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Heterosis analysis for yield in hybrids involving new plant type and *indica* lines of rice (*Oryza saiva* L.)

VG Shobhana, K Ashokkumar, A Karthikeyan, R Nirmal Kumar, A Sheeba and P Vivekanandan

VG Shobhana
Department of Plant Breeding and Genetics, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India

K Ashokkumar
Division of Crop Improvement, Cardamom Research Station, Kerala Agricultural University, Pampadumpara, Idukki, Kerala, India

A Karthikeyan
Department of Plant Breeding and Genetics, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India

R Nirmal Kumar
Indian Institute of Food processing Technology, Thanjavur, Tamil Nadu, India

A Sheeba
Department of Plant Breeding and Genetics, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India

P Vivekanandan
Department of Plant Breeding and Genetics, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India

Abstract

A line x tester analysis was carried out in rice with nine new plant type lines and four testers to measure the expression and magnitude of heterosis in single plant yield and nine other yield attributing characters. The study revealed that the hybrids differed significantly among themselves for all the characters. Evaluation of hybrids based on mean performance disclosed that the hybrids, L_6 x T_2, L_9 x T_4, L_5 x T_4, L_4 x T_4, L_3 x T_1, L_1 x T_2, L_1 x T_3, L_2 x T_2 and L_3 x T_3 were superior for most of the yield contributing traits. The hybrids, L_3 x T_1, L_3 x T_3, L_1 x T_2, L_6 x T_2 and L_7 x T_1 had significantly high *sca* effects for maximum number of traits. The hybrids were evaluated for their extent of heterosis on the basis of commercially exploitable standard heterosis for yield traits. It was inferred from the studies that cross combinations *viz*., L_2 x T_3, L_3 x T_1, L_3 x T_3, L_4 x T_1, L_4 x T_3, L_4 x T_4, L_5 x T_1, L_5 x T_2, L_6 x T_2, L_8 x T_2 and L_9 x T_4 expressed significantly superior heterosis percent for most of the characters including single plant yield. On the basis of superior mean performance, *sca* effects and heterosis percent, the hybrids namely, L_3 x T_1, L_3 x T_3 and L_6 x T_2 were suitable for involving them in heterosis breeding.

Keywords: Rice, heterosis, new plant type, *indica* lines, hybrids, yield

1. Introduction

Rice is a vital crop around the globe and it is consumed widely by the masses as a stable food. For indians, rice is a major stable food after wheat and it occupies an imperative position in area and production of cereals. Being the backbone of livelihood for millions of the rural populace, rice plays a vital role in the food security of a country. So the term “rice is life” is very appropriate in the Indian context. One in every three people depends on rice for more than half of their daily food (Sureka *et al*., 2016) [26]. More than 90% of the world’s rice is grown and consumed in Asia where 60% of the earth’s people and about two-thirds of the world’s poor live (Khush and Virk, 2000) [14]. In the view of the growing population the basic objective of the plant breeder would always be towards yield improvement.

The population of rice consumers is increasing at a faster rate of 2% as opposed to 1.4% overall annual rate of growth. Global rice production must reach 800 m tons, from the present 599 m tons, to meet the demand in 2025. If this trend is not reversed, the demand for rice will exceed production by the early part of this century (Anderson, 1994) [1]. The yield potential of modern high yielding varieties in the tropics is 10t/ha during the favourable season. Plant physiologists have suggested that physical environment in the tropics is not a limiting factor for increasing rice yields. Maximum yield potential was estimated to be 9.5t/ha during the wet season and 15.9t/ha in the dry season in the tropics (Yoshida, 1981) [28].

The yield of a plant is directly related to its total dry matter and its harvest index which is commonly referred to the grain to straw ratio. So a direct increase in either the total dry matter or harvest index or both can enhance the yield of a crop studied. Rice cultivars with 22 tons of biomass and a harvest index of 0.55 to 0.60 are expected to yield 12-13 tons of grain per hectare. With this idea in mind, the plant breeders in the International Rice Research Institute (IRRI) designed a hypothetical model of the rice plant, the ideotype. The designed ideotype was expected to break the limits of rice grain yield and increasing the yield index of the plant. These designed plants are the “new plant type lines” (Khush, 2002) [11]. They had only a few tillers. All the tillers produced large, dense panicles containing about 200-250 grains. The stems were 90-100cm tall, thick and resistant to lodging.

Correspondence
VG Shobhana
Department of Plant Breeding and Genetics, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India

Erect and thick leaves that are dark green helped in higher photosynthetic ability. These lines were choice fully chosen for breeding programs in the view of increasing harvest index and yield (Flavio, 2013) [4]. Hybrids from breeding programs which include new plant type lines as one of their parents are believed to break the yield plateau that is a major crisis among the present day cultivars (Khush and Virk, 2002) [12].

Even when the NPT lines pose with some setbacks like poor grain filling and reduced biomass production, the NPT lines should have and increased yield potential since they are based on the *japonica* lines. The introduction of *indica* genes into NPT's tropical *japonica* background yield hybrids with a yield advantage of 20-25%. Selection for their good grain filling abilities and the choice of the suitable breeding strategies by the plant breeders are expected to refine of the original NPT lines (Khush and Aquino, 1994) [13].

