	0.48	1.04	0.06	0.11	0.28	0.41	69.30	0.43
	<i>BW</i>	<i>HI</i>	<i>100-SW</i>	<i>SCY</i>	<i>GOT</i>	<i>2.5% SL</i>	<i>UR</i>	<i>BS</i>	<i>MV</i>
<i>Lines</i>									
MC 4-3	-0.287**	-0.010*	-0.188	-0.524	-1.884**	0.390**	0.456**	0.750**	-0.094**
MC 5-1	-0.045	-0.006	-0.110	-2.351	-2.022**	-0.226*	-0.513**	0.277*	-0.030**
MC 9-1	0.072	-0.011*	0.001	-1.974	0.040	-0.078	-0.623**	0.352*	-0.117**
MC 16-3	0.072	0.010	0.098	0.174	1.822**	-0.093	-0.180**	0.439**	0.408**
MC 17-6	0.014	0.011*	0.055	4.124**	1.228	0.411**	0.738**	0.515**	-0.005
MC 23-2	0.174**	0.007	0.143	0.551	0.815	-0.404**	0.122	-0.834**	-0.161**
SE (Lines)	0.05	0.01	0.10	1.42	0.58	0.11	0.08	0.14	0.01
<i>Testers</i>									
NH 630	0.145**	-0.018**	0.542**	-0.172	0.491	0.571**	-0.599**	-0.766**	0.260**
MC 3-2	0.184**	0.006	0.013	1.113	-0.370	-0.160	0.564**	0.694**	0.210**
MC 17-1	0.145**	0.008	-0.375**	0.350	0.225	0.112	-0.605**	0.899**	-0.179**
MC 19-2	0.048	0.000	0.095	3.435*	1.766**	0.115	0.467**	-0.582**	-0.441**
MC 22-2	-0.135*	0.007	0.007	-1.985	-0.391	-0.198	0.661**	0.149	-0.216**
MC 11-1	-0.022	0.007	0.448	-3.470*	-1.660**	-0.112	-0.472**	0.735**	0.594**
MC 17-2	0.072	-0.010	-0.730**	0.728	-0.061	-0.329**	-0.017	-1.129**	-0.227**
SE (Testers)	0.06	0.01	0.11	1.52	0.63	0.12	0.09	0.15	0.01

* Significant at 5% level, ** Significant at 1% level. DFF – Days to 50% flowering, DFBB – Days to first boll bursting, PHT – Plant height (cm), NM – Number of monopodial branches, EI – Earliness index, NS – Number of sympodial branches, SL – Length of the sympodial branches (cm), LA – Leaf area, NB – Number of bolls/plant, BW – Boll weight (g), HI – Harvest index, 100-Seed weight (g), SCY – Seed cotton yield (g/pl). GOT – Ginning outturn (%), 2.5% SL – 2.5% Span length, UR – Uniformity ratio, BS – Bundle strength and MV – Micronaire value.

commercial exploitation by using them as straight varieties. Similarly, the cross combinations MC 9-1 × NH 630, MC 17-6 × MC 19-2 and MC 4-3 × MC 3-2 exhibited good *sca* effects in desirable direction for majority of the compact plant type characteristics and they could be exploited for

hybrid cotton development that are amenable for HDPS. The variance due to *sca* is greater than that of variance due to *gca*, indicating preponderance of non-additive gene action (dominance/epistasis) and hence heterosis breeding may be rewarding for developing hybrids suitable for HDPS by

Table 6 Specific combining effects (SCA) of the crosses for yield, yield contributing traits and quality parameters in cotton over three environments (pooled)

