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Estimation of combining ability and heterosis in TGMS based two-line hybrids of rice (*Oryza sativa*)

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ABSTRACT

The present study was carried out during summer and rainy (*kharif*) season of 2016 at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu to study general combining ability (*gca*) and specific combining ability (*sca*) and the level of heterosis using *Indica*/tropical *japonica* male parents by crossing with TGMS lines. During the study five thermosensitive genic male sterile (TGMS) lines and eight male fertile lines (4 *Japonica* and 4 *Indica*) were used to produce 40 hybrids. The combining ability and standard heterosis were analysed for 10 characters, viz. days to 50% flowering, plant height, number of productive tillers/plant, panicle length, number of filled grains/panicle, 100-grain weight, spikelet fertility%, single plant yield, harvest index and biomass yield. The results revealed that the lines, TNAU 95S and TNAU 14S, tropical *japonica* tester Palawan and *indica* tester CB 15137 showed positive significant *gca* effect for about five characters. These cultures can be utilized as parents in hybridization programmes due to their high general combining ability for over five characters. The eight hybrids namely, TNAU 14S × Palawan; TNAU 14S × KhaoKap Sang; TNAU 14S × CB 13212; TNAU 14S × CB 15137; TNAU 18S × CB 15117; TNAU 45S × Khao do ngoi; TNAU 45S × KhaoKap Sang; and TNAU 60S × Khao do ngoi showed significant *sca* effects for more than 4 characters and were found to be promising hybrids based on specific combining ability. Four hybrids selected with high standard heterosis for more than 5 characters, viz. TNAU 14S × AC 38479, TNAU 14S × CB 15121, TNAU 45S × CB 15137 and TNAU 95S × CB 15121 were considered as best hybrids and can be further used in heterosis breeding.

Keywords: General combining ability, Heterosis, Specific combining ability, Thermo-sensitive genic male sterility, Two-line hybrids

Rice (*Oryza sativa* L.) is currently cultivating in more than 100 countries providing staple food for nearly 3 billion people and supplying one-fifth of calories in their diet. But population growth mainly in rice consuming countries is increasing enormously leading to the condition of food insecurity. Among various breeding strategies of rice, developing hybrid rice is a practical way to move the yield plateau upward. Furthermore, in the early 1980s, there was a remarkable success of hybrid rice technology in China, which significantly increased rice production in that nation (Janaiah 2002).

Despite its effectiveness, the cytoplasmic genetic male sterility (CGMS) technology is costly and cumbersome. One of the main constraints is maintaining the CGMS lines and selecting a suitable restorer line to produce the fertile hybrids. Furthermore, the limited number of CGMS lines available for hybrid development reduces the genetic basis and raises the possibility of genetic vulnerability. The two-line breeding strategy that generates environmental sensitive genic male sterility (EGMS) is among the best option to replace the CGMS. The tropical country like India allows full manifestation of sterility at different times due to its substantial temperature variance at different elevations and seasons (Virmani *et al.* 2003). Utilizing the thermosensitive genic male sterile (TGMS) approach helps to solve issues related to CGMS and opens an opportunity for the simple development and maintenance of hybrids in rice.

General combining ability (*gca*) is one of the powerful tools for selection of best performing parents to produce superior hybrids. Meanwhile, specific combining ability is also a very useful method to predict the best performing hybrids from superior crosses which in turn helps in hybrid breeding (Fasahat *et al.* 2016). Among the three different types of heterosis, standard heterosis is one of the best ways of exploiting hybrid vigour. The availability of sufficient hybrid vigour is an important step for successful production of hybrids (Birchler *et al.* 2010). Keeping in view the importance of TGMS in hybrid rice, the present study is taken up to study *gca* and *sca* and the level of heterosis

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using *indica*/tropical *japonica* male parents by crossing with TGMS lines.

MATERIALS AND METHODS

The present study was carried out during summer and rainy (*kharif*) season of 2016 at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. This investigation consists of TGMS based two line rice hybrids obtained from crossing of five TGMS female parents (TNAU 14S, TNAU 18S, TNAU 45S, TNAU 60S and TNAU 95S) with eight non-TGMS male testers which includes four tropical *japonicas* (Palawan, KhaoKap Sang, Khao do ngoi and AC 38479) and four *indica cultures* (CB 13212, CB 15117, CB 15121 and CB 15137) from Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. This experiment was taken up in line × tester mating design to evaluate 40 crosses obtained from five female and eight male parents. The 40 hybrid combinations, their 13 parents, and the standard check (TNAU Rice hybrid CO4) were grown in two replications under randomized block design (RBD).