Heterosis refers to the increased or decreased vigour of F_1 hybrid over its parents. Shull (1948) [23] explained that heterosis was the genetic expression of the beneficial effects of hybridization. Jones (1926) [8] was the first to report increased vigour in culm number and grain yield of F_1 hybrids over their parents in rice. The exploitation of hybrid vigour is an alternative for making further breakthrough in crop yields. According to Hatchcock and Mc Daniel (1973) [7], the expression of heterosis even to a small magnitude for individual component character is a desirable factor for increasing the yield.

With these points in view, a line x tester analysis involving NPT lines and *indica* rice varieties was carried out to study the heterosis of ten yield component traits *viz*., days to 50 per cent flowering, plant height, number of productive tillers plant^{-1}, panicle length, number of grains per panicle^{-1}, 100 grain weight, spikelet fertility, leaf area index, harvest index and single plant yield in 36 hybrids and 13 parents, to identify the most suitable parents for further breeding programmes.

In the view of the growing population the basic objective of the plant breeder would always be towards yield improvement. For any planned plant breeding programme, investigations on the genetic parameters such as combining ability, heterosis and correlation and path analysis are of immense help to breeders in identifying the reliable characters and finally formulating selection strategy. Among different methods to assess the combining ability, line x tester analysis developed by Kempthorne (1957) [10] is more useful for self-pollinated crops like rice for rapid evaluation of large number of germplasms with reasonable degree of confidence.

Several studies have been reported heterosis on yield and yield attributing traits in 3rice. Recent reports in the literature Ram *et al*. (1998) [19], Banumathy *et al*. (2003) [2], Shanthi *et al*. (2003) [22], and Bagheri and Jelodar, (2010) [2] have determined that rice genotypes differ in yield component traits. The estimates of *per se* performance and heterosis provided useful information with regard to the possibilities and extent of improvement in the yield characters of breeding material through selection. Therefore, present study was conducted to ascertain the genetics of yield and component traits involving NPT lines and *indica* rice varieties besides to identify the most suitable parents for further breeding programmes. The objective of present study is (1) to study the *per se* performance and combining ability of yield and its components (2) to study the expression and magnitude of heterosis for yield and component traits.

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 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 parents were raised in a crossing block comprising of two rows of two meters 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) [20]. 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.

2.1. Observations recorded

Observations were recorded in each replication on five randomly selected plants in each cross and parent for traits namely, 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.

2.2. Analysis of variance

The analysis of variance of RBD and their significance for all the characters were worked out as suggested by Panse and Sukhatme (1964) [17]. To calculate the CD value, SEd values were multiplied with table't' value for error degrees of freedom.

2.3. Heterosis

The mean values of hybrids were used for the estimation of heterosis per cent under three categories (Fonseca and Patterson, 1968) [5].

2.3.1. Relative heterosis (d_i)

The superiority of F_1 over mid parental value (Matzinger *et al*., 1962) [15] was estimated as follows,

$$d_i = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

Where,

$\overline{F_1}$ = Mean value of hybrid

$\overline{MP}$ = Value of mid parent

2.3.2. Heterobeltiosis (d_{ii})

The superiority of F_1 over better parent was estimated as follows,

$$d_{ii} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

Where,

$\overline{BP}$ = Mean value of better parent

2.3.3. Standard heterosis (d_{iii})

The superiority of F_1 over the standard variety was estimated as follows,

$$d_{iii} = \frac{\overline{F_1} - \overline{SV}}{\overline{SV}} \times 100$$

Where,

$\overline{SV}$ = Mean value of standard variety

The variety MDU 5was used as standard variety in the present study.

2.3.4. Test of significance

Estimates of heterosis were tested for significance at error degrees of freedom as suggested by Turner (1953) [27].

$$\text{'t' for relative heterosis} = \frac{\overline{F_1} - \overline{MP}}{\sqrt{\frac{Me}{r} \times \frac{3}{2}}}$$

$$\text{'t' for heterobeltiosis} = \frac{\overline{F_1} - \overline{BP}}{\sqrt{\frac{Me}{r} \times 2}}$$

$$\text{'t' for standard heterosis} = \frac{\overline{F_1} - \overline{SV}}{\sqrt{\frac{Me}{r} \times 2}}$$

Where,

Me = Error variance

r = Number of replications

3. Experimental Results

The data recorded for ten yield component traits *viz.*, days to 50 percent 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 and single plant yield involving 13 parents (nine lines and four testers) and the corresponding 36 hybrids were used for estimating heterosis and to assess the breeding value of lines, testers and their hybrids. The results obtained by subjecting the mean values to statistical analysis are briefly highlighted here under.

3.1. Analysis of variance

The analysis of variance of RBD revealed that the hybrids taken for study differed significantly for all the traits observed (Table 4). The percentage of heterosis over mid parent (di), better parent (dii) and standard variety MDU 5 (diii) for all the ten characters were furnished in Table 1.

The relative heterosis for this trait ranged from –11.91(L_9 x T_3) to 13.81% (L_5 x T_1) with six negatively significant hybrids. The heterobeltiosis varied between –15.49 (L_9 x T_4) to 1.98% (L_5 x T_1). Twenty-three hybrids expressed significant negative heterobeltiosis. The range of standard heterosis was between 4.35 (L_9 x T_4) to 38.26% (L_2 x T_3 and L_8 x T_3). Three were no cross combinations that exhibited negative and significant standard heterosis.

