https://doi.org/10.48047/AFJBS.6.8.2024.1920-1929

African Journal of Biological Sciences

Research Paper **Open Access**

GENE ACTION, COMBINING ABILITY AND HETEROSIS STUDIES *via* LINE x TESTER DESIGN IN RICE (*Oryza sativa* L.)

N. ARUNA[1]*, R. ELANGAIMANNAN[2], M.V. SRIRAMACHANDRASEKHARAN[3] AND S. VENNILA[4]

[1,2]Department of Genetics and Plant Breeding, Faculty of Agriculture, Annamalai University. Tamilnadu. India. Corresponding Author: arunalakna@gmail.com

[3]Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture, Annamalai University. Tamilnadu. India.

[4]*Centre of Excellence in Millets, Athiyanthal, Tamil Nadu Agricultural University, Thiruvannamalai District. Tamilnadu. India.

Article History

Volume 6,Issue 8, 2024

Received:26 Mar 2024

Accepted : 29 Apr 2024

doi: 10.33472/AFJBS.6.8.2024.1920-1929

Abstract

Studies on gene action, combining ability and heterosis of ten parents (six lines and four testers) along with their twenty-four hybrids for nine yield and plant related traits were conducted using line x tester mating pattern. Analysis of variance for combining ability revealed significant differences among the lines, testers, and their interactions for almost every trait except kernel L/B ratio and GCA/SCA variance showcased the preponderance of non-additive gene effects in case of all the analysed traits. The line parents BPT 5204, Co 51 and tester parents Navara and Neelam Samba were pinpointed as good combiners from *gca* effects. Amongst hybrids, BPT 5204 x Neelam Samba, ADT 39 x Karuppukavuni, Co 51 x Navara, and BPT 5204 x Navara demonstrated outstanding *sca* effects and heterosis over their better parents. Therefore, these hybrids were recommended to move on for further breeding approaches to enhance the grain yield together with earliness and non-lodging traits.

Keywords: gene effects, combining ability, heterobeltiosis, yield traits

Introduction

Commercially grown rice varieties in Tamil Nadu, as in any agricultural context, play a crucial role in the state's economy, food security, and overall agricultural development. The emphasis on high-yielding commercial varieties may overshadow local rice varieties with diverse nutritional profiles, contributing to a lack of dietary diversity in communities reliant on commercially grown rice (Jebakani *et al*. 2019). Traditional rice varieties are known for their unique nutraceutical properties that offer potential health benefits beyond basic nutrition. These varieties exhibit a rich diversity of nutrients, including vitamins, minerals, antioxidants, phenolic compounds, flavonoids and phytochemicals which contribute to their superior nutritional profile compared to commercial varieties (Sundaram *et al*. 2019 & Shanmugam *et al*. 2023).

Incorporating traditional rice nutraceutical properties into high-yielding commercial varieties and the research efforts in this regard are essential to combat the evolving needs of farmers and consumers. To proceed further into this approach, line x tester mating design is preferably an applicable plant breeding tool, providing insights into the genetic interactions, and combining abilities of different properties of the parental lines systematically (Hossain *et al*. 2009). This information is instrumental in identifying superior parents, predicting the performance of specific hybrids, and tailoring breeding programs for the development of new varieties with improved agronomic traits (Vennela *et al*. 2023). The objective of this breeding endeavor is to explore the probability and potential for developing superior performing hybrids that could contribute significantly to the advancement of rice cultivation. Thereby, the present study was approached by crossing of commercially grown rice varieties and traditional rice land races in line x tester design of mating to explore and evolve new hybrids.