Hybridization: The five TGMS (male sterile) lines and eight testers (male fertile) were raised in a crossing block and in an order to coincide the flowering during high temperature at Paddy Breeding Station, Tamil Nadu Agricultural University during March-April, 2016. The Line × Tester (L × T) mating design was used for crossing among the five female (TGMS lines) and eight male parents (Testers). Threshold temperature for sterility in TGMS lines is >30^{o}C. The TGMS lines were expressed sterility during attempting crosses as the temperature was high and highest temperature reported to be 36^{o}C and lowest was 22.6 ^{o}C.

Examination of pollen sterility in TGMS lines: To assess pollen sterility, 10 spikelets were taken from each TGMS plant main panicle during flowering stage. The pollen grains that had been squeezed from the anthers were examined under a microscope after being stained in a 1% Iodine-Potassium Iodide (I-KI) solution for 2-min. The pollen grains were counted for their stainability. To exclude fertile female plants, the fertility and sterility status was calculated based on the quantity of stained and unstained pollen grains. 100% sterile plants were identified based on microscopic examinations of the anthers.

TGMS lines were not emasculated because they were male sterile, and the spikelets of the unopened panicles were trimmed to one-third of their length. To prevent contamination, the spikelets were wrapped in butter paper bags. Prior to the start of anthesis, this procedure had been done between 7:00 and 9:00 AM. Partially opened panicles were chosen from the testers (pollinators) during the peak anthesis period, which lasted from 10:00–11:30 AM. They were then rolled in a wet cloth and left for 10–15 min to allow the spikelets to fully open. Finally, they were sprinkled on top of the female TGMS bagged lines' panicles to facilitate pollination. After crossing the panicles were labeled and covered. When the F1 seeds reached a sufficient maturity (25–30 days post-pollination), they were gathered and sun-dried.

Evaluation of F_1 hybrids: Forty hybrids along with their 13 parents and a check (TNAU Rice hybrid CO 4) were sown in raised beds in *kharif* 2016. Under puddled conditions, 25-day old seedlings were moved to the main field. For each genotype, a single seedling per hill was planted in two rows of 2.0 m length with two replications, spaced 20 cm apart. Recommended fertilizer dose and other cultural practices were adopted. Ten quantitative characters were recorded in the field, viz. single plant yield (SPY), harvest index (HI), plant height (PH), biomass yield (BMY), panicle length (PL), number of filled grains/panicle (NFP), spikelet fertility percentage (SF), number of productive tillers per plant (NPT) and 100-grain weight (100 SW).

Statistical analysis: For statistical analysis, the mean values for the check, 40 hybrids, and 10 parent characters were recorded. The Panse and Sukhatme (1985) approach were used to calculate the analysis of variance (ANOVA) separately for each character. To analyze the line × testers and evaluate the general and specific combining ability effects of the parents and hybrids, the Kempthorne (1957) formula was applied. Using the formula put forward by Wynne *et al.* (1970), the relevance of standard heterosis over standard check was examined.

RESULTS AND DISCUSSION

Analysis of variance (ANOVA): For each of the 10 characters, the ANOVA showed that the variation resulting from lines and testers was significant. Except for harvest index and the quantity of productive tillers, the variance resulting from line and tester interaction was likewise very significant for eight characters. In the present study, the variances between lines and variances between testers were highly significant and could be effectively useful for studying combining ability effects.

General combining ability (gca): The general combining ability of 13 parents for 10 quantitative traits are presented in Table 1. The number of productive tillers, spikelet fertility percentage, biomass mass yield/plant, single plant yield, and harvest index were the six characters in the current study for which TGMS line TNAU 14S exhibited a positive significant *gca* effect. With the exception of days to 50% flowering, plant height, harvest index, and 100-seed weight, TNAU 95S exhibited a positive and substantial *gca* effect for six characters. TNAU 18S had positive significant *gca* effect for two characters. The line TNAU 60S and TNAU 45S had positive significant *gca* effect for only one character.

