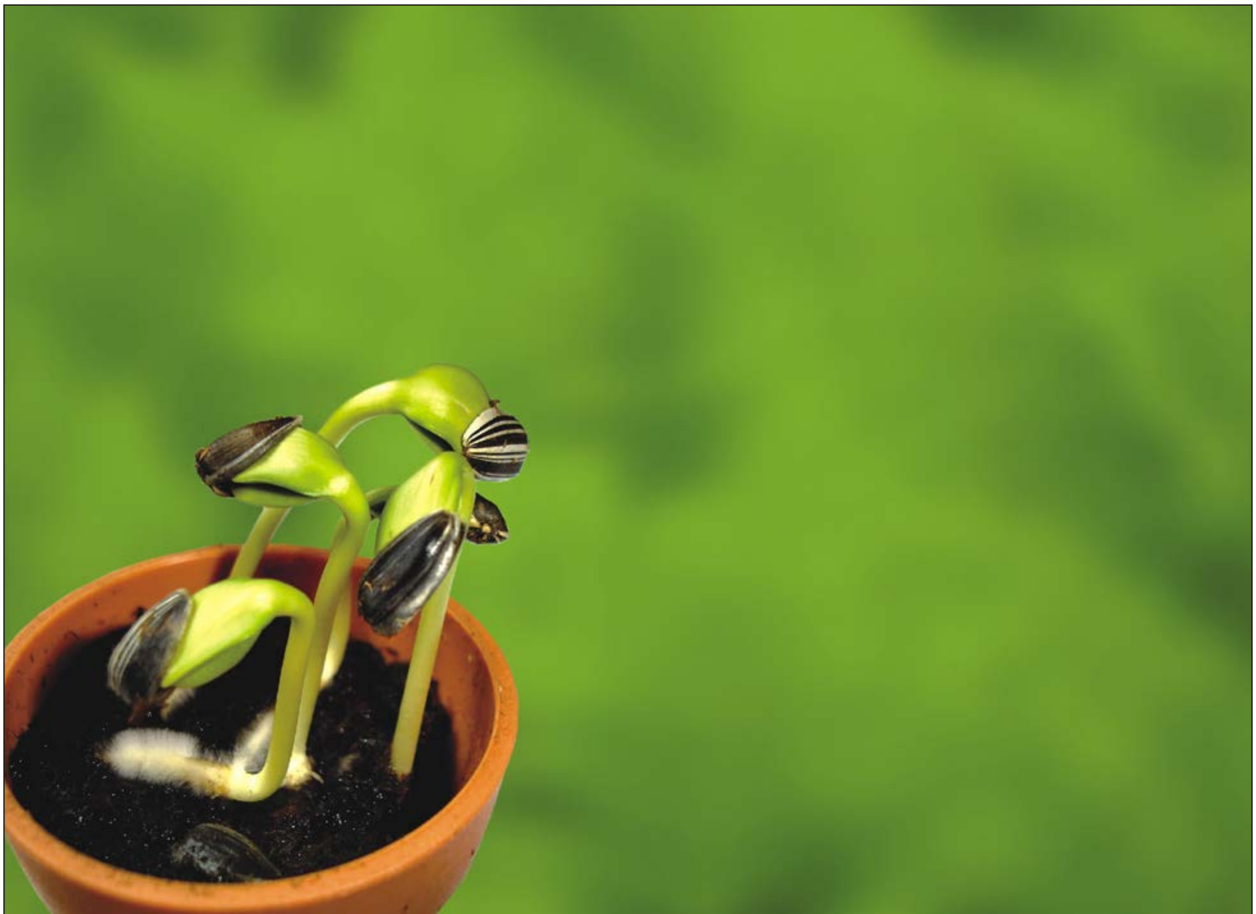

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Studies on Heterosis and Combining Ability of Well Known Blast Resistant Rice Genotypes with High Yielding Varieties of Rice (*Oryza sativa* L.)