Materials and methods

The crossing block was raised at Kodukoor village, Villupuram district of Tamil Nadu during *Rabi 2022* under the guidance of Department of Genetics and Plant Breeding, Annamalai University. In the pursuit of enhancing rice varieties with superior traits, a comprehensive breeding program has been initiated employing the line x tester mating design adopting randomized block design. Six distinct commercially well-established popular rice varieties listed in Table 1 are chosen as lines due to their noteworthy performance and diverse genetic characteristics. In addition with these lines, four traditional rice varieties, Mapillai Samba, Navara, Neelam Samba and Karuppukavuni had been specifically chosen as testers for their unique nutraceutical traits and compatibility with the selected lines. Two staggered sowing was taken up at 15 days interval to achieve synchronization in flowering. Ten parents for crossing program were sown in in seed trays to establish a crossing block in the main field with 22-to-25-day old seedlings following a spacing interval of 20 x 5 cm. including three replications, adhering to the advised agronomic and crop-handling techniques. Hand emasculation ad pollination was practiced very carefully to avoid contamination The data collection was done in F_1 evaluation for Nine crucial yield-related attributes *viz*., Days to fifty percent flowering (days), Plant height (cm), Number of tillers per plant (nos), Number of productive tillers per plant (nos), Panicle length(cm), Number of grains per panicle (nos), Kernel L/B ratio, 1000 grain weight (gm) and Single plant yield (gm). The data were analyzed for combining ability following Kempthorne (1957).

Results and discussion

In Table 2, the combining ability ANOVA for nine quantitative traits associated to yield is presented. Research on every attribute has revealed a highly substantial variability with respect to genotypes, parents, crosses and their interaction. Non-significant replication showed that the treatments performed invariably across the replications. The variance in the lines and testers was found to be significant for every character except number of productive tillers per plant (in testers alone) kernel L/B ratio (both in lines and testers). The greater range of crosses and parental interaction is illustrated by the highly significant variation among crosses and the interaction of line and testers in hybrids. These significant results suggest that there is a good chance of locating parental candidates and hybrid combinations that could improve yield by tweaking the individual components. Similar works were outlined by Patil *et al.* 2012, Hussein *et al.* 2021, El-Mowafi *et al.* 2023 and Arunkumar & Narayanan, 2024.

Across all yield and grain characteristics, the variances attributed to specific combining ability consistently surpassed those associated with general combining ability. The ratio of GCA to SCA for each trait was consistently less than unity (Table 1), underscoring the prevalence of non-additive gene activity, including dominance and epistatic effects. The presence of non-additive gene action suggests the potential utilization of heterosis in the genetic material. Gene action based on combining ability variances were previously examined by Saidaiah *et al.* 2010, Sundaram *et al.* 2019, Mohan *et al.* 2021, Vennela *et al.* 2023 and Abd-El-Aty *et al.* 2023.

Table 3, Table 4 and Table 5, respectively, indicate estimates of the parental *gca*, hybrid's *sca* and heterotic effects. Variables influencing yield appeared to show a positive direction for combining ability effects and heterosis. Conversely, traits associated with days to fifty percent flowering (early hybrids) and plant height (non-lodging hybrids) were anticipated to exhibit a negative direction.

Days to fifty percent flowering: Four parents reported significant and desirable *gca* impacts for flowering trait. It was found that Co 51 (-14.80), ADT 39 (-11.86) and Navara (-12.58) were good general combiners for this character. Fourteen of the 24 crosses had substantial *sca* effects. In relation to this trait, the crosses BPT 5204 x Neelam Samba (-18.69) and Co 51 x Navara (-10.32) exhibited the most substantial and statistically significant negative *sca* effects, establishing them as the top-performing specific combiners. Twenty-one hybrids recorded for negative heterosis with BPT 5204 x Neelam Samba (-43.84) and Co 51 x Neelam Samba (-40.45) as the greatest significant heterosis. Analogous results were documented by Vennila *et al.* 2011, Borah *et al.* 2017, Deepika *et al.* 2023 and Nivedha *et al.* 2024.

Plant height: Significant and negative *gca*, *sca* and heterosis influences for plant height characteristic were identified as five, eleven and eighteen members respectively. BPT 5204 (-27.07), ADT 39 (-9.28) and Navara (-19.30) were recorded to be effective general combiner while BPT 5204 x Neelam Samba (-20.25) and BPT 5204 x Navara (-16.95) were the best-performing specific combiners. The strongest significant heterosis registered was BPT 5204 x Neelam Samba

(-41.27) and BPT 5204 x Mapillai Samba (-43.51). Similar outcomes were previously recorded for plant height by Saidaiah *et al.* 2010, Borah *et al.* 2017, Hussein *et al.* 2021, Kiruba *et al.* 2023 and Negm *et al.* 2023.