The tropical *japonica* tester Palawan had positive significant *gca* effect for five characters, viz. spikelet fertility percentage, number of filled grains/panicle, single plant yield, harvest index and 100-grain weight. AC38479 had positive significant *gca* effects for biomass yield/plant, single plant yield and 100-seed weight and negative significant *gca* effect for days to 50% flowering. The remaining two *japonica* testers KhaoKap Sang and Khao do ngoi had significant *gca* effect for four and one character(s) respectively.

The tester CB 15137 demonstrated a positive and significant *gca* effect for five characteristics (number of

Table 1 General combining ability (*gca*) of 13 rice genotypes for 10 quantitative traits

S.No	Genotypes	Characters									
		DFF	PH	PL	NPT	SF	NFG	BMY	SPY	HI	100 SW
Lines											
1	TNAU14S	1.13**	-3.03**	0.71	2.74**	2.74**	-5.06**	8.41**	13.38**	0.03**	-0.03**
2	TNAU18S	1.81**	-6.90**	-2.10**	-3.33**	-9.16**	-19.13**	-17.32**	-13.01**	-0.00	0.11**
3	TNAU45S	-3.56**	3.10**	0.21	-2.70**	4.36**	26.69**	-3.08**	-4.09**	-0.01**	-0.16**
4	TNAU60S	-0.06	1.04*	0.03	0.49	-0.49	-10.56**	-6.03**	-7.92**	-0.01*	0.07**
5	TNAU95S	0.69	5.79**	1.15**	2.80**	2.55**	8.06**	18.02**	11.64**	-0.00	0.00
	SE	0.34	0.46	0.39	0.46	0.47	0.59	0.31	0.25	0.004	0.009
Testers											
1	Palawan	7.05**	11.05**	0.86	-1.41*	18.41**	21.81**	-27.25**	4.57**	0.03**	0.17**
2	Khao Kap Sang	-5.25**	8.55**	1.06*	-5.91**	-18.80**	-21.39**	26.30**	2.13**	-0.01	0.37**
3	Khao do ngoi	7.05**	12.35**	-0.04	-6.61**	-17.36**	-55.19**	-9.32**	-16.88**	-0.03**	0.28**
4	AC38479	-2.45**	15.25**	0.26	0.89	-4.80**	-5.79**	16.37**	6.33**	-0.00	0.42**
5	CB13212	1.75**	-4.55**	0.26	2.69**	-1.34*	-8.29**	29.28**	-0.56	-0.05**	-0.19**
6	CB15117	3.15**	-15.95**	-0.04	4.19**	4.59**	15.81**	-38.40**	6.75**	0.07**	-0.32**
7	CB15121	-4.45**	-20.05**	-2.34**	-1.01	3.07**	14.21**	-12.96**	-6.50**	0.01**	-0.38**
8	CB15137	-6.85**	-6.65**	-0.04	7.19**	16.22**	38.81**	15.98**	4.15**	-0.01**	-0.35**
	SE	0.44	0.58	0.50	0.59	0.59	0.75	0.40	0.31	0.005	0.01

*Significance at 5% level; **Significance at 1% level. DFF, Days to 50% flowering; PH, Plant height (cm); PL, Panicle length (cm); NPT, Number of productive tillers; SF, Spikelet fertility percentage; NFG, Number of filled grains/panicle; BMY, Biomass yield/plant; SPY, Single plant yield/plant; HI, Harvest Index; 100 SW, 100-seed weight (g).

productive tillers/plant, spikelet fertility percentage, number of filled grains/panicle, biomass yield/plant, and single plant yield) in addition to having a negative *gca* effect for two characteristics (days to 50% flowering and plant height). A single plant yield, harvest index, spikelet fertility percentage, number of filled grains per panicle, and number of productive tillers per plant were the five characters for which CB 15117 shown a negative *gca* effect. CB 13212 and CB 15121, the other two testers, demonstrated a positive and strong *gca* impact for two and three characters, respectively.

The average performance of a line in a sequence of cross combinations is known as general combining ability (*gca*), and it is mostly due to additive and additive × additive gene effects, which are primarily an interallelic interaction with some intraallelic interaction as well. Therefore, choosing parents based on favourable GCA will impact the breeding programme. From this study, the lines TNAU 95S and TNAU 14S, tropical *japonica* tester Palawan and *indica* tester CB 15137 showed positive significant *gca* effect for about five characters and these are considered as desirable genotypes based on general combining ability for using as a parental breeding material. This type of high *gca* effect of parental lines were also reported by few other workers in rice, viz. Mishra *et al.* (1991), Elsy (1997), Cherian (1998), Sampoornam (1998), Kalaiyarasi (2002), Sundar (2003), Satheesh and Saravanan (2010), Karpagam (2011), Arasakesary (2012), and Kumar (2015).

