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Combining ability analysis for yield in hybrids of new plant type lines and *indica* varieties of rice (*Oryza sativa* L.)

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Abstract
The present investigation in rice was undertaken to study the combining ability of experimental hybridsthrough a line x tester mating designfor single plant yield and their attributing traits in Madurai. Nine new plant type lines*viz.*, IR 71700-247-1-1-2, IR 72158-11-5-2-3, IR 72165-63-2-3-3, IR 72981-92-1-1-2-2, IR 72985-65-3-1, IR 73896-51-2-1-3, IR 73907-53-3-2-2, IR 73935-51-1-3-1 and IR 75282-10-3-3-2 and four *indica* varieties, namely, ADT 45, ASD 16, IR 72 and MDU 5, as testers and their hybrids were studied for ten characters namely days to 50% flowering, plant height, number of productive tillers plant^{-1}, panicle length, number of grains panicle^{-1}, spikelet fertility, 100 grain weight, leaf area index, harvest index and single plant yield. The hybrids exhibited significant variation among themselves for the ten traits studied. The LxT analysis revealed the importance of dominance gene action for all the traits except days to 50 per cent flowering and harvest index. Heterosis breeding or hybridization followed by selection in later generations was suggested for the improvement of these traits. Evaluation of parents based on *per se* and *gca*effects revealed that the following two lines IR 72985-65-3-1 and IR 73896-51-2-1-3 and the tester ASD 16 were the best and crosses involving them would result in improvement of yield.

Keywords: Rice, combining ability, NPT lines, indica lines, dominance, yield

1. Introduction

In India, the major emphasis has been on increasing the grain yield of rice and as such the breeding goals for this crop have been made for understanding the nature and magnitude of gene effects and genetic variances controlling gene effects of various traits. Certain specific gene combinations cause the superiority of the improved new variety and how rapidly these gene combinations can be marshaled in a single plant or variety depends on the system through which the genes in the available material are mobilized. So, it is understood the success of plant breeding programme largely depends on the correct choice of parents. The combining ability studies provide useful informations for the selection of high order parents, it also helps to understand the nature and magnitude of gene action in the expression of desired traits, which is essential to plan appropriate and efficient hybridization strategies.

Mainly two types of gene action determine the combining ability *viz.*, additive and non-additive. The additive effects are mainly due to polygenes that act in additive manner, producing fixable effects. The non-additive gene action results from dominance, epistasis and various other interaction effects that are non-fixable. The combining ability measures these effects in terms of general combining ability and specific combining ability. Sprague and Tatum (1942) [25] defined the term 'general combining ability' as the average performance of a line or population in several hybrid combinations and defined 'specific combining ability' to those effects in certain combinations that significantly depart from what would have been expected on the basis of average performance of the lines involved. They attributed *gca*to additive effects of gene and *sca* to dominant deviation and epistatic interactions. Among different methods to assess the combining ability, line x tester analysis is more useful for self-pollinated crops like rice for rapid evaluation of large number of germplasms with reasonable degree of confidence.

Yield is a function of total dry matter and harvest index (the grain to straw). Therefore enhancing either the total dry matter or harvest index or both can increase yield.

The yield plateau that has been arrived after the hybrid rice revolution using the modern cultivars needed to be enhanced by designing cultivars producing 22 tons of biomass and with a harvest index of 0.55 to 0.60 should produce 12-13 tons of grain per hectare. Three main ecotypes of rice are known differently relating to their geographical habitation where they are vastly cultivated, *viz.,* i*ndica* (tropics and sub tropics), j*aponica* (Japan, Korea and Northern China) and j*avanica* (Indonesia) (Khush and Virk, 2002) [10].

To achieve this goal, in the late 1980's, breeders conceived the new plant type rice plants based on the ideotype concept in IRRI to increase the yield potential in the tropical countries where rice is the prime staple food crop. With this idea in mind the hybridization activities were initiated with new plant type lines as one of the parents. The NPT rice lines were conceived with several agronomic traits inherited from tropical japonica-type varieties: low tiller number, low number of unproductive tillers, large panicle with 200-250 grains, thick culm, lodging resistant tall stems (90-100 cm), dark green, erect flag leaves with vigorous root system (Laza *et al*. 2003 [11]; Khush 1995 [9]). The plants had growth duration of 100-130 days, possessing multiple disease and insect resistance and acceptable grain quality.

Certain bottlenecks observed among the designed NPT lines were poor grain filling and reduced biomass production. So the introgression of *indica* genes into NPT's tropical *japonica* background for their good grain filling abilities and a fine-tuning of the original NPT line are the projected breeding strategies in the hands of the rice breeders. The NPT rices were useful in increasing the yield potential of hybrid rice since the NPT lines are built over the*japonica* germplasms. Hybrids produced from them and the elite *indica* lines pronounced a yield benefit of 20-25% (Khush and Aquino 1994 [8]; Peng *et al*. 1999 [17]).