Cross combination	DFE	DFFB	PHT	NM	EI	NS	LS	LA	NBP
MC 4-3 × NH 630	0.802	1.156	7.370**	0.028	-0.611*	-2.154**	-1.037	2.680	-1.236
MC 4-3 × MC 3-2	0.875	0.879	2.324	-0.315*	6.336**	0.899	0.022	230.356	2.159*
MC 4-3 × MC 17-1	0.617	-0.361	-1.797	-0.143	0.808**	-0.489	-0.596	-246.192	-1.507
MC 4-3 × MC 19-2	-0.790	-0.491	-4.524	0.181	-1.624**	-0.197	1.027	-104.190	-2.881**
MC 4-3 × MC 22-2	0.505	-0.792	4.104	0.136	-1.212**	0.228	1.888	373.785*	2.552*
MC 4-3 × MC 11-1	-0.494	0.083	-2.951	0.250	-2.571**	1.321	0.146	-38.958	1.031
MC 4-3 × MC 17-2	-1.514	-0.474	-4.527	-0.137	-1.127**	0.391	-1.449	-217.481	-0.117
MC 5-1 × NH 630	1.005	-0.304	-1.193	-0.015	5.652**	0.552	-0.644	-392.726*	0.757
MC 5-1 × MC 3-2	-0.585	-1.137	-1.622	-0.169	-3.605**	0.975	0.768	-35.649	-0.572
MC 5-1 × MC 17-1	-0.310	-1.821	4.593	-0.010	-5.244**	-0.590	0.467	-117.347	-0.058
MC 5-1 × MC 19-2	1.082	1.269	1.653	-0.049	-0.044	0.706	-0.517	110.435	0.448
MC 5-1 × MC 22-2	2.267	0.641	1.031	-0.007	-1.069**	0.214	0.658	-29.387	-1.479
MC 5-1 × MC 11-1	-0.731	1.399	-4.114	0.307	2.239**	1.527*	0.012	263.514	0.860
MC 5-1 × MC 17-2	1.249	-0.047	-0.347	-0.057	2.070**	-3.383**	2.114*	201.160	0.045
MC 9-1 × NH 630	-4.287**	0.773	-8.239**	0.118	4.216**	2.376**	1.149	574.041**	3.696**
MC 9-1 × MC 3-2	1.653	0.476	-1.525	0.305	-4.523**	-0.715	1.032	-79.445	1.287
MC 9-1 × MC 17-1	1.618	1.925	0.186	-0.003	-1.416**	-2.489**	-0.863	65.376	-2.572*
MC 9-1 × MC 19-2	0.987	-0.314	1.197	-0.062	1.660**	0.863	-1.270	143.652	1.087
MC 9-1 × MC 22-2	-2.051	-1.282	-2.492	-0.123	2.242**	-0.629	-0.642	-320.146	-1.293
MC 9-1 × MC 11-1	-1.497	-1.521	3.276	-0.196	-2.063**	0.467	1.246	93.101	0.536
MC 9-1 × MC 17-2	-0.400	-0.077	2.250	-0.040	-0.116	0.127	-0.652	-476.579**	-2.742*
MC 16-3 × NH 630	-0.373	-1.016	1.496	-0.066	-0.720*	-0.466	-1.555	-89.096	-1.014
MC 16-3 × MC 3-2	0.479	0.814	6.103*	-0.066	4.583**	-0.113	-0.510	-203.873	-1.140
MC 16-3 × MC 17-1	1.441	0.350	-2.893	-0.107	-1.656**	-0.154	0.322	22.162	0.528
MC 16-3 × MC 19-2	-0.409	0.444	1.708	0.187	-0.566*	0.232	1.292	-157.208	1.337
MC 16-3 × MC 22-2	-0.891	-0.297	2.569	-0.225	-3.574**	0.199	-0.660	203.979	0.136
MC 16-3 × MC 11-1	-0.113	-0.646	-2.854	0.113	0.494	-0.461	0.665	3.197	0.006
MC 16-3 × MC 17-2	-0.133	0.351	1.585	0.165	1.438**	0.763	0.446	220.837	0.121
MC 17-6 × NH 630	-2.642	-0.906	-0.920	0.017	5.030**	0.023	1.412	-62.462	-1.431
MC 17-6 × MC 3-2	0.320	-0.073	-3.063	0.030	-0.554*	-0.098	0.324	-36.355	0.424
MC 17-6 × MC 17-1	-1.161	-0.540	1.865	0.155	1.984**	-1.277	0.896	368.060*	4.342**
MC 17-6 × MC 19-2	-1.015	-0.779	-5.222*	-0.051	0.463	3.815**	-2.199*	126.432	-1.359
MC 17-6 × MC 22-2	0.283	2.040	-1.193	0.058	-0.881**	-0.052	-1.539	-410.536*	-0.873
MC 17-6 × MC 11-1	2.284	0.017	3.505	-0.215	-0.827**	-2.355**	-0.242	-118.819	-0.794
MC 17-6 × MC 17-2	1.931	0.241	2.659	0.005	-5.216**	-0.055	-0.193	133.681	-0.309
MC 23-2 × NH 630	1.518	0.298	-3.860	0.262	-4.829**	-0.331	0.676	-32.437	-0.772
MC 23-2 × MC 3-2	-2.742	-0.979	-2.216	-0.128	-5.449**	-0.948	-1.635	124.966	-2.158*
MC 23-2 × MC 17-1	1.773	0.447	3.392	0.170	-0.005	-0.093	-0.226	-92.059	-0.733
MC 23-2 × MC 19-2	0.145	-0.129	2.819	-0.205	0.111	0.327	0.127	-119.123	1.369
MC 23-2 × MC 22-2	-0.113	-0.310	-4.020	0.160	4.494**	0.041	3.152**	182.305	0.929
MC 23-2 × MC 11-1	0.551	0.668	5.505*	-0.259	2.728**	-0.499	-1.827	-202.034	-1.639