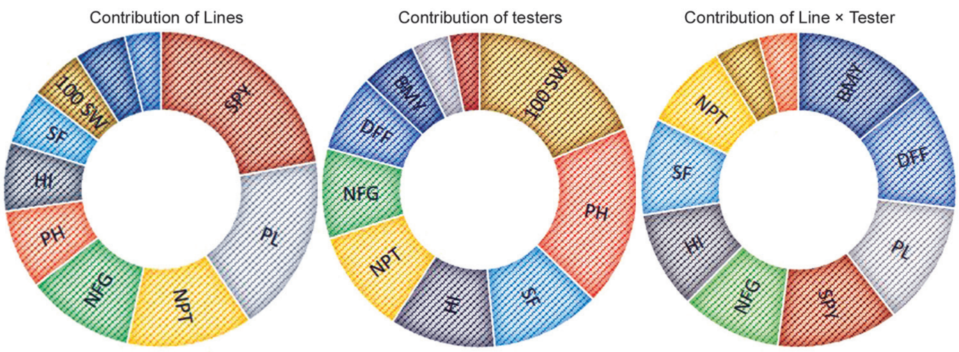

Fig. 1 The proportional contribution towards heterosis for different characters in rice. DFF, Days to 50% flowering; PH, Plant height (cm); PL, Panicle length (cm); NPT, Number of productive tillers; SF, Spikelet fertility percentage; NFG, Number of filled grains/panicle; BMY, Biomass yield/plant; SPY, Single plant yield/plant; HI, Harvest Index; 100 SW, 100-seed weight (g).

Specific combining ability (sca): The specific combining ability effects of 40 hybrids for 10 quantitative traits are presented in Table 2. The hybrids obtained from *japonica* testers, TNAU 14S/ Palawan showed positive significantly *sca* effects for six characters except plant height, panicle length, number of productive tillers and biomass yield and remaining four hybrids TNAU 14S ×

Table 2 Specific combining ability (*sca*) of 40-hybrids for 10 quantitative traits