Hence, the present study was conducted to study the nature of gene action in the inheritance of yield and its components and to estimate the general and specific combining ability of parents and hybrids respectively for yield and its component traits involving NPT lines and *indica* rice varieties besides the identification of the most suitable parents for further breeding programmes.

2. Materials and Methods

The study was undertaken in the Department of Plant Breeding and Genetics, Agricultural College and Research Institute, Madurai. Thirteen genotypes of rice were utilized for the study. The following nine new plant type (NPT) lines *viz*., IR 71700-247-1-1-2, IR 72158-11-5-2-3, IR 72165-63-2-3-3, IR 72981-92-1-1-2-2, IR 72985-65-3-1, IR 73896-51-2-1-3, IR 73907-53-3-2-2, IR 73935-51-1-3-1 and IR 75282-10-3-3-2 which were received from the International Rice Research Institute, Manila, Philippines, were used as lines. Four high yielding cosmopolitan varieties of rice *viz*., ADT 45, ASD 16, IR 72 and MDU 5 were used as testers. The parental materials were raised in a crossing block and the F_1 generation along with their parents was raised.

The parents were raised in a crossing block comprising of two rows of two metres length with a spacing of 20 x 10 cm. Three staggered sowings were taken at an interval of 15 days. All the recommended agronomic practices were carried out and crossing was taken up in Line x Tester fashion.For artificial crossing, panicles from main tillers that were likely to bloom on the next day were selected. Emasculation technique was followed as per the wet cloth method suggested by Ramiah (1953) [19]. The crossed seeds were collected from the matured panicles at full maturity. Selfing of parents was also done and selfed seeds were collected at maturity.

The 36 hybrids obtained along with the 13 parents were raised in a randomized block design with three replications. The seedlings of each cross were planted in a spacing of 20x10 cm in a single row of 1.5 m length. In each replication, fifteen plants were maintained. Recommended cultural operations and package of practices were followed. Observations were recorded in each replication on five randomly selected plants in each cross and parent for the following traits; days to 50 per cent flowering, plant height, number of productive tillers per plant, panicle length, number of grains per panicle, 100 grain weight, spikelet fertility, leaf area index (LAI), harvest index (HI) and single plant yield.

Statistical Analysis

The mean data of the above observations were utilized to statistically test the parents and hybrids for their significance based on their respective means. The analysis of variance of RBD and their significance for all the characters were worked out as suggested by Panse and Sukhatme (1964) [16]. To calculate the CD value, SEd values were multiplied with table't' value for error degrees of freedom.The combining ability was estimated by using Line x Tester method described by Kempthorne (1957) [6].

3. Experimental results and discussion

The data recorded for ten yield component traits involving thirteen parents (nine lines and four testers) and the corresponding 36 hybrids were used for estimating combining ability to assess the breeding value of lines, testers and their hybrids. The analysis of variance of RBD revealed that the hybrids taken for study differed significantly for all the traits observed. The analysis of variance for combining ability using line x tester mating design for all the ten characters was also found to be significant(Table 1).The estimates inferred that the lines, testers, hybrids and line x tester interaction were significant for all the characters under study, indicating the presence of a wide genetic variation. Differences among the lines, testers and line x tester interactions were significant, indicating the importance of both additive and non-additive gene action in the inheritance of these characters. The additive and dominance genetic variancesand their relative proportions for the ten traits studied were presented in table 2.

The results revealed that the dominance genetic variance (σ_D^2) was higher in magnitude than the additive genetic variance (σ_A^2) for eight traits *viz.,* plant height, number of productive tillers plant^{-1}, panicle length, number of grains panicle^{-1}, 100 grain weight, spikelet fertility, leaf area index and single plant yield. The traits that showed higher amount of additive genetic variance were days to 50 per cent flowering and harvest index. This finding is in conformation with the earlier reports (Ram *et al*. 1998 [18]; Meenakshi and Amirthadevarathinam 1999 [13]; Shanthi *et al*. 2003 [23]).

Table 1: Analysis of variance for combining ability for different traits

S. No.	Source	df	Mean square									
			Days to 50 per cent flowering	Plant height (cm)	Number of productive tillers plant^{-1}	Panicle length (cm)	Number of grains panicle^{-1}	100 grain weight (g)	Spikelet fertility (%)	Leaf area index	Harvest index	Single plant yield (g)
1.	Replication	2	1.07	3.33	0.40	0.01	78.81	0.002	2.42	0.01	0.0001	0.85
2.	Hybrid	35	129.11*	277.23*	20.92*	7.47*	1125.85*	0.22*	293.04*	4.31*	0.002*	197.28*
3.	Lines	8	517.84*	335.69*	15.23*	11.56*	975.34*	0.28*	93.58*	12.59*	0.005*	125.94*
4.	Testers	3	72.30*	887.01*	8.09*	4.25*	2189.34*	0.13*	503.87*	1.77*	0.006*	249.13*
5.	Line x Tester interaction	24	6.64*	181.52*	24.42*	6.51*	1043.09*	0.20*	333.17*	1.86*	0.001*	214.58*
6.	Error	70	0.80	1.51	0.46	1.06	57.14	0.004	1.10	0.012	0.0001	1.61