The heterosis over mid parent for plant height differed from –21.71(L_8 x T_1) to 28.40% (L_7 x T_3) with thirteen hybrids showing negatively significant relative heterosis. Heterobeltiosis had a range from –23.95 (L_3 x T_3) to 20.71% (L_7 x T_3) with nineteen hybrids having negative significant heterobeltiosis percent. The hybrid L_1 x T_3 (-12.51%) showed the minimum standard heterosis percent, while the hybrid L_7 x T_3 (38.00%) recorded the other extreme value. Seven cross combinations had negatively significant standard heterosis for this trait.The relative heterosis for this trait varied from –28.89 (L_3 x T_2) to 88.78% (L_6 x T_2). Twenty-six hybrids exhibited positively significant relative heterosis. The heterosis over better parent varied between –33.73 (L_3 x T_2) to 82.17% (L_6 x T_2) with 23 hybrids with positive and significant heterobeltiosis. The heterosis over standard parent exhibited a range –29.56 (L_3 x T_2) to 79.87% (L_6 x T_2) with twenty-three cross combinations with positively significant heterosis standard.

The minimum and maximum relative heterosis for this trait was recorded by L_4 x T_2 (-9.67%) and L_9 x T_2 (20.68%) respectively. Nine out of 36 hybrids registered positively significant relative heterosis percent. The hybrids L_4 x T_2 (-14.49%) and L_9 x T_4 (15.63%) had the minimum and maximum percent of heterosis over the better parent respectively. Only one hybrid (L_9 x T_4) showed significant and positive heterobeltiosis percent. Minimum and maximum standard heterosis percent was recorded by L_1 x T_1 (-6.82%) and L_9 x T_4 (26.20%) respectively. Fifteen hybrids were positively significant found to have standard and heterosis percent.

The hybrid L_6 x T_1 (-21.47%) recorded the minimum percent of heterosis over mid parent while L_3 x T_3 (80.34%) recorded the maximum value. About 25 hybrids had positive and significant relative heterosis. The range figures out as –27.77 (L_6 x T_1) to 76.41% (L_3 x T_3) for the heterobeltiosis per cent with fifteen hybrids that are positively significant. L_4 x T_1 (38.34) and L_3 x T_3 (130.60) showed the least and the highest values for standard heterosis percent with all the hybrids possessing significant standard heterosis for this trait.

Among the hybrids L_5 x T_3 (-29.31%) and L_4 x T_1 (22.35%) had the minimum and maximum heterosis percent over the mid parent respectively. Likewise the minimum (-36.19%) and maximum (15.29%) heterobeltiosis was recorded by the hybrids L_5 x T_3 and L_1 x T_2 respectively. In case of standard heterosis, the minimum and maximum heterosis percent was recorded by L_7 x T_1 (-27.69%) and L_6 x T_3 (14.36%) respectively. Eight, three and three cross combinations had positive relative heterosis, heterobeltiosis and standard heterosis respectively.

Spikelet fertility had the mid, better and standard parental heterosis ranging from –35.52 (L_2 x T_3) to 16.32% (L_3 x T_3), -36.26 (L_2 x T_3) to 9.41% (L_3 x T_3) and -42.35 (L_2 x T_3) to 8.46% (L_5 x T_1) respectively. Significant and positive heterosis was noticed in 15, nine and a single cross combination respectively for mid, better and standard parental heterosis respectively.

The range of heterosis percent for this trait was between 49.07 (L_1 x T_2) and 74.99 (L_4 x T_1), -59.35 (L_1 x T_2) and 67.80% (L_7 x T_1) and between –46.47 (L_1 x T_4) and 49.23% (L_4 x T_2) for relative heterosis, heterobeltiosis and standard heterosis respectively. Positive and significant heterosis over mid, better and standard parents was noticed in 22, 14 and 25 hybrids respectively.

The mid-parental heterosis for harvest index differed between –7.34 (L_5 x T_4) and 20.83% (L_2 x T_2). Similarly, the minimum and maximum heterosis per cent over better parent (-15.83% and17.07 % respectively) was recorded by L_7 x T_4 and the L_3 x T_1 respectively. In the event of standard heterosis, the minimum and maximum heterosis per cent was recorded by L_3 x T_4, L_7 x T_4 (-3.31%) and L_2 x T_1 (19.84%) respectively. Positively significant heterosis per cent over mid, better and standard parents was recorded in 20, 9 and 26 hybrids respectively. The mid-parental heterosis for harvest index differed between –15.06 (L_6 x T_1) and 134.27% (L_5 x T_5). Correspondingly, the minimum and maximum heterosis per cent over better parent was recorded by L_7 x T_1 (-33.56 %) and L_3 x T_3 (90.08 %) respectively. Moreover standard heterosis, the minimum and maximum heterosis percent was recorded by L_3 x T_2 (27.25%) and L_6 x T_2 (232.70%) respectively. Positively significant heterosis percent over mid, better and standard parents was recorded in 28, 22 and 36 hybrids respectiely.