Number of tillers per plant: Respectively four, ten and four counts were identified as considerable and desirable *gca*, *sca*, and heterosis, for this attribute. The results showed that BPT 5204 (4.09), Ponmani (1.21) and Neelam Samba (1.23) were the most effective general combiners, while the strongest specific combiners were ADT 39 x Karuppukavuni (5.32) and Co 51 x Navara (4.15). Both ADT 39 x Karuppukavuni (32.19) and BPT 5204 x Mapillai Samba (16.95) exhibited the greatest amount of significant heterosis observed. Hussein *et al.* 2017, Mohan *et al.* 2021 and Arunkumar & Narayanan, 2024 noted similar results.

Number of productive tillers per plant: Best *gca* parents were BPT 5204 (4.75), Ponmani (0.81) and Navara (0.34) whereas high-scoring *sca* hybrids were ADT 39 x Karuppukavuni (6.21) and Co 51 x Navara (4.10) with an overall of four parents and nine hybrids exhibited positive yet significant *gca* and *sca* effects. Highest degree of positive, significant heterosis was recorded by ADT 39 x Karuppukavuni (39.95), Co 51 x Navara (19.65) and ADT-37 x Karuppukavuni (16.19). Results are in correlation with Rashid *et al.* 2007, Vennila *et al.* 2011, Sundaram *et al.* 2019 and Kiruba *et al.* 2023.

Panicle length: The top-scoring *sca* hybrids were ADT 39 x Karuppukavuni (3.83) and Co 51 x Navara (3.26), whereas the best *gca* parents were White Ponni (2.81), BPT 5204 (1.89), and Neelam Samba (1.13). In total, four parents and nine hybrids showed positive, substantial *gca* and *sca* influences. Co 51 x Navara (10.38), ADT 39 x Karuppukavuni (7.82), and BPT 5204 x Neelam Samba (7.63) all had the highest amounts of positive, significant heterosis over better parent. Saidaiah *et al.* 2010, Borah *et al.* 2017, Deepika *et al.* 2023 and Arunkumar & Narayanan, 2024 registered parallel findings for panicle length.

Grains per panicle: ADT-39 x Karuppukavuni (34.85) and BPT 5204 x Neelam Samba (30.76) were the highest rated *sca* hybrids, however BPT 5204 (16.52), C0-51 (12.32), Ponmani (7.69) and Karuppukavuni (5.87) were the most outstanding general combiners among the parents. Twelve hybrids and six parents together had strong, beneficial *sca* and *gca* impacts. BPT 5204 x Neelam Samba (30.77) and BPT 5204 x Navara (22.45) displayed greatest level of beneficial, considerable heterosis over superior parent. Equivalent findings had already been released by Hasib *et al.* 2002, Hossain *et al.* 2009, Borah *et al.* 2017, Negm *et al.* 2023 and El-Mowafi *et al.* 2023.

Kernel L/B ratio: Significant as well as desired *gca* and *sca* were found in three and four genotypes, respectively. BPT 5204 x Neelam Samba (0.31) and BPT 5204 x Navara (0.30) were the most potent specific combiners, whereas Co 51 (0.31), BPT 5204 (0.31) and Navara (0.05) were the most successful general combiners for L/B rtatio. The highest degree of notable heterobeltiosis was seen in only two hybrids *viz.*, Ponmani x Navara (5.95) and ADT 39 x Neelam Samba (5.61). Deepika *et al.* 2023, Vennela *et al.* 2023, Nivedha *et al.* 2024 and Arunkumar & Narayanan, 2024 reported comparable outcomes.

1000 grain weight (gm): Effective general combiners were found to be BPT 5204 (3.22), Ponmani (2.22) among lines and Karuppukavuni (3.19) among testers, while the best-performing *sca* hybrids were ADT-39 x Karuppukavuni (7.11) and BPT 5204 x Neelam Samba (6.00). For 1000 grain weight, four and ten members were found significant and exert positive influences for *gca* and *sca* effects respectively. The cross BPT 5204 x Neelam Samba is the only cross which showed positive significant heterobeltiosis for 1000 grain weight. Previously, related results were documented by Patil *et al.* 2012, Borah *et al.* 2017, Mohan *et al.* 2021 and Abd-El-Aty *et al.* 2023.