* Significant at 5 % level

Table 2: Magnitude of genetic variance for different traits

S. No.	Characters	GCA variance	SCA variance	σ_A^2	σ_D^2	σ_A^2/σ_D^2
1.	Days to 50 per cent flowering	14.79	1.95	29.58	1.95	15.17
2.	Plant height (cm)	22.04	60.01	44.08	60.01	0.73
3.	Number of productive tillers plant^{-1}	0.65	7.99	1.31	7.99	0.16
4.	Panicle length (cm)	0.07	1.81	0.14	1.81	0.08
5.	Number of grains panicle^{-1}	21.65	328.65	55.31	328.65	0.17
6.	100 grain weight (g)	0.0001	0.07	0.0002	0.07	0.003
7.	Spikelet fertility (%)	1.77	110.69	3.53	110.69	0.03
8.	Leaf area index	0.27	0.62	0.55	0.62	0.89
9.	Harvest index	0.00002	0.0003	0.0004	0.0003	1.33
10.	Single plant yield (g)	1.39	70.99	2.77	70.99	0.04

3.1. Gene action

Nature of gene action as measured by GCA and SCA variance is of great importance in deciding the importance of a character and thereby selection of suitable breeding programme. Panse (1942) [15] suggested that if additive variance is greater then, the chance of fixing superior genotypes in early segregating generations would be greater, where as if non additive gene action is predominant, selection should be postponed to late generations.

The magnitude of additive variances was greater for the traits days to 50 per cent flowering and harvest index. The results were in agreement with Shanthi *et al*. (2003) [23] and Ram *et al*. (2017) [20] for days to 50 per cent flowering and Mahapatra and Debjani (2000) [12] for harvest index. The predominance of additive gene action in controlling these traits indicated that the improvement of these traits is possible through simple selection procedures. When additive effects form the principle factor for genetic variance, use of pedigree method would be desirable.

The non-additive genetic variance (σ^2_D) was greater in magnitude for all the traits studied except days to 50 per cent flowering and harvest index indicating the preponderance of dominance gene action in controlling the expression of these traits. This was in agreement with the findings of Shanthi *et al*. (2003)[23]and Yogameenakshiand Vivekanadan (2015) [27] for spikelet fertility, productive tillers plant^{-1}, panicle length, number of grains panicle^{-1}; Swain *et al*. (2003) [26] and Yogameenakshiand Vivekanadan(2015) [27] for number of grains panicle^{-1} and single plant yield; Banumathy *et al*. (2003) [3]for plant height, number of productive tillers plant^{-1}, panicle length, number of grains panicle^{-1}, spikelet fertility, 100 grain weight and single plant yield and Annadurai and Nadarajan (2001) [1] for leaf area index. An experiment by Samrath and Deepak (2014) [22] reported similar dominant gene action for all the eight traits. Similar dominance effect has been reported by Bagheri and Jelodar (2010) [2] and Damodar Raju *et al*. (2014) [4] for number of productive tillers per plant, number of grains per panicle and Saidaiah *et al*. (2010) [21] and Damodar Raju *et al*. (2014) [4] for single plant yield.

The preponderance of non-additive gene action for the traits, plant height, productive tillers plant^{-1}, panicle length, number of grains panicle^{-1}, spikelet fertility, 100 grain weight, leaf area index and single plant yield offers the scope for exploitation of heterosis in rice. Nevertheless rice, being a self-pollinated crop, heterosis breeding is not widely adopted unlike recombination breeding. Hence to obtain better genotypes by the way of recombination breeding hybridization followed of selection at later generations is advisable for exploiting dominant gene action.

3.2. Evaluation of Parents

3.2.1. Mean Performance

The research team of Singh (1993) [24] opined that the parents with high order *perse* would be of greater importance in breeding programme. In the present study also, parents with superior performance than their estimated grand mean were identified. Parents with high mean performance are preferred for all traits except days to 50 per cent flowering and plant height because earliness in flowering and dwarfness in plant height are the desirable attributes. Five lines *viz*., IR 71700, IR 72985, IR 73896, IR 73967and IR 75282 and three testers *viz*., ADT 45, ASD 16 and MDU 5 were found to have earlier flowering. Similarly, four lines, IR 71700, IR 72985, IR 73967and IR 75282 with two testers IR 72 and MDU 5 were identified as short statured. Likewise, the parents IR 71700, IR 72165, IR 72981, IR 73896, IR 73967, IR 73935, ASD 16 and MDU 5 for number of productive tillers plant $^{-1}$; IR 72165, IR 72981, IR 72985, IR 73935 and ASD 16 for panicle length; IR 72981, IR 72985, IR 73896, ADT 45 and ASD 16 for number of grains panicle $^{-1}$; IR 72158, IR 72981, IR 72985, IR 73967, IR 72 and MDU 5 for 100 grain weight; IR 72158, IR 72981, IR 73896, IR 73967, IR 73935and ASD 16 for spikelet fertility; IR 72158, IR 72985, IR 73896, IR 73935 and ASD 16 for leaf area index; IR 72981, IR 72985, IR 73896, IR 73967, IR 75282, IR 72 and MDU 5 for harvest index and IR 72158, IR 72985, IR 73896and ASD 16 for single plant yield.