Table 1: Heterosis percentage for the ten traits studied in the thirty six hybrids

Experimental hybrids	Days to 50% flowering			Plant height			No. of productive tillers/plant			Panicle length		
	d_i	d_{ii}	d_{iii}	d_i	d_{ii}	d_{iii}	d_i	d_{ii}	d_{iii}	d_i	d_{ii}	d_{iii}
IR 71700-247-1-1-2 X ADT 45	3.59*	-5.19*	19.13*	-17.86*	-22.05*	-10.41*	43.06*	28.75*	29.56*	-7.04*	-8.10*	-6.82*
IR 71700-247-1-1-2 X ASD 16	7.35*	-1.38	23.91*	14.27*	7.17*	26.30*	45.75*	39.38*	40.25*	2.10	0.30	5.43
IR 71700-247-1-1-2 X IR 72	-2.19*	-4.61*	26.09*	-14.15*	-15.22*	-12.51*	65.06*	55.00*	55.98*	-1.00	-1.68	-0.31
IR 71700-247-1-1-2 X MDU 5	5.97*	-4.84*	19.57*	-9.98*	-11.38*	-8.54*	-0.94	-1.25	-0.63	-0.85	-1.53	-0.16
IR 72158-11-5-2-3 X ADT 45	11.79*	-2.19*	36.09*	1.15	-1.80	19.86*	51.36*	50.78*	22.33*	-5.63*	-8.15*	-3.88
IR 72158-11-5-2-3 X ASD 16	12.10*	-1.56*	36.96*	1.71	-0.04	22.01*	26.55*	19.18*	9.43	2.14	1.92	7.13*
IR 72158-11-5-2-3 X IR 72	1.92*	-0.63	38.26*	-9.37*	-17.33*	0.91	68.09*	61.21*	42.45*	-4.24	-6.37*	-2.02
IR 72158-11-5-2-3 X MDU 5	10.91*	-4.69*	32.61*	-4.60*	-13.22*	5.92*	-2.43	-11.64*	-11.64*	-8.03*	-10.07*	-5.89
IR 72165-63-2-3-3 X ADT 45	10.47*	-2.55*	33.04*	-1.14	-5.96*	19.76*	69.70*	49.11*	58.49*	10.24*	4.80	15.19*
IR 72165-63-2-3-3 X ASD 16	8.99*	-3.50*	31.74*	1.97	-1.84	25.01*	-28.89*	-33.73*	-29.56*	-3.53	-5.64	3.72
IR 72165-63-2-3-3 X IR 72	-3.24*	-4.78*	30.00*	-15.03*	-23.95*	-3.15*	60.26*	46.75*	55.98*	-2.95	-7.33*	1.86
IR 72165-63-2-3-3 X MDU 5	9.19*	-5.14*	29.13*	2.75*	-8.28*	16.80*	35.98*	31.95*	40.25*	4.43	-0.28	9.61*
IR 72981-92-1-1-2-2 X ADT 45	10.71*	-1.93*	32.61*	13.70*	10.90*	34.08*	25.61*	14.01*	12.58*	4.72*	-3.56	13.49*
IR 72981-92-1-1-2-2 X ASD 16	8.86*	-3.22*	30.87*	1.48	0.20	21.15*	35.64*	30.89*	39.25*	-9.67*	-14.49*	0.62
IR 72981-92-1-1-2-2 X IR 72	-1.14	-2.25*	32.17*	7.78*	-1.26	19.38*	22.35*	15.92*	14.47*	7.41*	-.066	16.90*
IR 72981-92-1-1-2-2 X MDU	9.80*	-4.50*	29.13*	13.44*	3.63*	25.30*	47.15*	46.23*	46.27*	3.56	-4.22	12.71*
IR 72985-65-3-1 X ADT 45	13.81*	1.98*	34.35*	2.36*	2.06*	18.00*	10.27	7.41	-8.81	7.79*	0.82	14.73*
IR 72985-65-3-1 X ASD 16	10.46*	-0.66	30.87*	3.74*	2.75*	21.10*	26.69*	21.92*	11.95*	0.00	-3.82	9.46*
IR 72985-65-3-1 X IR 72	1.15	0.99	33.48*	-5.61*	-11.73*	2.05	55.35*	52.31*	34.59*	-6.02*	-11.72*	0.47
IR 72985-65-3-1 X MDU	12.95*	-0.66	30.87*	1.44	-5.41*	9.36*	75.51*	62.26*	62.26*	6.60*	0.14	13.15*
IR 73896-51-2-1-3 X ADT 45	11.65*	0.33	31.30*	-10.15*	-11.10*	4.39*	35.44*	22.93*	21.38*	2.22	-0.15	3.72
IR 73896-51-2-1-3 X ASD 16	8.28*	-2.33*	27.83*	11.83*	11.62*	31.55*	88.78*	82.17*	79.87*	4.75*	4.13	9.46*
IR 73896-51-2-1-3 X IR 72	2.48*	1.97*	34.78*	7.75*	0.04	17.47*	10.25*	4.46	3.15	3.12	1.19	5.12
IR 73896-51-2-1-3 X MDU	9.98*	-2.99*	26.96*	-1.47	-8.78*	7.11*	16.77*	16.04*	16.04*	6.92*	4.93	8.99*
IR 73907-53-3-2-2 X ADT 45	11.24*	1.02	29.13*	-6.39*	-6.65*	7.30*	39.52*	24.54*	27.67*	-3.07	-7.16*	0.47
IR 73907-53-3-2-2 X ASD 16	9.33*	-0.34	27.39*	4.52*	2.96*	21.34*	-6.15	-11.04*	-8.81	-5.81*	-7.16*	0.47
IR 73907-53-3-2-2 X IR 72	2.68*	0.99	33.48*	28.40*	20.71*	38.00*	4.78	-2.45	0.00	0.82	-3.01	4.96
IR 73907-53-3-2-2 X MDU	11.45*	-0.68	26.96*	-1.25	-7.43*	5.82*	-8.70	-9.82	-7.55*	-3.95	-7.59*	0.00
IR 73935-51-1-3-1 X ADT 45	9.52*	-3.79*	32.61*	-21.70*	-23.86*	-7.40*	6.84	-8.38	3.15	-0.51	-7.07*	6.05
IR 73935-51-1-3-1 X ASD 16	10.91*	-2.21*	34.78*	6.92*	5.26*	28.02*	14.77*	4.19	17.30*	7.92*	3.67	18.30*
IR 73935-51-1-3-1 X IR 72	2.42*	0.32	38.26*	9.92*	0.43	22.15*	9.55*	-2.24	-2.24	-0.22	-6.39*	6.82*
IR 73935-51-1-3-1 X MDU	11.52*	-3.79*	32.61*	-14.28*	-21.90*	-5.01*	-9.47*	-14.53*	-3.77	-0.36	-6.52*	6.67*
IR 75282-10-3-3-2 X ADT 45	-8.02*	-15.14*	4.78*	-5.72*	-7.31*	6.54*	34.07*	26.83*	14.47*	0.07	-4.55	4.19
IR 75282-10-3-3-2 X ASD 16	-3.80*	-10.92*	-10.00*	4.80*	1.78	19.95*	5.35	4.45	-4.09	-7.09*	-8.81*	-0.47
IR 75282-10-3-3-2 X IR 72	-11.91*	-14.80*	-12.61*	-1.47	-6.10*	4.30*	56.69*	55.05*	39.94*	-6.00*	-9.94*	-1.71
IR 75282-10-3-3-2 X MDU	-6.62*	-15.49*	-4.35*	-16.69*	-20.84*	-12.08	39.94*	45.60*	45.60*	20.68*	15.63*	26.20*