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ABSTRACT

Twenty six rice genotypes were selected based on the rice blast disease reaction and yield attributes. Blast disease screening was done for all the entries under natural and artificial conditions to know their disease reaction. Line x tester analysis was carried out from the 20 selected entries with 4 lines having higher to moderate yield and 16 testers which showed blast disease resistance. General combining ability of parents and specific combining ability and heterosis among 64 hybrids for yield and its components were analysed. Under natural conditions and artificial screening conditions, among the 26 genotypes screened, highly significant lower mean disease reaction score and mean Potential Disease Incidence [PDI%] was recorded by a West African land race, Moroberekan. Mean squares due to females were larger in magnitude than male parents for all the characters. The magnitude of SCA variance was higher than GCA variance for all the characters except grain yield where the GCA variance was higher. Among the lines, IR 50 was found to be a good general combiner for six traits. Among the testers, IR 64 recorded high *per sec* performance along with high *gca* effects for panicle length, filled grains per panicle, 1000 grain weight and grain yield per plant. Most of the hybrids recorded positive significant standard heterosis values for grain yield per plant. IR 50/IR 64 recorded highest heterosis values for relative heterosis and TN 1/IR 64 recorded high heterobeltiosis and standard heterosis over the standard check ASD 16. Among 26 selected F_1s, Most of the combinations were resistant.

Key words: Rice, GCA, SCA, gene action, rice blast disease, *Magnaporthe grisea*

INTRODUCTION

Rice is the world's most important cereal crop. The recorded rice consumption in 2005 in India was around 85 million tonnes. Ten years down the line, it is expected to soar up to 92 million tonnes demanding more production from the paddy fields which is most unlikely to happen given the scenario of dwindling paddy fields (Subbiah, 2006). In Tamil Nadu, during the year 2007-2008, rice is being grown in an area of 17.89 lakh hectares with an production of 50 Lakh tonnes (Statistical Hand Book, 2010).

The estimated doubling of the population by 2050 will require a similar increase in food production. This has to be achieved by the development of high yielding rice varieties with improved nutritional quality and tolerance to biotic and abiotic stresses. Asia's Green Revolution achieved with increase in crop productivity that were sufficient to lower the proportion of population suffering from chronic hunger from 40 to 20% while the overall population growth is more than doubled. In addition, by increasing yields on land already in production, hundreds of millions of hectares of tropical forests and other natural environments were saved from conversion to agriculture (Toenniessen *et al.*, 2003).

Unfortunately, these expectations are short lived because the large areas of high yielding but genetically identical cultivars proved to be susceptible to pest and diseases. Among the biotic stresses diseases continue to be the major threat for increased production. Hence, the most urgent need is to increase the yield of rice by managing the problems caused by biotic and abiotic stresses (Hittalmani *et al.*, 1995).

Biotic and abiotic stresses cause severe yield losses which can be managed to certain extent by evolving genotypes employing resistance breeding strategies. To counter such yield losses is identification of resistant varieties available in nature and introgression of major resistance genes in high yielding varieties to increase productivity and crop diversification, while developing a more sustainable agriculture (Hittalmani *et al.*, 2000). The other way is by elucidating the basis of plant resistance through a comprehensive analysis of the molecular events that occur during pathogen-host recognition and the subsequent defense responses (Er-ming *et al.*, 2005). Among the available genetic resources to increase rice productivity, hybrid rice has faired well and secured a good track record in uplifting the curse of 'yield barrier'. Rice hybrids have an yield advantage of about 15 to 20% or more over the best conventionally bred varieties (Virmani, 1996).

The rice blast disease caused by *Magnaporthe grisea* (Hebert) Barr. (Asexual form known as *Pyricularia grisea* (Cooke) Sacc.), is one of the most serious fungal diseases which are widespread threatening the world rice production. Genetic resistance to rice blast has been and continues to be extensively used by rice breeders and pathologists to combat this disease. Numerous races of the fungus are prevalent (Ou, 1985). Blast resistance genes, commonly called *Pi* genes, providing a broad spectrum of resistance against the most prevalent races can be extremely valuable in rice breeding efforts (Fjellstrom *et al.*, 2003). In many cultivars, blast-resistance is quite short-lived in field conditions as the pathogen mutates very often favored by the environment to spread the disease. Hence, breeding for more durably resistant cultivars has become a priority in rice improvement programmes throughout the world.