Several parents possessed desirable mean for more than one trait. The line IR 72985 and IR 73896 exhibited desirable mean for a maximum of eight traits namely days to 50 per cent flowering, number of grains panicle^{-1}, 100 grain weight, leaf area index, harvest index and single plant yield in both lines; plant height, panicle length in IR 72985 and number of productive tillers plant $^{-1}$ and spikelet fertility in IR 73896. Similarly the tester ASD 16 was identified with desirable mean for six traits *viz.*, days to 50 per cent flowering, number of productive tillers plant $^{-1}$, panicle length, number of grains panicle^{-1}, leaf area index and single plant yield. Hence, the parents IR 72985, IR 73896 and ASD 16 were considered as preferable for getting the genotypes with higher yield potential.

3.2.2. General combining ability effects

The general combining ability effects of parents were furnished in table 3 for all the ten characters. The *gca* effects represent the additive nature of gene action. Gravois and McNew (1993) [5] pointed out that if additive gene action is predominant in self-pollinated species like rice, the breeder could effectively select at various levels of inbreeding, because additive genetic effects are readily transmissible from one generation to another.

Parents that had negative and significant *gca* effects were taken for the traits, days to 50 per cent flowering and plant height, while for other traits, parents with positively significant *gca*effects were taken into consideration. Many of the parents exhibited good *gca* effects for several traits. The line, IR 72981 was considered as the best general combiner as it recorded a maximum of six traits *viz*, number of productive tillers plant $^{-1}$, panicle length, number of grains panicle^{-1}, 100 grain weight, leaf area index and single plant yield. The lines IR 72165, IR 72985 and IR 73896 were the next best as they were observed to possess significantly desirable general combining ability effects for five traits each.

Among the testers, IR 72 was the best general combiner as it had significant *gca* effects for six traits *viz.*, plant height, number of productive tillers plant $^{-1}$, 100 grain weight, spikelet fertility, leaf area index and single plant yield followed by MDU 5 and ASD 16 which expressed significantly desirable *gca*effects for five traits *viz.*, days to 50 per cent flowering, plant height, panicle length, 100 grain weight and single plant yield for MDU 5 and number of grains panicle^{-1}, spikelet fertility, leaf area index, harvest index and single plant yield for ASD 16.

An overall perusal of parents for general combining ability revealed the parents IR 72981, IR 72985, IR 72165 and IR 73896 among the lines and IR 72, MDU 5 and ASD 16 among the testers as the best general combiners and could be exploited for the development of high yielding genotypes.

Table 3: General combining ability effects of parents for different traits

Genotype		Days to 50 per cent flowering	Plant height	Number of productive tillers plant^{-1}	Panicle length	Number of grains panicle^{-1}	100 grain weight	Spikelet fertility	Leaf area index	Harvest index	Single plant yield
Lines											
L_1	IR 71700	-4.69*	-9.47*	1.05*	-1.33*	1.28	-0.01	1.40*	-2.17*	0.01*	-0.43
L_2	IR 72158	5.89*	-0.07	-0.61*	-1.48*	-3.23	-0.02	-2.70*	-0.29*	0.03*	-4.26*
L_3	IR 72165	2.06*	1.63*	1.05*	0.41	19.29*	-0.05*	4.96*	0.77*	0.00	0.90*
L_4	IR 72981	2.22*	8.87*	0.45*	1.12*	4.37*	0.25*	0.33	1.18*	-0.01*	3.71*
L_5	IR 72985	3.14*	0.25	0.38	0.85*	4.34*	-0.11*	1.15*	0.80*	-0.01*	1.12*
L_6	IR 73896	1.47*	2.00*	0.93*	0.24	-3.94	0.16*	-1.68*	0.37*	0.03*	3.86*
L_7	IR 73907	0.72*	4.08*	-1.97*	-0.91*	-8.95*	0.01	-3.65*	0.37*	-0.02*	-5.68*
L_8	IR 73935	4.81*	-1.98*	-1.56*	0.81*	-11.36*	0.06*	-2.19*	-0.82*	-0.01*	-0.68
L_9	IR 75282	-15.61*	-5.31*	0.28	0.29	-1.81	-0.28*	2.43*	-0.21*	-0.02*	1.46*
S.E (5%)		0.26	0.35	0.20	0.30	2.18	0.02	0.30	0.03	0.002	0.37
Testers											
T_1	ADT 45	-0.14	-1.42*	-0.14	-0.10	-10.94*	-0.06*	0.73*	-0.14*	0.01*	-4.50*
T_2	ASD 16	-0.03	8.22*	-0.55*	0.07	11.06*	-0.06*	1.93*	0.24*	0.01*	2.12*
T_3	IR 72	2.08*	-1.70*	0.76*	-0.46*	0.69	0.06*	-6.24*	0.20*	-0.01*	1.02*
T_4	MDU 5	-1.92*	-5.10*	-0.07	0.50*	-0.81	0.05*	3.58*	-0.29*	-0.02*	1.37*
	S.E (5%)	0.17	0.24	0.13	0.20	1.45	0.01	0.20	0.02	0.001	0.24