Single plant yield (gm): Amongst 10 parents, significant and desired *gca* influences for the grain yield were identified by four parents *viz*., BPT 5204 (6.96), Co 51 (5.26), Ponmani (2.31) and Neelam Samba (0.75) were discovered to be effective general combiners. Among the 24 hybrids, eight exhibited significant *sca* impacts. The crosses BPT 5204 x Neelam Samba (9.75) and ADT 39 x Karuppukavuni (9.54) had the strongest and most statistically significant positive *sca* effects with respect to this feature, making them the top-performing specific combiners. There were only four hybrids that showed positive as well as significant heterosis, with the two greatest heterotic hybrids *viz.*, BPT 5204 x Neelam Samba (40.12) and ADT 39 x Karuppukavuni (33.25). Comparable studies were published by Hasib *et al.* 2002, Rashid *et al.* 2007, Saidaiah *et al.* 2010, Borah *et al.* 2017, Sundaram *et al.* 2019, Negm *et al.* 2023, Kiruba *et al.* 2023 and Arunkumar & Narayanan, 2024 for single plant yield.

Among the hybrids evaluated, BPT 5204 x Neelam Samba, ADT 39 x Karuppukavuni, Co 51 x Navara, and BPT 5204 x Navara stood outstanding for the yield contributing characters. These hybrids displayed significant specific combining ability effects for six, six, four, and two grain yield attributes, respectively. Moreover, they have also exhibited significant heterotic effects. The cross BPT 5204 x Neelam Samba portrayed significantly superior heterotic effect for seven yield parameters *viz*., Days to fifty percent flowering, Plant height, Number of tillers per plant, Panicle length, Grains per panicle, 1000 grain weight and Single plant yield. Similarly, the other three crosses namely ADT 39 x Karuppukavuni, Co 51 x Navara, and BPT 5204 x Navara also exhibited superior significant heterotic effects for three, two and two yield attributes in order. Consequently, these hybrids can be considered as the top performers for further utilization in breeding programs aimed at enhancing the nutraceutical properties coupled with grain yield characteristics.

Conclusion

In conclusion of present examination for various yield-associated traits revealed a prevalent presence of non-additive effects. BPT 5204 and Co 51 among lines, as well as Navara and Neelam Samba, among testers were determined as promising general combiners. Noteworthy crosses, such as BPT 5204 x Neelam Samba, ADT 39 x Karuppukavuni, Co 51 x Navara, and BPT 5204 x Navara exhibited significant *sca* and heterotic effects, particularly in relation to nine quantitative traits, including earliness and non-lodging trait. Therefore, meticulous parent selection will contribute to enhancing early, non-lodging and plant yield simultaneously. These hybrids can now be incorporated into a future strategy of heterosis breeding, wherein selection can be deferred until subsequent generations.

References

ABD-EL-ATY, M. S., BAHGT, M. M., IBRAHIM, O. M., KORANY, S. M., ALSHERIF, E. A., ABDELGAWAD, H., & EL-TAHAN, A. M. (2023). Mode of gene action and heterosis for physiological, biochemical, and agronomic traits in some diverse rice genotypes under normal and drought conditions. *Frontiers in plant science*, *14*, 1108977.

ARUNKUMAR, P., & NARAYANAN, R. (2024). Combining Ability and Gene Action for Productivity Traits in Rice (*Oryza sativa* L.) under Saline Conditions. *Mysore J. Agric. Sci*, *58*(1), 40-47.

BORAH, P., SARMA, D., & HAZARIKA, G. N. (2017). Magnitude of heterosis for yield and its components in hybrid rice (Oryza sativa L.). *International Journal of Agricultural Science and Research*, *7*(2), 209-216.

DEEPIKA, K., MANIMARAN, R., PUSHPA, R., BAMA, K. S., UMAMAGESWARI, C., & SURESH, R. (2023). Studies on variability and heterosis for yield and nutritional traits in rice (Oryza sativa L.). *Electronic Journal of Plant Breeding*, *14*(3), 1135-1146.