Plant breeding strategies leading to selection of hybrids needs expected level of heterosis as well as the specific combining ability. In breeding high yielding varieties of crop plant for qualitative and quantitative traits, plant breeders often face with the problem of selecting parents and crosses. Combining ability analysis is one of the valuable tools available to ascertain the combining ability effects and helps in selecting the desirable parents and crosses for the exploitation of heterosis. Line x tester analysis provides information related to general combining ability (*gca*) and specific combining ability (*sca*) effects of parents and it is helpful in estimating various types of gene actions (Rashid *et al.*, 2007). Ganapathy *et al.* (2007) assessed the combining ability four best cross combination by line x tester analysis in rice including Moroberekan/MDU 5 and Moroberekan/CO 47 as best crosses in terms of higher yield and drought resistant. Line x tester analysis was done similarly to identify the was done in rice (Devi *et al.*, 2006; Venkatesan *et al.*, 2008; Kumar *et al.*, 2008).

The main objective of this breeding program is to select the high yielding hybrids with leaf blast resistance under field conditions. The choice of the parents for the breeding program was based on the earlier reports for the testers. The lines were selected based on three important factors. They are as follows: The extensive usage of these rice varieties for cooking purpose in Southern parts of India (TamilNadu, Andhra Pradesh, Karnataka) for its fine grain quality, (e.g., White ponni, BPT 5204 and IR 50), Grain yield per hectare, consistency of leaf blast disease reaction (TN 1).

The testers namely ARBN 97, ARBN 138, ARBN 139, ARBN 142, ARBN 144 and ARBN 153 harboring major blast resistance genes *Pi*-5(t), *Pi*-9(t), *Pi*-12(t), *Pi*-1(t) + *Pi*-2(t), *Pi*-1(t) + *Pi*-4(t) and *Pi*-5(t) respectively, were obtained from Central Rice Research Institute, CRRI, Cuttack in the year 2004 were used directly in the crossing program to study the yield and the reaction of high yielding combination for leaf blast disease reaction. The genotypes or the accessions CB98002, CB98004, CB98006 and CB98013 obtained from Paddy Breeding Station, Coimbatore, were selected based on the records of the earlier evaluation trials, with moderate to higher yield combined with moderate to resistant leaf blast disease reaction.

Inheritance of resistance in the varieties Te-tep and Tadukkan were found to be trigenic (Padmanabhan *et al*., 1973; Padmavathi *et al*., 2005). Te-tep was used as a resistance source in breeding program (Ahn and Ou, 1982; Dillon *et al*., 2006). Rice cultivar with durable resistance has been reported in many countries. Moroberekan (*Japonica*), in West Africa. (Nottegham, 1993; Wang *et al*., 1994; Chen *et al*., 1999; Jeon *et al*., 2003; Wu *et al*., 2004). IR 64 is one of the most cultivated varieties in Asia and is highly resistant to blast disease (Berruyer *et al*., 2003). IR 64 harboured more than four blast resistance genes. (Sallaud *et al.,* 2003; Lawrence *et al*., 2000). ARBN 153 (Pai-Kan-Tao) is a *Japonica* type NIL consisted of major resistance gene for leaf blast as reported by Ahn *et al*. (1996), Chen *et al*. (1999), Inukai *et al*. (1994), Mackill and Bonman (1992). CO 39 was highly susceptible for blast disease (Chen *et al*., 1999; Padmavathi *et al*., 2005; Hittalmani *et al*., 1995; Jeon *et al*., 2003). IR 50 was used as a susceptible check (Calvero, 1992; Jyothi *et al*., 2001).

In the light of the above facts and considering the potentials of resistance breeding, the present study was undertaken with the following objectives: 1) selection of highly reputed blast resistant genotypes with resistance genes and blast susceptible varieties having moderate to higher yield and to screen the rice genotypes for leaf blast disease reaction at two environments, 2) effecting hybridization among the chosen blast resistant and susceptible genotypes, study their heterosis pattern, combining ability, screening the F_1 hybrids under artificial condition for rice blast resistance.

MATERIALS AND METHODS

Twenty six rice genotypes representing different geographical origin were obtained from Paddy Breeding Station, Coimbatore and Central Rice Research Institute (CRRI), Cuttack in the year 2004. (ARBN, Asian Rice Biotechnological Network) lines were introgressed with leaf blast disease resistance genes (Table 1).