S.No.	Hybrid combination	DFF	PH	PL	NPT	SF	NFG	BMY	SPY	HI	100SW
1	TNAU14S × Palawan	-10.93**	15.32**	3.39**	-3.34*	4.29**	28.56**	21.23**	18.07**	0.03**	0.16**
2	TNAU14S × Khao Kap Sang	-4.63**	-4.18**	-2.81*	5.16**	-8.68*	-34.24**	9.90**	2.99**	-0.01	-0.08**
3	TNAU14S × Khao do ngoi	15.07**	-2.98*	0.79	-6.64**	-16.34**	-19.44**	-71.23**	-31.91**	-0.06**	-0.10**
4	TNAU14S × AC38479	-0.42	9.63**	-0.01	-1.64	18.65**	53.66**	1.39**	-7.52**	-0.05**	-0.05
5	TNAU14S × CB 13212	2.38*	-11.57**	-0.51	2.56	5.69**	-13.34**	88.79**	40.96**	0.04**	-0.06*
6	TNAU14S × CB 15117	5.97**	-10.18**	-2.21	-7.44**	0.49	-25.44**	-73.82**	-37.54**	-0.01	0.08**
7	TNAU14S × CB 15121	-1.43	0.92	0.59	8.76**	-7.74**	-1.84	5.47**	3.30**	0.08**	-0.06*
8	TNAU14S × CB 15137	-6.03**	3.03*	0.79	2.56	3.65**	12.06**	18.28**	11.65**	-0.01	0.11**
9	TNAU18S × Palawan	-12.11**	-10.30**	0.70	5.22**	5.00**	20.63**	-6.29**	-4.05**	-0.06**	0.34**
10	TNAU18S × Khao Kap Sang	6.19**	0.20	-0.00	0.22	-21.59**	-17.67**	-23.41**	-8.34**	-0.01	0.25**
11	TNAU18S × Khao do ngoi	13.89**	0.40	0.60	0.43	-2.27	-1.38	-31.27**	-5.72**	0.05**	0.10**
12	TNAU18S × AC38479	-2.61*	12.00**	2.80*	2.92*	-2.97	32.72**	-12.23**	1.63*	0.01	-0.14**
13	TNAU18S × CB 13212	7.19**	4.80**	0.80	10.13**	2.76*	11.23**	76.34**	20.96**	-0.04**	-0.14**
14	TNAU18S × CB 15117	-6.71**	-6.80**	-0.40	-0.87	8.47**	-3.88*	69.35**	14.53**	0.03**	-0.11**
15	TNAU18S × CB 15121	-0.11	2.80*	-1.60	-7.67**	-0.74	-14.77**	-41.99**	-14.48**	-0.01	-0.12**
16	TNAU18S × CB 15137	-5.71**	-3.10*	-2.90*	-10.38**	11.34**	-26.88**	-30.50**	-4.54**	0.04**	-0.18**
17	TNAU45S × Palawan	-2.74**	-3.80**	0.39	2.10	-2.06	-3.69*	-41.90**	-15.13**	-0.00	-0.29**
18	TNAU45S × Khao Kap Sang	9.06**	-6.80**	-2.81*	-3.90**	29.59**	89.01**	54.83**	29.35**	0.06**	-0.46**
19	TNAU45S × Khao do ngoi	-13.74**	-5.60**	-0.71	8.80**	-18.49**	-12.19**	80.74**	31.26**	0.01	0.04
20	TNAU45S × AC38479	4.76**	-0.50	0.49	1.80	-19.71**	-44.59**	12.93**	6.69**	0.03**	0.21**
21	TNAU45S × CB 13212	2.06*	-0.20	-2.51*	-3.00*	9.58**	-0.59	-58.31**	-25.29**	-0.00	-0.03
22	TNAU45S × CB 15117	1.66	6.70**	2.79*	2.00	-16.59**	-64.69**	-53.45**	-12.55**	0.02*	0.14**
23	TNAU45S × CB 15121	1.26	0.80	-1.91	-3.30*	16.17**	15.91**	-30.37**	-19.27**	-0.08**	0.19**
24	TNAU45S × CB 15137	-2.34*	9.40**	4.29**	-4.50**	1.52	20.81**	35.53**	4.94**	-0.04**	0.21**
25	TNAU60S × Palawan	12.76**	-4.74**	-2.92*	-5.59**	-6.33**	14.06**	47.43**	6.33**	0.07**	-0.07**
26	TNAU60S × Khao Kap Sang	-4.94**	-1.24	1.88	0.41	23.03**	34.26**	-12.19**	-2.82**	0.01	-0.16**
27	TNAU60S × Khao do ngoi	-7.74**	8.46**	1.48	-1.89	37.09**	26.06**	54.90**	15.34**	-0.05**	-0.01
28	TNAU60S × AC38479	2.76**	-8.44**	-0.82	-1.39	-0.60	-44.34**	-2.01**	1.38	0.01	-0.11**
29	TNAU60S × CB 13212	-1.44	10.36**	1.17	-1.19	-29.16**	-37.34**	-35.30**	-18.54**	-0.05**	0.46**
30	TNAU60S × CB 15117	-0.34	9.76**	2.47*	2.31	-3.67**	29.06**	-18.29**	4.16**	-0.02	-0.17**
31	TNAU60S × CB 15121	3.76**	-6.14**	-0.22	1.51	-17.46**	-21.34**	11.60**	8.20**	0.01	0.06*
32	TNAU60S × CB 15137	-4.84**	-8.04**	-3.03**	5.81**	-2.89*	-0.44	-46.14**	-14.05**	0.02	-0.00
33	TNAU95S × Palawan	13.01**	3.51*	-1.55	1.60	-0.90	-59.56**	-20.47**	-5.22**	-0.03**	-0.14**
34	TNAU95S × Khao Kap Sang	-5.69**	12.01**	3.75**	-1.90	-22.34**	-71.36**	-29.13**	-21.18**	-0.05**	0.46**
35	TNAU95S × Khao do ngoi	-7.49**	-0.29	-2.15	-0.70	0.01	6.94**	-33.14**	-8.97**	0.06**	-0.03
36	TNAU95S × AC38479	-4.49**	-12.69**	-2.45*	-1.70	4.63**	2.54	-0.07	-2.18**	0.01	0.08**
37	TNAU95S × CB 13212	-10.19**	-3.39*	1.05	-8.50**	11.14**	40.04**	-71.52**	-18.09**	0.05**	-0.23**
38	TNAU95S × CB 15117	-0.59	0.51	-2.65*	4.00**	11.29**	64.94**	76.22**	31.40**	-0.02*	0.06*
39	TNAU95S × CB 15121	-3.49**	1.61	3.15**	0.70	9.77**	22.04**	55.29**	22.25**	0.00	-0.07**
40	TNAU95S × CB 15137	18.91**	-1.29	0.85	6.50**	-13.61**	-5.56**	22.82**	2.00**	-0.01	-0.14**
	SE	0.98	1.31	1.12	1.32	1.33	1.69	0.92	0.70	0.01	0.02