EL-MOWAFI, H. F., REDA, A. M., ABDALLAH, R. M., ARAFAT, E. F., EL-SHARNOBY, D. E., & HADIFA, A. A. (2023). Combining ability and gene action analysis in Egyptian basmati hybrid rice. *Egypt. J. Plant Breed*, *27*(2), 169–191.

HASIB, K. M., GANGUL, P., & KOLE, P. C. (2002). Line x Tester analysis for yield and its components in scented rice. *Madras Agric. J.*, *89*(1), 278-281.

HOSSAIN, K. A., AKTER, H. B., ANSARI, A., & RAHMAN, M. M. (2009). Line x tester analysis for yield and its related traits in rice (Oryza sativa L.). *Bangladesh Journal of Plant Breeding and Genetics*, *22*(2), 01-06.

HUSSEIN, F. A. (2021). Heterosis and combining ability of some colored rice genotypes for yield characteristics and grain micronutrient content using Line X Tester analysis. *Journal of Plant Production*, *12*(6), 635-643.

JEBAKANI, K. S., AISHWARYA, D., PRAMITHA, J. L., RAMCHANDER, S., DEVASENA, N., WILSON, D., ... & SAMUNDESWARI, R. (2023). Assessing the genetic diversity and association of traits among the rice (*Oryza sativa* L.) landraces and varieties from Tamil Nadu. *Electronic Journal of Plant Breeding*, *14*(3), 818-832.

KEMPTHORNE, O. 1957. An Introduction to general statistics. *John Wiley and Sons*, New York. pp. 545.

KIRUBA, G., GEETHA, S., SARASWATHI, R., SANTHI, R., UMA, D., & PUSHPA, R. (2023). Heterosis, character association and path analysis for grain protein content in rice (Oryza sativa L.). *Electronic Journal of Plant Breeding*, *14*(3), 876-883.

MOHAN, Y. C., KRISHNA, L., SINGH, T. V., RAJU, C. D., BABU, T. K., AND, N. V., & RAMANA, M. V. (2021). Combining ability and heterosis studies for grain yield in rice (Oryza sativa L.). *Journal of Crop and Weed*, *17*(2), 245-254.

NEGM, M. E., ABO-MARZOKA, E. A., ABDELHAMEED, M. M., & GHIDAN, W. F. (2023). Inheritance of some biochemical, morpho-physiological and yield attributes trait of some rice genotypes under salinity condition. *Egyptian Journal of Agricultural Research*, *101*(2), 552-568.

NIVEDHA, R., MANONMANI, S., KALAIMAGAL, T., RAVEENDRAN, M., & KAVITHA, S. (2024). Comprehensive assessment of combining ability and heterosis for the development of superior three-line hybrids in rice (Oryza sativa L.). Electronic Journal of Plant Breeding, *15*(1), 1-11.

PATIL, P. R., SURVE, V. H., & MEHTA, H. D. (2012). Line x tester analysis in rice (Oryza sativa L.). *Madras Agric. J*., *99*(4-6), 210-213.

RASHID, M., CHEEMA, A. A., & ASHRAF, M. (2007). Line x tester analysis in basmati rice. *Pakistan Journal of Botany*, *39*(6), 2035-2042.

SAIDAIAH, P., RAMESHA, M. S., & KUMAR, S. S. (2010). Line x tester analysis in rice (Oryza sativa L.). *Madras Agric. J., 97*(4-6), 110-113.

SHANMUGAM, A., SURESH, R., RAMANATHAN, A., ANANDHI, P., & SASIKUMAR, D. (2023). Unravelling genetic diversity of South Indian rice landraces based on yield and its components. *Electronic Journal of Plant Breeding*, 14(1), 160-169.

SUNDARAM, K. M., RAJESWARI, S., SARASWATHI, R., & JEYAPRAKASH, P. (2019). Heterosis and combining ability analysis for yield related traits in rice hybrids involving land races. *Electronic Journal of Plant Breeding*, *10*(1), 92-100.

VENNELA, M., SRINIVAS, B., REDDY, V. R., & BALRAM, N. (2023). Combining ability analysis for grain quality traits in hybrid rice (Oryza sativa. L). *Journal of Crop and Weed*, *19*(1), 58-65.