*Significant at 5 % level

3.2.3. Mean performance and GCA effects

The mean performance of parent may not necessarily reveal it to be a good or poor combiner. However, the ability of parents to produce better off springs can be adjudged by comparing the mean performance and general combining ability effects since authenticity of *gca* effect is guaranteed by matching the *per se* of parents. Hence, the parents were also evaluated for high *per se* coupled with high *gca*effects.

Analysis of mean performance of the parents and their *gca* effects revealed that *per se* performance of the parents is a reflection of their *gca*effects in most of the cases. The parents, IR 71700, IR 75282 and MDU 5 were found to have desirable mean and *gca* effects for the traits, days to 50 per cent flowering and plant height along with IR 72 for plant height alone. Likewise the parents IR 72981, IR 72985 and IR 73935 for panicle length; IR 72981, IR 72985 and ASD 16 for number of grains panicle^{-1}; IR 72981, IR 73896, IR 72 and MDU 5 for 100 grain weight; IR 75282 for spikelet fertility; IR 72165, IR 72985, IR 73896 and ASD 16 for leaf area index and IR 72985, IR 73896 and ASD 16 for single plant yield.

Based on the overall performance, the parents IR 72985 and IR 73896 were considered as superior since it had high mean and *gca*effectsfor four traits each. The line IR 72985 had desirable performance *viz.*, panicle length, number of grains panicle^{-1}, leaf area index and single plant yield while IR 73896 for 100 grain weight, leaf area index, harvest index and single plant yield. It was followed by ASD 16 which possessed desirable *per se* and *gca* effects for number of grains panicle^{-1}, leaf area index and single plant yield. From the above discussion, it could be concluded that the parents IR 72985 and IR 73896 among the lines and ASD 16 among the testers were superior and crosses involving these parents would result in superior segregants with desirable genes for improvement of grain yield.

3.3. Evaluation of Hybrids

Hybridization aims to combine the favourable genes present in different parents into a single genotype. The hybrids thus obtained may be utilized in two ways (i) utilizing the F_1 hybrids commercially with a view to exploit heterosis and (ii) selecting superior segregants from the hybrids in the subsequent generations and releasing best performing recombinants after attaining homozygosity.

3.3.1. Specific combining ability effects of hybrids

The specific combining ability (*sca)* effects of hybrid for ten characters were presented from table 4.Development of commercial hybrids in rice without employing male sterile lines is very limited. Instead, recombination breeding has been the major avenue for rice improvement over decades. The hybrids selected for recombination breeding should satisfy the criteria that they should possess non-significant*sca*effects with their parents showing significant *gca*effects. The basic idea underlying this is that the segregation of these hybrids is likely to throw more recombinants possessing favourable additive genes from both the parents**.** Therefore, it will be useful to select only those hybrids having parents with high *gca*effects and without significant *sca*effects for recombination breeding (Nadarajan 1986 [14] and Khorgadeet *et al.*1989 [7]).

The hybrids chosen for recombination breeding based on significant *gca* effects of both the parents and with non significant*sca*effects of the hybrids for each character was presented in table 5. For days to 50 per cent flowering, negatively significant *gca* effects was noticed in IR 71700 (L_1), IR 75282 (L_9) and MDU 5 (T_4) among the parents and two cross combinations involving these parents *viz*., L_1 x T_4 and L_9 x T_4 could be identified with non-significant *sca* effects. Therefore, they were recommended for recombination breeding to generate early duration varieties.

For plant height, significantly negative *gca* effects were observed in lines IR 71700 (L_1), IR 73935 (L_8) and IR 75282 (L_9) and the testers ADT 45 (T_1), IR 72 (T_3) and MDU 5 (T_4). Among the crosses involving above mentioned parents, only one cross combination *viz.*, L_1 x T_4 showed non significant*sca* effects and hence could be utilized in recombination breeding for producing genotypes with short plant stature.

IR 72981 (L_4), IR 72985 (L_5), IR 73935 (L_8) and MDU 5 (T_4) among the parents and L_4 x T_4, L_5 x T_4 and L_8 x T_4 among the hybrids involving above parents for the trait panicle length and IR 72165 (L_3), IR 72981 (L_4), IR 72985 (L_5) and ASD 16 (T_2) among the parents and L_3 x T_2 and L_5 xT_2 among the hybrids developed from their parents for the character number of grains panicle^{-1} hadsignificant *gca*effects and non significant*sca*effects respectively. Hence, these hybrids were recommended for recombination breeding for the improvement of these two traits.