*Significant at 5% level

Table 1: Heterosis percentage for the ten traits studied in the thirty six hybrids (Continued)

Hybrids	Leaf area index (LAI)			Harvest index			Single plant yield		
	d_i	d_i	d_i	d_i	d_i	d_i	d_i	d_{ii}	d_{iii}
IR 71700-247-1-1-2 X ADT 45	-26.57*	-29.65*	-40.15*	6.83*	0.76	9.92*	18.07*	12.12*	40.27*
IR 71700-247-1-1-2 X ASD 16	-49.07*	-59.35*	-42.01*	13.01*	5.30*	14.88*	55.76*	51.20*	100.92*
IR 71700-247-1-1-2 X IR 72	-19.12*	-21.54*	-33.25*	7.14*	2.27	11.57*	79.28*	65.38*	106.91*
IR 71700-247-1-1-2 X MDU 5	-42.16*	-46.47*	-46.47*	2.77	-1.52	7.44*	27.53*	14.74*	43.54*
IR 72158-11-5-2-3 X ADT 45	-11.99*	-13.32*	-32.44*	19.34*	15.08*	19.84*	2.22	-8.58	30.38*
IR 72158-11-5-2-3 X ASD 16	24.27*	-4.95*	35.60*	20.83*	15.08*	19.84*	29.23*	24.82*	78.00*