VENNILA, S., Y. ANBUSELVAM & K. PALANIRAJA. (2011). Heterosis studies for yield and its components in rice *(Oryza sativa L.)*. *International Journal of Recent Scientific Research*. 2(9). Pp. 261-262.

Table 1. List of Lines and Testers

Lines	**Paddy Variety**	**Testers**	**Paddy Variety**
L1	White Ponni	T1	Mapillai Samba
L2	Ponmani	T2	Navara
L3	Co-51	T3	Neelam Samba
L4	ADT 37	T4	Karuppukavuni
L5	ADT 39		
L6	BPT 5204		

Table 2. Analysis of variance for combining ability for economic traits

Source of variation	Replication df = 2	Genotype df = 33	Cross df =23	Line df =5	Tester df =3	LxT interaction df =15	Error df =66	GCA	SCA	GCA/SCA
Days to fifty per cent flowering	6.25	1144.73**	841.34**	2249.18**	1294.18**	281.49**	1.59	14.12	93.57	0.15
Plant height (cm)	7.87	1887.93**	1594.77**	4114.03**	3554.38**	363.09**	4.63	31.06	120.32	0.26
Number of tillers per plant	0.83	31.42**	33.64**	80.78**	13.83*	21.89**	0.39	0.30	7.25	0.04
Number of productive tillers	0.74	38.71**	34.82**	85.95**	2.35	24.28**	0.38	0.27	8.08	0.03
Panicle length (cm)	0.51	25.52**	27.42**	48.62**	26.89*	20.46**	0.62	0.18	6.77	0.03
Grains per panicle	7.85	2007.70**	1442.67**	2393.96**	1363.45**	1141.42**	6.80	7.60	380.20	0.02
Kernel L/B ratio	0.02	0.39	0.35	1.21	0.02	0.13	0.01	0.01	0.04	0.25
1000 grain weight (gm)	0.85	115.46**	68.65**	59.13**	216.38**	42.28**	0.21	0.67	14.09	0.05
Single plant yield (gm)	3.57	142.65**	141.15**	386.24**	4.54	86.78**	0.87	1.37	28.74	0.05

[*Significance at 5% level, **Significance at 1% level]

Table 3. General combining ability (*gca*) effects of parents for economic traits

Plant characters	Days to fifty percent flowering	Plant height	Number of tillers per plant	Number of productive tillers per plant	Panicle length	Grains per panicle	Kernel L/B ratio	1000 grain weight	Single plant yield
LINES									
White Ponni (L1)	10.45**	26.53**	-1.53**	-1.59**	2.81**	-18.18**	0.01	-1.19**	-3.70**
Ponmani (L2)	21.20**	1.27**	1.21**	0.81**	-1.75**	7.69**	-0.12**	2.22**	2.31**
Co-51 (L3)	-14.80**	-4.47**	0.97**	0.41**	0.16	12.32**	0.31**	-1.28**	5.26**
ADT 37 (L4)	-0.69**	13.03**	-3.04**	-2.57**	-2.22**	-6.42**	-0.54**	-2.47**	-7.33**
ADT 39 (L5)	-11.86**	-9.28**	-1.70**	-1.81**	-0.88**	-11.93**	0.03	-0.49**	-3.49**
BPT 5204 (L6)	-4.30**	-27.07**	4.09**	4.75**	1.89**	16.52**	0.31**	3.22**	6.96**
TESTERS									
Mapillai Samba (T1)	2.99**	9.98**	-0.72**	-0.27**	-1.57**	-12.78**	-0.01	-4.15**	-0.35
Navara (T2)	-12.58**	-19.30**	-0.53**	0.34**	-0.34**	5.14**	0.05*	2.50**	-0.21
Neelam Samba (T3)	5.90**	10.85**	1.23**	-0.35**	1.13**	1.76**	0.00	-1.54**	0.75**
Karuppukavuni (T4)	3.69**	-1.53**	0.02	0.29**	0.78**	5.87**	-0.04	3.19**	-0.19
SE (lines)	0.25	0.42	0.11	0.06	0.11	0.26	0.03	0.04	0.22
SE (testers)	0.21	0.35	0.09	0.05	0.09	0.22	0.02	0.03	0.18