Field screening for leaf blast disease reaction: All the rice genotypes were screened at Hybrid Rice Evaluation Centre, Gudalur, Tamilnadu, India (hot spot for leaf blast), where disease occurrence is throughout the year and maximum during winter season. Each entry was sown in a single row and replicated thrice with every adjacent row planted with Bharti, (a highly susceptible local cultivar for leaf blast). The entire nursery was surrounded on all sides by two rows of Bharti, as a spreader source for the pathogen. The observation of disease reaction was recorded, when the susceptible check was severely infected by leaf blast.

Table 1: Details of rice genotypes

Genotypes	Parentage	Habit	Duration (days)	Place of collection	Geographic origin
Ajaya	IET 4141 / CR 987216	Semi dwarf	105	India	South Asia
ASD 16	ADT 39 / CO 39	Semi dwarf	110-115	India	South Asia
BPT 5204	GEB-24 / T(N) 1 / Mahsuri	Semi dwarf	140-145	India	South Asia
CB 98002	TNAU 89093 / ASD 5	Semi dwarf	130	India	South Asia
CB 98004	TNAU 89093 / ADT 40	Semi dwarf	130	India	South Asia
CB 98006	Ponni / CO 43	Semi dwarf	135	India	South Asia
CB 98013	CO 45 / IR 64	Semi dwarf	138	India	South Asia
Pusa Basmati	Pusa 167 / Karnal local	Semi dwarf	115	India	South Asia
IR 50	IR 2153-14 / IR 28 / IR 36	Dwarf	115	Philippines	South East Asia
ARBN 138	*Oryza minuta* (Acc. 10114) / (WHD-IS-1-127) / (DM 360)	Dwarf	135	Philippines	South East Asia
ARBN 142	BL 142	Semi dwarf	130	Philippines	South East Asia
IR 36	IR 1561-228 // IR 244 / *O. nivara* // CR 94-13.	Dwarf	110	Philippines	South East Asia
IR 64	IR 5657-3-3-3-1 / IR 2061-465-1	Semi dwarf	115-120	Philippines	South East Asia
Milyang 46	Doosan 8 / Sacheon 8	Dwarf	110	South Korea	South East Asia
Tadukan	Philippine *indica* cultivar (Luzon)	Semi dwarf	130-135	Philippines	South East Asia
Tetep	Vietnamese *indica* cultivar	Semi dwarf	130-135	Vietnam	South East Asia
TN 1	Chow-Woo-Gen / Tsai-Yuan-Chung.	Dwarf	12-125	Taiwan	South East Asia
White Ponni	Taichung 65/2 / Mayang Ebos- 80	Tall	125-130	Malaysia	South East Asia
ADT 43	IR 50 / Improved White ponni	Semi dwarf	110	India	South / S.E. Asia
CO 43	Dasal / IR 20	Dwarf	130-135	India	South / S.E. Asia
ARBN 153	C-101-Pai Kan Too (*japonica*)	Tall	110-115	China	Central Asia
ARBN 97	RIL 45 (Moroberekan / CO 39)	Semi dwarf	135	India	South Asia / Africa
ARBN 139	RIL 10 (Moroberekan / CO 39)	Dwarf	140	India	South Asia / Africa
ARBN 144	RIL 249 (Moroberekan / CO 39)	Semi dwarf	135	India	South Asia / Africa
Moroberekan	Guinean (West Africa) cultivar, *japonica*	Semi dwarf	130	Guinea (Africa)	Africa
Columbia - 2	Columbian *indica* cultivar	Semi dwarf	135	Columbia	Latin America

Individual plant in each entry was scored based on the leaf blast severity following Standard Evaluation System (SES, IRRI, 2002) on a 0-9 scale as detailed at 35th day after sowing, when the susceptible check (Bharti) was fully infected. The Potential Disease Incidence (PDI%) was worked out using the formula given by McKinney (1923):

$$\text{PDI \%} = \frac{\text{Sum of numerical rating}}{\text{Number of leaves observed}} \times \frac{100}{\text{Maximum disease score}}$$