Positive and significant *gca* effects for 100 grain weight was observed in the lines IR 72981(L_4), IR 73896 (L_6) and IR 73935 (L_8) and IR 72 (T_3) and MDU 5 (T_4) in the testers. Among the hybrids generated by crossing these parents, the hybrids *viz.*, L_8 x T_3, L_6 x T_4, L_8x T_4 could be utilized for recombination breeding since they recorded non significant*sca* effects for this trait.

For leaf area index, the parents IR 72165 (L_3), IR 72981 (L_4), IR 72985 (L_5), IR 73896 (L_6) and IR 73907 (L_7) among the lines and ASD 16 (T_2) and IR 72 (T_3) among the testers showed significantly positive *gca* effects. The following two hybrids *viz.*, L_4 x T_2 and L_4 x T_3 registered non significant*sca* effects for this trait among the crosses from those parents. Hence, recombination breeding may be resorted for the improvement of leaf area index by exploiting the above-mentioned hybrids.

For the trait harvest index, positively significant *gca* effects was observed in parents, IR 71700 (L_1), IR 72158 (L_2), IR 73896 (L_6), ADT 45 (T_1) and ASD 16 (T_2) while non significant*sca*effects was found in cross combinations involving these parents L_1 x T_2, L_2 x T_1, L_2 x T_2 and L_6 x T_1 hence, these hybrids were suggested for recombination breeding for the improvement of harvest index.

Even though the parents, IR 71700 (L_1), IR 72165 (L_3), IR 72981 (L_4), IR 73896 (L_6) and IR 72 (T_3) for number of productive tillers plant^{-1} and IR 71700 (L_1), IR 72165 (L_3), IR 72985 (L_5), IR 75282 (L_9), ADT 45 (T_1), ASD 16 (T_2) and MDU 5 (T_4) for spikelet fertility were found to have significant *gca*effects, none of the hybrids had non-significant *sca*effects. Hence, hybrids could not be suggested for improvement of these two traits through recombination breeding.

The parents with positively significant *gca* effects for single plant yield include IR 72165 (L_3), IR 72981 (L_4), IR 72985 (L_5), IR 73896 (L_6), IR 75282 (L_9), ASD 16 (T_2), IR 72 (T_3) and MDU 5 (T_4). Among the cross combinations involving the above said parents, L_9 x T_4 alone had non-significant *sca* effects which can be exploited for improvement of single plant yield through recombination breeding. Based on the above discussion, it can be concluded that the hybrid IR 75282–10 – 3-3-2 / MDU 5 (L_9 x T_4) was recommended for recombination breeding for isolation of early duration segregants besides high yield (Fig.1).

Partitioning of combining ability variances into additive and non-additive genetic variance indicated the preponderance of additive gene action for the traits, days to 50 per cent flowering and harvest index suggesting that the improvement of these traits is possible through simple selection procedures. Dominance gene action was found to be predominant in governing the expression of all the characters except days to 50 per cent flowering and harvest index. Therefore, heterosis breeding or hybridization followed by selection in later generations is suggested for these traits.

Evaluation of parents based on mean performance revealed that the parents L_5 (IR 72985), L_6 (IR 73896) and T_2 (ASD 16) excelled others by expressing high mean values for majority of yield contributing characters including single plant yield. Hence these parents were considered as desirable for improving the yield potential. Based on the *gca* effects, IR 72981, IR 72985, IR 72165 and IR 73896 among the lines and IR 72, MDU 5 and ASD 16 among the testers as the best general combiners. While considering the combination of mean and *gca*effects, IR 72985 and IR 73896 among the lines and ASD 16 among the testers were superior and crosses involving these parents would result in superior segregants with desirable genes for improvement of grain yield. The hybrids suitable for recombination breeding were selected based on significant *gca* effects of the parents and non-significant *sca* effects of the hybrids (Table 6). Accordingly the cross combination L_9 x T_4 was suitable for recombination breeding to combine earliness and high yield potential.