IR 72158-11-5-2-3 X IR 72 IR 72158-11-5-2-3 X MDU 5	49.11* 16.67*	45.03* 2.43*	15.98* 2.43*	14.63* 8.50*	11.91* 6.35*	16.53* 10.74*	33.43* 5.39	-16.17 -10.36*	65.67* 27.84*
IR 72165-63-2-3-3 X ADT 45 IR 72165-63-2-3-3 X ASD 16 IR 72165-63-2-3-3 X IR R 72165-63-2-3-3 X MDU 5	31.20* -4.92* 15.68* 3.96*	2.71 -6.54* -8.59* -10.30*	41.53* 33.33* 25.95* 23.60*	20.00* 15.61* 4.53* -4.10*	17.07* 11.38* 3.25 -4.88*	19.01* 13.22* 4.96* -3.31*	56.89* -2.09 107.50* 46.23*	47.89* -4.23 90.08* 30.66*	87.91* 27.25* 141.50* 66.09*
IR 72981-92-1-1-2-2 X ADT 45 IR 72981-92-1-1-2-2 X ASD 16 IR 72981-92-1-1-2-2 X IR 72 IR 72981-92-1-1-2-2 X MDU	74.99* 30.08* 71.11* 36.87*	66.08* 4.61* 64.39* 27.82*	44.12* 49.23* 42.66* 27.82*	7.39* 1.58 -5.39* -1.92	-1.43 -7.86* -12.14* -8.57*	14.05* 6.61* 1.65 5.79*	46.48* 33.79* 51.30* 110.02*	34.36* 32.84* 34.98* 82.92*	81.10* 79.05* 81.94* 146.55*
IR 72985-65-3-1 X ADT 45 IR 72985-65-3-1 X ASD 16 IR 72985-65-3-1 X IR 72 IR 72985-65-3-1 X MDU	31.67* -8.69* 10.20* 18.01*	3.45* -10.69* -12.60* 2.26*	41.12* 27.14* 19.22* 39.50*	9.02* 2.38* -6.98* -7.34*	0.73 -6.52* -13.04* -13.04*	14.88* 6.61* -0.83 -0.83	-0.66 -11.64 5.02 134.27*	-16.93* -20.72* -14.30* 87.17*	38.94* 32.60* 43.33* 213.63*
IR 73896-51-2-1-3 X ADT 45 IR 73896-51-2-1-3 X ASD 16 IR 73896-51-2-1-3 X IR 72 IR 73896-51-2-1-3 X MDU	46.85* 13.29* 23.91* -12.42*	26.60* -0.63 7.99* -15.52*	36.25* 41.77* 16.22* -9.08*	8.0* 6.98* 4.55* 8.68*	-2.08 -4.17* -4.17* 0.00	16.53* 14.05* 14.05* 19.01*	-15.06* 100.31* 13.25* 3.10	-33.56* 66.93* -13.34* -22.59*	32.42* 232.70* 72.73* 54.29*
IR 73907-53-3-2-2 X ADT 45 IR 73907-53-3-2-2 X ASD 16 IR 73907-53-3-2-2 X IR 72 IR 73907-53-3-2-2 X MDU	71.14* 7.14* 67.47* 4.52*	67.80* -15.98* 66.30* -5.35*	36.09* 19.87* 34.87* -5.35*	-3.91* 4.35* -3.48* -10.00*	-11.51* -5.04* -10.17* -15.83*	1.65 9.09* 3.31* -3.31*	14.24* 10.28* 17.43* 10.88*	2.49 8.01 3.51 -4.55	43.41* 49.67* 43.43* 32.27*
IR 73935-51-1-3-1 X ADT 45 IR 73935-51-1-3-1 X ASD 16 IR 73935-51-1-3-1 X IR 72 IR 73935-51-1-3-1 X MDU	-17.63* -23.88* -4.40* -32.82*	-34.46* -26.78* -23.20* -40.92*	-13.63* 4.46* 1.22* -22.14*	13.92* 12.82* 2.50 2.91	12.50* 10.00* 2.50 2.48	11.57* 9.09* 1.65 2.48	26.84* 49.44* 63.43* 65.53*	25.79* 39.04* 51.24* 55.13*	43.87* 84.74* 79.85* 77.43*
IR 75282-10-3-3-2 X ADT 45 IR 75282-10-3-3-2 X ASD 16 IR 75282-10-3-3-2 X IR 72 IR 75282-10-3-3-2 X MDU	-18.13* -18.10* 58.98* 49.47*	-21.49* -34.68* 54.35* 38.20*	-33.33* -6.81* 31.06* 38.20*	-5.43* 1.18 1.92 -6.11*	-13.48* -8.51* -5.67* -12.77*	0.83 6.61* 9.92* 1.65	21.79* 60.74* 72.50* 70.45*	16.66* 54.68* 60.47* 54.60*	43.31* 105.52* 97.13* 89.91*

*Significant at 5% level

SE (5%) = 0.90 (d_i)
= 1.04 (d_{ii} and d_{iii})
d_i = Relative heterosis
d_{ii} = Heterobeltiosis
d_{iii} = Standard heterosis

4. Discussion

4.1. 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.

4.2. Heterosis Breeding

To exploit hybrid vigour through heterosis breeding, the parameters like mean performance, *sca* effects and standard heterosis of hybrids have to be taken into account. Therefore, in the present study also the hybrids were evaluated based on their mean performance, *sca* effects and magnitude of heterosis, for their utilization in heterosis breeding.

4.3. Mean performance of hybrids

The mean performance is the primary criterion to evaluate the value of a hybrid. Nadarajan (1986) [16] suggested that mean performance of hybrids appeared to be a useful index for judging the hybrids. Accordingly the hybrid L_6 x T_2 recorded high mean values for all the traits except plant height and 100 grain weight. The following five hybrids *viz*., L_1 x T_2, L_3 x T_1, L_4 x T_4, L_5 x T_4 and L_9 x T_4 showed high mean values for seven different traits each including single plant yield. They were followed by the cross combinations L_1 x T_3, L_2 x T_2 and L_3 x T_3 which had high mean performance for six traits including single plant yield. Next to them were the hybrids L_8 x T_4 and L_9 x T_3 with high mean performance for four different traits apart from single plant yield. Therefore in the present investigation, the hybrids L_6 x T_2, L_9 x T_4, L_5 x T_4, L_4 x T_4, L_3 x T_1, L_1 x T_2, L_1 x T_3, L_2 x T_2 and L_3 x T_3 were considered as outstanding one for improving grain yield.