[*Significance at 5% level, **Significance at 1% level]

Table 4. Specific combining ability of crosses for economic traits

Crosses	Days to fifty percent flowering	Plant height	No. of tillers per plant	No. of productive tillers per plant	Panicle length	Grains per panicle	Kernel L/B ratio	1000 grain weight	Single plant yield
L1 x T1	2.48**	3.75**	1.18**	1.72**	-0.55**	5.84**	0.10	1.12**	2.21**
L1 x T2	-4.10**	4.95**	-0.32	0.12	-0.35	-3.99**	-0.03	-2.51**	-1.10*
L1 x T3	7.65**	-1.91**	1.16**	-1.17**	0.16	-5.84**	-0.00	0.52**	-1.95**
L1 x T4	-6.04**	-6.78**	-2.02**	-0.67**	0.74**	3.98**	-0.06	0.87**	0.85
L2 x T1	-2.03**	-9.85**	1.10**	1.55**	1.62**	10.93**	0.18**	1.58**	2.60**
L2 x T2	3.23**	-1.56	-2.29**	-1.11**	1.46**	1.93**	-0.17**	1.06**	-2.57**
L2 x T3	0.74	6.56**	1.06**	0.72**	-1.99**	-12.66**	-0.10	-1.82**	-0.93*
L2 x T4	-1.94**	4.84**	0.12	-1.16**	-1.09**	-0.20	0.08	-0.83**	0.90*
L3 x T1	-4.06**	4.58**	0.13	-0.30**	-2.22**	-7.58**	-0.16**	-1.07**	0.72
L3 x T2	-10.32**	-11.93**	4.15**	4.10**	3.26**	21.39**	0.15**	5.68**	4.41**
L3 x T3	-3.16**	4.00**	-0.82**	-0.13	-0.21	0.73	-0.09	-2.40**	-2.21**
L3 x T4	-3.10**	3.34**	-3.46**	-3.67**	-0.83**	-14.55**	0.10	-2.21**	-2.91**
L4 x T1	-9.26**	5.18**	1.25**	0.62**	2.09**	2.04**	0.05	3.42**	1.70**
L4 x T2	-9.52**	-5.40**	-1.10**	-0.74**	-3.49**	-7.63**	-0.07	-2.25**	-1.34**
L4 x T3	6.55**	-3.35**	-1.78**	-1.06**	-0.09	1.27**	-0.05	-0.13	-0.93*
L4 x T4	12.22**	3.57**	1.63**	1.18**	1.49**	4.32**	0.07	-1.05**	0.57
L5 x T1	-0.18	2.79**	-1.10**	-1.06**	-0.26	6.62**	0.01	-1.65**	-1.10*
L5 x T2	3.12**	-3.01**	-2.43**	-3.28**	-3.48**	-27.21**	-0.17**	-3.28**	-4.71**
L5 x T3	6.91**	14.95**	-1.79**	-1.88**	-0.09	-14.26**	-0.07	-2.18**	-3.73**
L5 x T4	-9.85**	-14.72**	5.32**	6.21**	3.83**	34.85**	0.24**	7.11**	9.54**
L6 x T1	13.04**	-6.45**	-2.57**	-2.54**	-0.68**	-17.85**	-0.18**	-3.39**	-6.12**
L6 x T2	-3.06**	-16.95**	1.98**	0.92**	2.60**	15.50**	0.30**	1.30**	5.31**
L6 x T3	-18.69**	-20.25**	2.18**	3.51**	2.23**	30.76**	0.31**	6.00**	9.75**
L6 x T4	8.70**	9.75**	-1.59**	-1.90**	-4.15**	-28.41**	-0.43**	-3.90**	-8.95**
SE (crosses)	0.51	0.85	0.21	0.13	0.22	0.53	0.05	0.08	0.44

[*Significance at 5% level, **Significance at 1% level]
White Ponni (L1), Ponmani (L2), Co-51 (L3), ADT 37 (L4), ADT 39 (L5), BPT 5204 (L6), Mapillai Samba (T1), Navara (T2), Neelam Samba (T3), Karuppukavuni (T4)