*Significance at 5% level; **Significance at 1% level.

DFF, Days to 50% flowering; PH, Plant height (cm); PL, Panicle length (cm); NPT, Number of productive tillers; SF, Spikelet fertility percentage; NFG, Number of filled grains/panicle; BMY, Biomass yield/plant; SPY, Single plant yield/plant; HI, Harvest Index; 100 SW, 100-seed weight (g).

Table 3 Standard heterosis of 40 hybrids over standard check TNAU Rice hybrid CO 4 for 10 quantitative traits

S.No.	Hybrid Combination	DFF	PH	PL	NPT	SF	NFG	BMY	SPY	HI	100 SW
1	TNAU14S × Palawan	-15.77**	27.04**	75.00**	39.29**	94.60**	48.28**	31.93**	78.86**	10.00**	19.68**
2	TNAU14S × Khao Kap Sang	-21.17**	4.59*	37.50**	67.86**	-6.10	-43.10**	142.58**	45.17**	-6.67	17.42**
3	TNAU14S × Khao do ngoi	7.66**	9.69**	53.13**	-21.43	-18.57**	-59.48**	-14.54**	-58.47**	-24.44**	13.12**
4	TNAU14S × AC38479	-14.86**	25.51**	50.00**	67.86**	76.85**	46.12**	144.67**	33.04**	-15.56**	21.72**
5	TNAU14S × CB 13212	-8.56**	-16.33**	46.88**	110.71**	57.78**	-13.79**	252.75**	113.02**	-6.67	-6.79**
6	TNAU14S × CB 15117	-4.05**	-26.53**	34.38**	50.00**	59.25**	-3.45	-14.09**	-23.87**	8.89*	-6.11**
7	TNAU14S × CB 15121	-17.57**	-19.39**	37.50**	128.57**	39.70**	15.52**	2.79	29.19**	16.67**	-15.16**
8	TNAU14S × CB 15137	-23.87**	-3.57	53.13**	142.86**	88.92**	48.71**	32.32**	65.70**	-8.89*	-6.11**
9	TNAU18S × Palawan	-16.22**	-3.06	40.63**	57.14**	72.15**	29.31**	63.67**	-14.40**	-17.78**	33.94**
10	TNAU18S × Khao Kap Sang	-10.81**	5.10**	37.50**	-10.71	-55.86**	-40.95**	31.96**	-27.35**	-14.44**	38.69**
11	TNAU18S × Khao do ngoi	7.21**	9.18**	34.38**	-14.29	-14.20**	-56.03**	-26.56**	-58.86**	-6.67	28.05**
12	TNAU18S × AC38479	-16.22**	23.98**	50.00**	57.14**	9.59*	15.95**	60.56**	-0.11	-8.87*	23.76**
13	TNAU18S × CB 13212	-3.60**	-3.57	37.50**	121.43**	28.04**	-4.74*	170.21**	23.82**	-28.89**	-4.07*
14	TNAU18S × CB 15117	-14.86**	-27.04**	28.13**	53.57**	51.40**	3.02	-8.34**	25.48**	11.11**	-8.60**
15	TNAU18S × CB 15121	-15.77**	-21.43**	6.25	-32.14*	29.88**	-7.76**	-25.62**	-55.73**	-7.78*	-11.76**
16	TNAU18S × CB 15137	-22.97**	-13.78**	12.50	7.14	80.49**	3.02	35.47**	-16.15**	-3.33	-13.35**
17	TNAU45S × Palawan	-12.61**	13.78**	53.13**	39.29**	85.10**	47.84**	34.92**	-18.55**	-6.67	-6.56**
18	TNAU45S × Khao Kap Sang	-13.06**	8.16**	34.38**	-35.71*	73.93**	90.52**	156.41**	62.26**	-1.11	-5.66**
19	TNAU45S × Khao do ngoi	-22.52**	13.27**	40.63**	50.00**	-19.64**	-25.86**	143.35**	29.37**	-16.67**	13.35**
20	TNAU45S × AC38479	-14.41**	21.43**	50.00**	53.57**	3.12	-11.21**	-20.99**	26.77**	-6.67	27.38**