4.4. Sca effects

The second important criterion for the evaluation of hybrids is the specific combining ability effects. According to Peng *et al*., 1999 [18], *sca* effect is the index to determine the usefulness of a particular cross combination for exploitation of heterosis. The *sca* effects are due to non-additive and epistatic gene action (Sprague and Tatum, 1942)[25]. The *sca* effects of hybrids have also been attributed to the combination of positive favourable genes from different parents or might be due to the presence of linkage in repulsion phase (Sarsar *et al*., 1986) [21].

In the present investigation, negative *sca* effects were taken into consideration for days to 50 per cent flowering and plant height, while for all the other traits positive *sca* effects were considered. Significantly several cross combinations for every trait recorded high sca effects. Several hybrids also recorded high *sca* effects for many of the characters. Among them, the hybrid L_3 x T_1 was adjudged as the best specific combiner which showed high *sca* effects for seven yield contributing traits *viz*., number of productive tillers plant^{-1}, panicle length, 100 grain weight, spikelet fertility, leaf area index, harvest index and single plant yield. The cross L_3 x T_3 was the next best specific combiner for six traits. It recorded high *sca* effects for all traits except panicle length, 100-grain weight, leaf area index and harvest index. High *sca* effects for five different yield contributing traits were recorded by L_1 x T_2, L_6 x T_2 and L_7 x T_1. They were followed by the hybrids L_2 x T_2, L_2 x T_3, L_4 x T_1, L_4 x T_4 and L_5 x T_4 which were identified as good specific combiners for four traits including single plant yield. Hence from the above discussion, it could be concluded that the hybrids L_3 x T_1, L_3 x T_3, L_1 x T_2, L_6 x T_2 and L_7 x T_1 were considered as good specific combiners for majority of yield contributing characters including single plant yield.

The phenomenon of hybrid vigour has been extensively met with in rice for enhancing the yield. A good hybrid selected should manifest high amount of heterosis for commercial exploitation. Among the three types of heterosis, relative heterosis is of limited importance since it is only the deviation of F_1 from mid parental value (Grakh and Chaudhary, 1985) [6]. Further the need for computing standard heterosis for commercial exploitation of hybrid vigour has been stressed by Kadambavanasundaram (1983) [9] and Siddiq (1987) [24]. Hence in the present study, the hybrids were evaluated based on heterosis over the standard variety MDU 5 and promising hybrids were selected for quantitative traits including single plant yield.

Significant heterosis over the standard variety MDU 5 was observed for a maximum of six traits in eleven hybrids *viz*., L_2 x T_3, L_3 x T_1, L_3 x T_3, L_4 x T_1, L_4 x T_3, L_4 x T_4, L_5 x T_1, L_5 x T_2, L_6 x T_2, L_8 x T_2 and L_9 x T_4; for five traits in L_1 x T_1, L_1 x T_3, L_2 x T_2, L_3 x T_4, L_4 x T_2, L_5 x T_4, L_6 x T_1, L_6 x T_3, L_6 x T_4 and L_9 x T_3 and for four traits in L_1 x T_2, L_1 x T_4, L_2 x T_1, L_2 x T_4, L_3 x T_2, L_5 x T_3, L_7 x T_1, L_7 x T_2, L_7 x T_3, L_8 x T_1, L_8 x T_3 and L_8 x T_4. From the above discussion, it was clear that the above said hybrids are highly suitable for involving them in heterosis breeding.

4.5. Hybrids for heterosis breeding

The hybrids suitable for heterosis breeding for individual traits based on mean performance, *sca* effects and heterosis per cent (standard heterosis) were given in Table 2. Based on the three selection criteria, the hybrids L_3 x T_1 was adjudged as the best since it expressed high mean, *sca* and standard heterosis for five traits namely number of productive tillers plant^{-1}, panicle length, leaf area index, harvest index and single plant yield. The hybrids L_3 x T_3 and L_6 x T_2 were the next best for four traits such as number of productive tillers plant^{-1}, number of grains panicle^{-1} and single plant yield in both the hybrids along with plant height in L_3 x T_3 and leaf area index in L_6 x T_2. This was followed by the hybrids, L_1 x T_3, L_2 x T_2, L_4 x T_4, L_5 x T_4 and L_9 x T_3 for three traits each including single plant yield.

The present study concluded that the hybrid IR 72165-63-2-3-3 / ADT 45 (L_3 x T_1), IR 72165-63-2-3-3 / IR 72 (L_3 x T_3) and IR 73896-51-2-1-3 / ASD 16 (L_6 x T_2) are highly suitable for commercial exploitation of hybrid vigour through heterosis breeding (Figure 1).