Artificial screening for leaf blast disease reaction: Artificial screening for rice blast disease was done in the specially constructed screen house with good irrigation facilities fitted with mist blowers, which can spray water in a fine mist inside the chamber. Subsequently, the seedlings were misted 4-5 times at intervals. The screen house was maintained at 32-37°C (day temperature) and 94 to 96% Relative Humidity (RH) for the potential disease occurrence. The rate of sporulation increases with increase in relative humidity provided with lower night temperature with minimum of 25°C. Inoculations with *M. grisea* Hebert (Barr) were performed 3 weeks after sowing either by spraying with conidial suspensions. For the spray method, 30 mL of a 50,000 conidia suspension with 0.5% gelatin were sprayed on each tray. The observation on the disease incidence was recorded, when the susceptible check was severely infected by blast. Observations were recorded from 20 plants in each entry following Standard Evaluation System (SES, IRRI, 2002) on 0-9 scale at 25th day after sowing. The resistant check used was IR 64. Observations were recorded in plants, when they were at third leaf stage. The Grade and criterion based on standard evaluation system is as follows, score 0-No lesions observed; score 1- Small brown specks of pin point size or larger brown specks without sporulating centre; score 3- Small roundish to slightly elongated necrotic grey sporulating spots about 1-2 millimeters in diameter with a distinct brown margin; score 5- Narrow or slight elliptical lesions, 1-2 mm in breadth, more than 3 mm long with brown margin; score 7-Broad spindle shaped lesion with yellow, brown or purple margin; score 9-Rapidly coalescing small, whitish, greyish or bluish lesions without distinct margins.

Selection, hybridization and biometric observations of F_1s and parents: Twenty genotypes with 16 rice blast resistant lines viz., (ARBN 97, ARBN 138, ARBN 139, ARBN 142, ARBN 144, ARBN 153, IR 64, CB 98002, CB 98004, CB98013, CB 98006, Columbia 2, Milyang-46, Moroberekkan, Tadukkan, Te-tep) and four high yielding blast susceptible testers (IR 50, White ponni, TN 1, BPT5204) were selected based on the blast disease reaction after the screening procedures. The genotypes were raised in nursery beds with three staggered sowings at 10-15 days interval to ensure synchronized flowering to enable hybridization. Hybridization was carried out by wet cloth method or blowing method (Chaisang *et al*., 1967) and clipping method (Jennings *et al*., 1979). Crosses were effected between four female lines and sixteen male parents in a Line x Tester mating design and a total of 64 cross combinations were obtained. The 64 hybrids and 20% were raised along with the standard check ASD-16 in a Randomized Block Design which was replicated five times by adopting a spacing of 20×20 cm between rows and plants in a single row of each 1.5 m length consisting of 10 plants per row Single seedling per hill was planted. The recommended packages of practices were followed.

The following biometrical observations were recorded for the randomly selected hybrids and parents. Days to 50% flowering (DFL), Plant Height (PH), number of tillers per plant (NOTP), number of productive tillers per plant (NOPTP), Panicle Length (PL), number of filled grains per panicle (NOFLP), Days to Maturity (DM), Test Weight (TW) and Grain Yield per Plant (GYP).

Natural screening for rice blast disease was done separately by raising selected F_1 hybrids at hot spot location of Tamilnadu (Gudalur, Nilgris District) to check the disease reaction of hybrids. The mean values recorded for nine characters in the parents and F_1 generation was subjected to statistical analysis. The data was subjected to combining ability analysis following the method given by Kempthrone (1957). The ratio of GCA/SCA was done for each trait to determine the predominance of additive or non-additive gene action, assuming simple additive dominance model. Standard heterosis was worked out as percent mean deviation of the mean F_1 performance over the mean performance of the standard variety (ASD 16). The statistical analysis was done using the INDOSTAT statistical package (Indostat services, Hyderabad, India).

RESULTS AND DISCUSSION

The 26 rice genotypes selected based on earlier reports were subjected to natural screening at Hybrid Rice Evaluation Centre (HREC), Gudulur (hot spot for leaf blast). Among the genotypes screened, highly significant lower mean disease reaction score (2.30) and mean PDI per cent (25.25)

Table 2: Rice blast disease reaction at HRE, Gudalur (Field screening)