Table 5. Heterosis over better parent for yield and its component traits

Crosses	Days to fifty percent flowering	Plant height	No. of tillers per plant	No. of productive tillers per plant	Panicle length	Grains per panicle	Kernel L/B ratio	1000 grain weight	Single plant yield
L1 x T1	-7.16**	-6.95**	-8.63**	2.77	-5.93*	0.59	-2.58	-36.46**	-2.49
L1 x T2	-13.66**	-9.67**	-16.11**	-4.87	-0.08	7.83**	-5.40	-41.04**	-13.17**
L1 x T3	-16.21**	6.00**	2.36	-20.05**	3.10	3.15	-5.89*	-27.27**	-12.83**
L1 x T4	-3.36**	-5.61**	-22.67**	-11.28**	-1.74	12.92**	-11.20**	-34.89**	-6.53*
L2 x T1	-2.19**	-29.22**	-20.16**	-22.29**	-10.35**	-17.13**	0.77	-23.20**	-12.84**
L2 x T2	-9.78**	-1.11	-33.85**	-32.56**	-1.99	-11.97**	5.95*	-21.98**	-25.27**
L2 x T3	-13.63**	-3.46**	-11.98**	-26.84**	-23.14**	-22.36**	1.59	-23.50**	-18.85**
L2 x T4	-0.87	-8.08**	-21.16**	-33.06**	-25.37**	-12.78**	-10.48**	-30.57**	-16.63**
L3 x T1	-32.48**	-24.24**	-6.59**	-13.00**	-18.88**	-18.89**	-8.59**	-44.31**	-14.23**
L3 x T2	4.90**	-10.46**	16.02**	19.65**	10.38**	10.47**	3.73	-18.91**	-5.19**
L3 x T3	-40.45**	-9.15**	-1.25	-12.46**	-8.70**	-4.58**	-5.88*	-37.94**	-18.55**
L3 x T4	-23.18**	-13.34**	-21.82**	-31.37**	-17.32**	-11.58**	-1.02	-42.97**	-22.41**
L4 x T1	-25.38**	-13.86**	-3.00	-1.91	-24.78**	-35.40**	-20.69**	-32.95**	-14.46**
L4 x T2	-3.31**	10.81**	-13.53**	-8.49	-40.66**	-30.97**	-9.01**	-43.84**	-9.39**
L4 x T3	-24.44**	-2.19	-10.22**	-10.72*	-22.87**	-28.01**	-14.91**	-34.09**	-13.59**
L4 x T4	2.98**	-0.48	1.10	16.19**	-18.34**	-24.16**	-26.27**	-43.02**	-13.35**
L5 x T1	-27.04**	-28.02**	-13.53**	-20.28**	-19.46**	-19.10**	-0.51	-43.58**	-10.89**
L5 x T2	-4.83**	-4.95**	-20.77**	-32.69**	-27.62**	-29.88**	3.23	-41.26**	-6.29
L5 x T3	-31.70**	-4.94**	-5.53	-27.18**	-12.31**	-23.40**	5.61	-34.35**	-9.74**
L5 x T4	-26.57**	-29.93**	32.19**	39.95**	-3.98	12.64**	0.36	-17.27**	33.25**
L6 x T1	-10.50**	-43.51**	-14.92**	-31.04**	-10.64**	-13.49**	-13.10**	-36.83**	-9.21**
L6 x T2	-25.18**	-2.67	7.68**	-12.90**	7.82**	22.45**	4.22	-18.59**	24.42**
L6 x T3	-43.84**	-41.27**	16.95**	-4.39	7.63**	30.77**	3.35	7.71**	40.12**
L6 x T4	-3.36**	-25.09**	-6.71**	-25.70**	-23.23**	-7.81**	-22.19**	-35.84**	-16.96**

*Significance at 5% level, **Significance at 1% level

White Ponni (L1), Ponmani (L2), Co-51 (L3), ADT 37 (L4), ADT 39 (L5), BPT 5204 (L6), Mapillai Samba (T1), Navara (T2), Neelam Samba (T3), Karuppukavuni (T4)