Table 2: Hybrids recommended for heterosis breeding

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

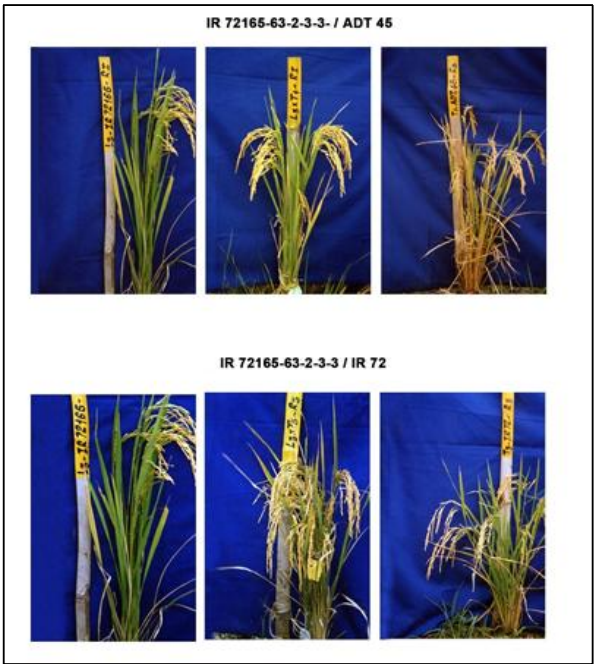

Fig 1: Hybrids recommended for heterosis breeding

References

1. Anderson PP. World food trends and future food security. In: Food Policy Report. International Food Policy Research Institute, Washington DC, 1994.
2. Bagheri N, Jelodar NB. Heterosis and combining ability analysis for yield and yield related traits in hybrid rice. Internat J Biol. 2010; 2(2):222-226.
3. Banumathy S, Thiyagarajan K, Vaithyanathan P. Study on magnitude of heterosis of rice hybrid for yield and its components. Crop Res. 2003; 25(2):287-293.
4. Flavio B. Traditional and Modern Plant Breeding Methods with Examples in Rice (*Oryza sativa L.*) J. Agric. Food Chem. 2013; 61:8277-8286.
5. Fonseca S, Patterson FL. Hybrid vigour in seven parent diallel cross in common wheat (*Triticum aestivum L.*), Crop Sci. 1968; 2:85-88.
6. Grakh SS, Chaudhary MS. Heterosis for early maturity and high yield in *Gossypium arboreum*. Indian J. Agric. Sci. 1985; 55(1):10-13.
7. Hatchcock R, Mc Daniel. Yield and yield component heterosis in Avena Hybrids. Crop Sci. 1973; 13:8-18.
8. Jones JW. Hybrid vigour in rice. J. Amer. Soc. Agron. 1926; 18:423-428.

9. Kadambavanasundaram M. Heterotic system in cultivated species of *Gossypium*. An appraisal (Abst). Genetic and crop improvement of heterotic systems. In: Pre-congress scientific meeting of xv International congress of genetics, 7-9 December, TNAU, Coimbatore, 1983, 20.
10. Kempthorne O. An introduction to genetic statistics. John Wiley and Sons Inc. New York. 1957.
11. Khush GS. New plant type in rice. IRRI, Los Banos, Philippines, 2002.
12. Khush GS, PS Virk. Rice Improvement: Past, present and future. Crop Improvement. Challenges in the twenty first century. Food Products Press, Inc., New York. 2002; 17-42.
13. Khush GS, Aquino RC. Breeding tropical japonicas for hybrid rice production. In: Hybrid Rice Technology: New Developments and Future Prospects. 1994.
14. Khush GS, Virk PS. Rice breeding. Achievements and future strategies. Crop Improv. 2000; 27(2):115-144.
15. Matzinger AK, Mann TJ, Cockerham CC. Diallel cross in *Nicotiana tabacum*. Crop Sci. 1962; 2:383-435.
16. Nadarajan N. Genetic analysis of fibre characters in cotton (*Gossypium hirsutum* L.). *Ph.D. Thesis*, TNAU, Coimbatore, 1986.
17. Panse VG, Sukhatme PV. Statistical methods for agricultural research workers, ICAR, New Delhi. 1964.
18. Peng S, Cassman KG, Virmani SS, Shetty J, Khush GS. Yield potential trends of tropical rice since the release of IR 8 and the challenge of increasing rice yield potential. Crop Sci. 1999; 39:1552-1559.
19. Ram T, Singh J, Singh RM. Combining ability for yield and its components in rice. Oryza. 1998; 35(3):237-241.
20. Ramiah K. Rice Breeding and Genetics, ICAR. New Delhi, Monograph 2002; 19:1953.
21. Sarsar SM, Patil RA, Bhatda SS Heterosis, combining ability in upland cotton. Indian J. Agric. Sci. 1986; 56:567-73.
22. Shanthi P, Shanmugasundaram P, Nagarajan P. Combining ability analysis in rice. Oryza. 2003; 40(1, 2):11-13.
23. Shull GH. What is heterosis? Genetica, 1948; 33:439-446.
24. Siddiq EA. Hybrid rice research of the Indian Agricultural Research Institute paper at the group meeting on hybrid rice. Directorate of Rice Research. Hyderabad. 1987.
25. Sprague GF, Tatum LA. General vs specific combining ability in single cross of corn. J AmmerSocAgron.1942; 34:983-992.
26. Surekha YP, Radhakrishnan VV, Mohanan KV. The importance of optimum tillering in rice–an overview. South Indian Journal Of Biological Sciences 2016; 2(1):125-127.
27. Turner JH. A study of heterosis in upland cotton II - Combining and inbreeding effects. Agron. J. 1953; 45:457-490.
28. Yoshida, S. Fundamentals of Rice Crop Science, IRRI, Los Banos, Philippines. 1981.