Table 4: Specific combining ability effects of hybrids for different traits

Lines	Hybrids	Days to 50 per cent flowering	Plant height (cm)	Number of productive tillers plant^{-1}	Panicle length (cm)	Number of grains panicle^{-1}	100 grain weight (g)	Spikelet fertility (%)	Leaf area index	Harvest index	Single plant yield (g)
L_1(IR 71700)	L_1 x T_1	-2.19*	-4.94*	-0.05	-1.27*	-17.88*	-0.14*	4.05*	0.16*	-0.02*	-1.07
	L_1 x T_2	1.36*	11.04*	1.50*	1.20*	-5.95	0.36*	3.23*	-0.30*	0.01	2.67*
	L_1 x T_3	0.92	-6.14*	1.86*	0.49	6.65	-0.10*	-5.84*	0.10	0.01	4.79*
	L_1 x T_4	-0.08	0.04	-3.32*	-0.43	17.19*	-0.12*	-1.44*	0.04	0.00	-6.38*
L_2 (IR 72158)	L_2x T_1	0.22	6.79*	0.85*	-0.48	-2.34	-0.27*	12.28*	-1.14*	0.00	1.07
	L_2 x T_2	0.78	-1.36	-0.11	1.72*	8.62	0.02	6.95*	1.01*	0.00	2.58*
	L_2 x T_3	-0.73	-6.17*	2.09*	0.28	-7.88	-0.09*	-17.64*	0.24*	0.01	1.58*
	L_2 x T_4	-0.67	0.74	-2.83*	-1.51*	1.60	0.34*	-1.59*	0.16*	-0.01	-5.23*
L_3 (IR 72165)	L_3x T_1	1.72*	5.02*	3.02*	1.73*	6.51	0.09*	1.80*	0.57*	0.03*	5.74*
	L_3 x T_2	0.61	-0.96	-5.90*	-0.90	3.27	0.06	-6.49*	-0.14*	0.01	-11.25*
	L_3 x T_3	-2.83*	-10.70*	1.86*	-0.77	30.81*	-0.12*	11.59*	-0.41*	-0.01	9.38*
	L_3 x T_4	0.50	6.64*	1.02*	-0.06	-40.59*	-0.03	-6.89*	-0.02	-0.03*	-3.87*
L_4 (IR 72981)	L_4x T_1	1.22*	7.78*	-1.25*	0.65	-22.14*	0.27*	3.40*	0.27*	0.01	1.76*
	L_4 x T_2	-0.22	-10.90*	0.94*	-2.28*	-21.11*	-0.20*	-9.00*	0.10	-0.01	-5.21*
	L_4 x T_3	-1.33*	-2.21*	-1.94*	1.74*	-1.28	0.17*	-3.77*	-0.13	-0.02*	-3.62*
	L_4 x T_4	0.33	5.33*	2.25*	-0.11	44.53*	-0.24*	9.37*	-0.25*	0.01	7.07*
L_5 (IR 72985)	L_5x T_1	1.64*	5.17*	-3.45*	1.19*	6.83	0.47*	3.58*	0.53*	0.03*	-2.85*
	L_5 x T_2	-1.14*	-2.31*	-0.83*	-0.11	-1.41	-0.14*	-8.76*	-0.42*	0.00	-10.56*
	L_5 x T_3	-1.25*	-5.69*	0.26	-1.51*	-2.21	-0.30*	-1.47*	-0.71*	-0.02*	-7.62*
	L_5 x T_4	0.75	2.82*	4.02*	0.43	-3.20	-0.03	6.65*	0.60*	-0.01	21.03*

*Significant at 5% level

Lines	Hybrids	Days to 50 per cent flowering	Plant height (cm)	Number of productive tillers plant^{-1}	Panicle length (cm)	Number of grains panicle^{-1}	100 grain weight (g)	Spikelet fertility (%)	Leaf area index	Harvest index	Single plant yield (g)
L_6 (IR 73896)	L_6 x T_1	0.97	-6.08*	-0.79*	-0.57	-6.19	-0.10*	-3.57*	0.76*	-0.01	-6.71*
	L_6 x T_2	-1.81*	3.24*	5.83*	0.50	15.74*	-0.34*	0.08	0.61*	-0.02*	20.89*
	L_6 x T_3	1.42*	3.33*	-3.61*	0.09	16.47*	0.45*	15.15*	-0.40*	0.00	-5.34*
	L_6 x T_4	-0.58	-0.50	-1.43*	-0.03	6.92	0.00	-11.66*	-0.96*	0.03*	-8.84*
L_7 (IR 73907)	L_7x T_1	0.06	-6.13*	2.77*	-0.12	18.64*	-0.36*	-5.78*	0.75*	-0.02*	4.71*
	L_7 x T_2	-1.39*	-5.97*	-0.68	-0.28	-0.42	0.01	12.44*	-0.30*	0.02*	-0.84
	L_7 x T_3	1.17*	15.58*	-1.06*	1.21*	-11.98*	0.13*	2.08*	0.36*	0.01	-0.81
	L_7 x T_4	0.17	-3.48*	-1.03*	-0.81	-6.24	0.22*	-8.74*	-0.81*	-0.01	-3.06*
L_8 (IR 73935)	L_8x T_1	-1.36*	-10.34*	-0.24	-0.63	1.94	0.10*	-23.08*	-0.11	0.01	-0.21
	L_8 x T_2	0.19	4.75*	1.68*	1.83*	-1.33	-0.10*	9.47*	0.26*	0.00	0.15
	L_8 x T_3	0.75	10.57*	-0.40	-0.11	12.98*	-0.03	3.75*	0.16*	-0.01	0.41
	L_8 x T_4	0.42	-4.99*	-1.04*	-1.10	-13.59*	0.02	9.85*	-0.31*	0.00	-0.35
L_9 (IR 75282)	L_9x T_1	-2.28*	2.72*	-0.87*	-0.52	14.64*	-0.06	7.33*	-1.52*	-0.03*	-2.40*
	L_9 x T_2	1.61*	2.44*	-2.42*	-1.68*	2.60	0.33*	-7.94*	-0.82*	0.00	1.56*
	L_9 x T_3	1.50*	1.43*	0.94*	-1.42*	-10.64*	-0.10*	-3.84*	0.78*	0.03*	1.23*
	L_9 x T_4	-0.83	-6.60*	2.36*	3.62*	-6.61	-0.17*	4.46*	1.56*	0.00	-0.35
S.E(5%)		0.52	0.71	0.39	0.59	4.36	0.04	0.61	0.06	0.006	0.73