21	TNAU45S × CB 13212	-13.06**	1.53	31.25**	32.14*	68.83**	24.57**	8.16**	-47.96**	-24.44**	-11.54**
22	TNAU45S × CB 15117	-12.16**	-3.06	62.50**	78.57**	28.23**	-9.91**	-19.84**	-9.43**	.7.78*	-9.28**
23	TNAU45S × CB 15121	-19.37**	-13.27**	18.75	3.57	90.90**	58.19**	9.16**	-47.80**	-26.67**	-9.73**
24	TNAU45S × CB 15137	-24.77**	9.18**	71.88**	53.57**	87.89**	83.62**	143.48**	19.21**	-24.44**	-7.92**
25	TNAU60S × Palawan	4.50**	10.71**	31.25**	7.14	66.80**	31.03**	16.59**	15.35**	8.89*	14.03**
26	TNAU60S × Khao Kap Sang	-22.52**	11.73**	62.50**	17.86	51.05**	11.21**	62.25**	-6.95**	-11.11**	18.33**
27	TNAU60S × Khao do ngoi	-13.96**	25.51**	53.13**	-3.57	82.16**	-25.00**	104.60**	-8.58**	-31.11**	21.27**
28	TNAU60S × AC38479	-13.06**	11.22**	40.63**	53.57**	31.75**	-43.10**	89.52**	9.20**	-10.00**	23.30**
29	TNAU60S × CB 13212	-13.06**	10.20**	53.13**	67.86**	-18.62**	-39.22**	35.18**	-42.32**	-33.33**	21.27**
30	TNAU60S × CB 15117	-10.81**	-2.04	59.38**	103.57**	44.44**	38.79**	23.50**	15.35**	-1.11	-12.90**
31	TNAU60S × CB 15121	-13.96**	-22.45**	28.13**	60.71**	13.70**	-6.03**	61.69**	-2.34	-6.67	-4.98*
32	TNAU60S × CB 15137	-23.87**	-10.71**	25.00*	150.00**	69.32**	33.19**	29.60**	-24.64**	-10.00**	-7.01**
33	TNAU95S × Palawan	5.41**	23.98**	46.88**	75.00**	83.80**	-16.38**	-25.60**	30.73**	-11.11**	7.69**
34	TNAU95S × Khao Kap Sang	-22.52**	30.10**	81.25**	17.86	-33.89**	-63.79**	88.66**	-4.64**	-22.22**	43.44**
35	TNAU95S × Khao do ngoi	-13.06**	21.43**	37.50**	21.43	13.86**	-25.43**	35.32**	-17.72**	-5.56	17.87**
36	TNAU95S × AC38479	-18.92**	11.73**	37.50**	67.86**	48.33**	13.36**	141.29**	39.96**	-10.00**	28.73**
37	TNAU95S × CB 13212	-20.27**	1.02	59.38**	32.14*	68.34**	43.53**	35.61**	-3.87	-10.00**	-13.12**
38	TNAU95S × CB 15117	-10.36**	-6.63**	34.38**	132.14**	80.55**	85.78**	65.30**	105.33**	-1.11	-5.43**
39	TNAU95S × CB 15121	-19.82**	-9.69**	56.25**	71.43**	74.44**	47.41**	169.67**	62.26**	-6.67	-14.25**
40	TNAU95S × CB 15137	-1.80	1.02	56.25**	171.43**	53.90**	44.83**	171.59**	43.80**	-16.67**	-16.06**
Check Mean	TNAU Rice hybrid CO 4	111.00	98.00	16.00	14.00	49.84	116	74.31	52.01	4.52	2.06

*Significance at 5% level; **Significance at 1% level. DFF, Days to 50% flowering; PH, Plant height (cm); PL, Panicle length (cm); NPT, Number of productive tillers; SF, Spikelet fertility percentage; NFG, Number of filled grains/panicle; BMY, Biomass yield/plant; SPY, Single plant yield/plant; HI, Harvest Index; 100 SW, 100-seed weight (g).