Contnd.

Table 6 (Contnd.)

Cross combination	DFE	DFFB	PHT	NM	EI	NS	LS	LA	NBP
MC 23-2 × MC 17-2	-1.132	0.005	-1.621	0.063	2.949**	2.157**	-0.266	138.382	3.003**
SE (Crosses)	1.46	1.17	2.54	0.16	0.27	0.69	1.01	169.74	1.06
	BW	HI	100-SW	SCY	GOT	2.5% SL	UR	BS	MV
MC 4-3 × NH 630	0.190	-0.049**	-0.267	-0.865	2.101	-0.341	-0.248	-0.051	0.055
MC 4-3 × MC 3-2	0.180	0.032*	0.967**	10.260**	2.919	-0.559	0.752**	0.689	0.226**
MC 4-3 × MC 17-1	-0.111	0.000	0.014	-4.681	-1.323	-0.889**	-0.666**	-0.232	0.016
MC 4-3 × MC 19-2	0.203	-0.028*	-0.797**	-7.040	-1.602	-0.295	0.085	-0.545	0.028
MC 4-3 × MC 22-2	-0.221	0.016	-0.425	4.125	2.077	0.509	-0.532*	-0.183	-0.009
MC 4-3 × MC 11-1	-0.101	-0.004	0.330	2.960	-3.182*	1.302**	0.041	0.535	-0.180**
MC 4-3 × MC 17-2	-0.138	0.033*	0.179	-4.758	-0.990	0.272	0.569**	-0.211	-0.135**
MC 5-1 × NH 630	-0.349*	0.050**	-1.378**	-5.828	-1.591	0.002	0.604**	-1.235**	-0.099**
MC 5-1 × MC 3-2	0.014	-0.014	-0.005	-1.087	-1.783	0.973**	-0.186	-0.478	0.157**
MC 5-1 × MC 17-1	-0.330*	0.028*	0.119	-3.438	0.808	-0.856**	0.033	2.198**	-0.031
MC 5-1 × MC 19-2	0.130	-0.028*	0.202	2.820	0.013	-0.579*	-0.039	-0.069	-0.048
MC 5-1 × MC 22-2	0.063	0.012	-0.137	-2.528	-3.075*	0.124	-0.313	0.147	0.177**
MC 5-1 × MC 11-1	0.273	-0.008	0.271	4.483	5.246**	-0.118	-0.107	0.565	-0.090**
MC 5-1 × MC 17-2	0.199	-0.041**	0.527*	5.578	0.381	0.455	0.008	-1.128**	-0.065*
MC 9-1 × NH 630	0.606**	0.037**	0.672*	11.092**	-1.623	-0.560	0.443*	-0.340	0.031
MC 9-1 × MC 3-2	-0.099	0.048**	0.194	1.673	-2.769	0.275	-0.110	-0.863*	0.021
MC 9-1 × MC 17-1	-0.066	-0.041**	-0.155	-0.261	0.572	0.326	0.335	0.339	-0.007
MC 9-1 × MC 19-2	-0.130	-0.010	0.614*	1.110	0.144	-0.317	0.103	0.133	-0.028
MC 9-1 × MC 22-2	0.100	0.003	-0.004	-1.192	2.979	1.606**	-0.250	0.188	-0.089**
MC 9-1 × MC 11-1	0.006	-0.008	0.088	1.170	-1.346	-0.833**	-0.135	0.206	0.003
MC 9-1 × MC 17-2	-0.418**	-0.029*	-1.007**	-13.592**	2.042	-0.497	-0.386	0.337	0.068*
MC 16-3 × NH 630	0.128	0.024	0.185	-1.530	1.772	-0.608*	0.134	0.183	0.319**
MC 16-3 × MC 3-2	-0.362	-0.070**	-0.176	-7.982*	2.197	0.707*	0.251	0.253	-0.087**
MC 16-3 × MC 17-1	0.150	-0.005	-0.325	0.477	2.854	0.291	0.393	-0.418	-0.032
MC 16-3 × MC 19-2	-0.286*	0.016	0.098	-0.071	-2.091	-0.185	-0.276	0.243	-0.160**
MC 16-3 × MC 22-2	0.353*	0.006	-0.124	5.493	-3.142**	-0.749*	0.181	0.302	0.009
MC 16-3 × MC 11-1	-0.010	0.000	-1.245**	-0.142	0.223	0.852**	-0.080	-0.864*	0.055
MC 16-3 × MC 17-2	0.326*	0.030*	1.587**	3.753	-1.812	-0.308	-0.602**	0.300	-0.103**
MC 17-6 × NH 630	-0.012	0.003	0.350	-0.740	0.945	0.105	-0.421*	0.913*	-0.214**
MC 17-6 × MC 3-2	-0.238	0.019	0.416	-2.175	-1.563	-0.027	0.392	-0.620	-0.081**
MC 17-6 × MC 17-1	-0.153	-0.006	-0.242	5.268	-2.476	-1.443**	-0.342	-1.458**	-0.066*
MC 17-6 × MC 19-2	0.508**	0.035**	0.839**	9.140*	3.859**	1.821**	0.675**	0.290	0.020
MC 17-6 × MC 22-2	-0.359*	-0.045**	-0.298	-10.630**	0.928	-0.632*	-0.301	-0.238	0.159**
MC 17-6 × MC 11-1	-0.039	0.005	-0.299	-2.322	1.443	-0.875**	-0.262	-0.214	0.075**
MC 17-6 × MC 17-2	0.293*	-0.011	-0.111	1.460	1.048	1.052**	0.259	1.327**	0.107**
MC 23-2 × NH 630	0.109	-0.020	0.184	-2.128	-1.605	1.402**	-0.512*	0.529	-0.092**
MC 23-2 × MC 3-2	0.506**	0.016	0.369	-0.689	1.000	-1.369**	0.185	1.019**	-0.038
MC 23-2 × MC 17-1	0.138	-0.009	0.590*	-1.237	-0.436	2.571**	0.247	-0.429	0.120**