*Significant at 5% level

Table 5: Hybrids recommended for recombination breeding

Characters	Parents with significant *gca* effects	Hybrids with non significant *sca* effects
Days to 50 per cent flowering	L_1, L_9, T_4	L_1 x T_4, L_9 x T_4
Plant height	L_1, L_8, L_9, T_1, T_3, T_4	L_1 x T_4
Number of productive tillers plant^{-1}	L_1, L_3, L_4, L_6, T_3	----
Panicle length	L_4, L_5, L_8, T_4	L_4 x T_4, L_5 x T_4, L_8 x T_4
Number of grains panicle^{-1}	L_3, L_4, L_5, T_2	L_3 x T_2, L_5 x T_2
100 grain weight	L_4, L_6, L_8, T_3, T_4	L_6 x T_4, L_8 x T_3, L_8 x T_4
Spikelet fertility	L_1, L_3, L_5, L_9, T_1, T_2, T_4	----
Leaf area index	L_3, L_4, L_5, L_6, L_7, T_2, T_3	L_4 x T_2, L_4 x T_3
Harvest index	L_1, L_2, L_6, T_1, T_2	L_1 x T_2, L_2 x T_1, L_2 x T_2, L_6 x T_1
Single plant yield	L_3, L_4, L_5, L_6, L_9, T_2, T_3, T_4	L_9 x T_4

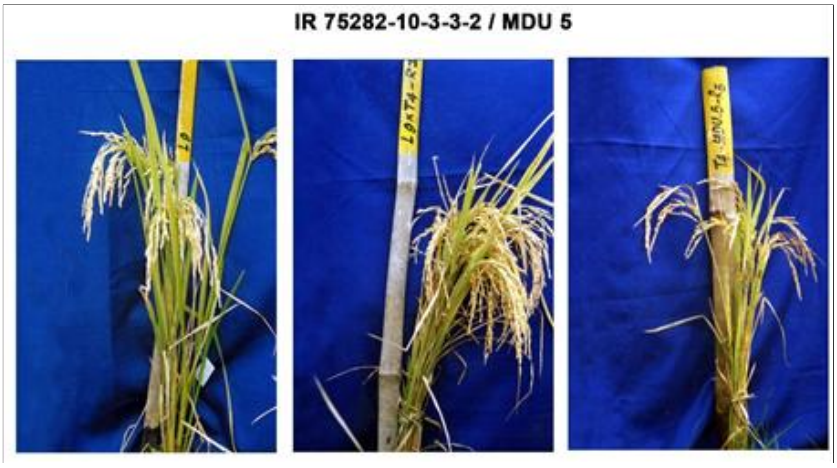

Fig 1: Best hybrid recommended for Recombination breeding

Table 6: Hybrids recommended for heterosis breeding based on mean, sca and heterosis

Characters	Combination of mean + *sca* + standard heterosis
Days to 50% flowering	----
Plant height	L_1 x T_1, L_1 x T_3, L_3 x T_3, L_8 x T_1, L_8 x T_4, L_9 x T_4
Number of productive tillers plant^{-1}	L_1 x T_2, L_1 x T_3, L_2 x T_1, L_2 x T_3, L_3 x T_1, L_3 x T_3, L_3 x T_4, L_4 x T_2, L_4 x T_4, L_5 x T_4, L_6 x T_2, L_7 x T_1, L_9 x T_3, L_9 x T_4,
Panicle length	L_2 x T_2, L_3 x T_1, L_4 x T_3, L_5 x T_1, L_8 x T_2, L_9 x T_4
Number of grains panicle^{-1}	L_1 x T_4, L_3 x T_3, L_4 x T_4, L_6 x T_2, L_8 x T_3, L_9 x T_1
100-grain weight	L_4 x T_3, L_6 x T_3
Spikelet fertility	L_5 x T_1
Leaf area index	L_2 x T_2, L_2 x T_3, L_3 x T_1, L_4 x T_1, L_5 x T_1, L_5 x T_4, L_6 x T_1, L_6 x T_2, L_7 x T_1, L_7 x T_3, L_9 x T_3, L_9 x T_4
Harvest index	L_3 x T_1, L_5 x T_1, L_6 x T_4
Single plant yields	L_1 x T_2, L_1 x T_3, L_2 x T_2, L_3 x T_1, L_3 x T_3, L_4 x T_1, L_4 x T_4, L_5 x T_4, L_6 x T_2, L_9 x T_2, L_9 x T_3
Overall	L_3 x T_1, L_3 x T_3

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