KhaoKap Sang, TNAU 45S × Khao do ngoi, TNAU 45S × KhaoKap Sang and TNAU 60S × Khao do ngoi showed positive significant *sca* effects for five characters. On the other hand, TNAU 14S × CB 13212, TNAU 14S × CB 15137 and TNAU 18S × CB 15117 showed positive significant *sca* effects for five characters.

To evaluate hybrids, it is crucial to consider the consequences of specific combining abilities which is connected to hybrid vigour. Superior cross combinations were determined by *sca*, and these included TNAU 14S × Palawan, TNAU 14S × KhaoKap Sang, TNAU 14S × CB 13212, TNAU 14S × CB 15137, TNAU 18S × CB 15117, TNAU 45S × Khao do ngoi, TNAU 45S × KhaoKap Sang, and TNAU 60S × Khao do ngoi. So, based on ability, above five *japonica* hybrids and three *indica* hybrids could be used for heterosis breeding.

From line × tester analysis, proportional contribution of lines was higher than testers for panicle length and single plant yield and for remaining eight characters major contribution was showed by testers (Fig. 1). With the exception of plant height and 100-seed weight, the line × tester interaction showed a higher proportional contribution to biomass yield, single plant yield, harvest index, days to 50% flowering, panicle length, number of productive plant, spikelet fertility, and number of filled grains for panicle.

Standard heterosis: The standard heterosis of 40 hybrids over standard check TNAU Rice hybrid CO 4 for 10 quantitative traits is represented in Table 3. In this experiment, the hybrid TNAU 14S/CB 15121 had better standard heterosis for spikelet fertility percentage, number of filled grains per panicle, number of productive tillers per plant, harvest index and for single plant yield. The hybrid TNAU 14S × AC38479 had better standard heterosis for biomass yield per plant, spikelet fertility percentage, number of filled grains/panicle and for single plant yield. The hybrid TNAU 45S × CB 15137 showed superior standard heterosis in terms of panicle length, biomass yield/plant, number of filled grains/panicle and single plant yield.

Superior standard heterosis was demonstrated by the hybrid TNAU 60S × CB 15117 in terms of single plant yield, number of productive tillers, number of filled grains/panicle, and panicle length. In terms of single plant yield, spikelet fertility percentage, number of filled grains/panicle, and number of productive tillers, the hybrid TNAU 95S × CB 15117 exhibited superior standard heterosis. The hybrid combinations TNAU 95S × CB 15121 and TNAU 95S × AC38479 exhibited superior standard heterosis in terms of biomass yield/plant, single plant yield, number of filled grains/panicle, and spikelet fertility percentage.

For the generation of hybrids requires knowledge of the extent of heterosis. Thus, in order to determine the best hybrid in this study, heterosis above the standard hybrid was selected. When compared to the check TNAU rice hybrid CO 4, nine of the 40 two-line hybrids outperformed the others in terms of yield-attributable traits such as single plant yield, days to 50% flowering, number of productive tillers, number of filled grains per panicle, spikelet fertility percentage, biomass yield and harvest index. However, four among the nine hybrids namely TNAU 14S × AC38479, TNAU 14S × CB 15121, TNAU 45S × CB 15137 and TNAU 95S × CB 15121 showed excellent performance over standard check and could be useful for heterosis breeding. Present observations which resulted in the identification of two-line rice hybrids with superior standard heterosis are in conformity with the similar findings reported earlier by Elsy (1997), Kalaiyarasi *et al.* (2002), Radhidevi *et al.* (2002), Karpagam (2011), Arasakesary (2012) and Kumar (2015).

From the results of *gca*, lines TNAU 95S and TNAU 14S, tropical *japonica* tester Palawan and *indica* tester CB 15137 were considered as best parents to develop superior hybrids. On the basis of *sca*, TNAU 14S × Palawan, TNAU 14S × KhaoKap Sang, TNAU 14S × CB 13212, TNAU 14S × CB 15137, TNAU 18S × CB 15117, TNAU 45S × Khao do ngoi, TNAU 45S × KhaoKap Sang and TNAU 60S × Khao do ngoi were identified as superior cross combinations and meanwhile results from standard heterosis revealed that crosses, viz. TNAU 14S × AC 38479, TNAU 14S × CB 15121, TNAU 45S × CB 15137 and TNAU 95S × CB 15121 showed excellent performance over standard check and could be useful for heterosis breeding.

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