Contnd.

Table 6 (Concluded)

	BW	HI	100-SW	SCY	GOT	2.5% SL	UR	BS	MV
MC 23-2 × MC 19-2	-0.425**	0.015	-2.064**	-2.089	-0.324	-0.445	-0.548*	-0.051	-0.011
MC 23-2 × MC 22-2	0.064	0.009	0.988	4.732	0.234	-0.858**	-0.068	-0.216	-0.246**
MC 23-2 × MC 11-1	-0.129	-0.031*	0.453	-6.149	-2.384	-0.328	0.544*	-0.228	0.137**
MC 23-2 × MC 17-2	-0.263	0.019	-1.175**	7.559*	-0.669	-0.974**	0.152	-0.624	0.129**
SE (Crosses)	0.14	0.01	0.26	3.74	1.53	0.29	0.21	0.37	0.03

* Significant at 5% level, ** Significant at 1% level. DFF – Days to 50% flowering, DFBB – Days to first boll bursting, PHT – Plant height (cm), NM – Number of monopodial branches. EI – Earliness index, NS – Number of sympodial branches, SL – Length of the sympodial branches (cm), LA – Leaf area. NB – Number of bolls/plant, BW – Boll weight (g), HI – Harvest index, 100-Seed weight (g), SCY – Seed cotton yield (g/pl). GOT – Ginning outturn (%), 2.5% SL – 2.5% Span length, UR – Uniformity ratio, BS – Bundle strength and MV – Micronaire value

combining seed cotton yield with quality parameters and compact plant type characters. The material can also be exploited for isolation of transgressive segregants in advance generations for the development of compact plant types.

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