Genotypes	Mean disease score	MeanPDI (%)	Blast disease reaction	Standard error	Standard deviation	Sample Variance	Significance (5% / 1 %)
ARBN 97	2.78**	30.96	R	0.340	1.701	2.893	0.702/0.941
ARBN 138	2.57**	28.59	R	0.595	2.972	6.840	1.227/1.730
ARBN 139	2.36**	26.22	R	0.270	1.352	1.827	0.558/0.791
ARBN 142	3.30**	36.74	MR	0.574	2.868	5.227	1.184/1.655
ARBN 144	6.05**	67.25	MS	0.432	2.160	4.667	0.892/1.265
ARBN 153	2.52**	27.99	R	0.623	3.113	6.663	1.285/1.782
IR 64	0.60*	6.67	R	0.208	1.041	1.083	0.438/0.805
CB 98002	3.48**	38.66	MR	0.530	2.651	7.027	1.094/1.546
CB 98004	3.10**	34.51	MR	0.399	1.993	3.973	0.823/1.137
CB 98006	5.10**	58.58	MR	0.494	2.471	6.107	1.020/1.446
CB 98013	0.60*	6.67	R	0.329	1.645	2.707	0.438/0.805
Columbia 2	0.30*	3.33	R	0.115	0.577	0.333	0.238/0.334
Moroberekan	2.30**	25.57	R	0.383	1.915	3.667	0.790/1.104
Milyang 46	2.57**	28.59	R	0.462	2.309	5.333	0.953/1.308
Tadukan	0.50	5.56	R	0.673	3.367	6.333	1.370/1.896
Tetep	0.33	3.39	R	0.374	1.869	3.493	0.772/1.069
IR 50	7.79**	87.78	S	0.360	1.523	2.333	0.631/0.882
TN 1	7.29**	81.33	S	0.503	2.517	6.333	1.309/1.444
White Ponni	7.52**	83.54	S	0.605	3.026	9.157	1.249/1.764
BPT 5204	7.07**	78.58	S	0.408	2.040	4.160	0.842/1.194
ADT 43	3.30**	36.74	MR	0.608	3.040	7.240	1.255/1.756
ASD 16	7.08**	78.66	S	0.346	1.732	3.000	0.715/1.00
CO 43	2.59**	28.77	R	0.400	2.010	4.350	0.826/1.167
Pusa Basmati	2.95**	32.77	R	0.562	2.812	5.907	1.161 / 1.644
Ajaya	5.18**	57.62	MS	0.364	1.818	3.037	0.751/1.055
IR 36	5.20**	57.72	MS	0.383	1.913	3.660	1.112/0.046

*-Significant at 5 % level; **-Significant at 1 % level, (SES, 2002). Blast disease score: 1-3.0 = R,(Resistant). 3.1-5.0 = MR(Moderately Resistant). 5.1-7.0 = MS(Moderately Susceptible). 7.1-9.0 = S (Susceptible)

was recorded by Moroberekan, followed by ARBN 139, ARBN 153, ARBN 138 and Milyang-46 with the mean disease reaction scores and mean PDI per cent of (2.36 and 26.22%), (2.52 and 27.99%), (2.57 and 28.59%) and (2.57 and 28.59%), respectively. Significant lowest mean leaf blast disease reaction score (0.30) and mean Potential Disease Incidence percentage (3.33) was recorded by Columbia-2, followed by IR 64 and CB98013 (0.60 and 6.67%). Highly significant, higher mean disease reaction scores and mean PDI per cent was recorded by IR 50 (7.79 and 87.78%) followed by White Ponni (7.52 and 83.54%), TN 1 (7.29 and 81.33%), ASD 16 (7.08 and 78.66%) and BPT 5204 (7.07 and 78.58) (Table 2).

The same 26 genotypes were subjected to the artificial screening at Paddy Breeding Station (PBS), Coimbatore. Highly significant, lower mean disease reaction score (0.84) and mean PDI per cent (9.33) was recorded by Moroberekan, followed by Columbia 2 (0.88 and 9.77%) and ARBN 142 (1.0688 and 11.25%). Significantly lowest mean disease reaction scores and PDI% was recorded by IR 64 (0.61 and 6.81%) followed by Tadukan (0.81 and 9.03%). Highly significant, higher mean disease reaction scores was recorded by TN 1 (8.60 and 95.55%) followed by White Ponni (8.50 and 94.50), BPT 5204 (8.25 and 91.70%), ARBN 153 (7.56 and 83.99%) and ASD 16 (7.21 and 80.14%) (Table 3).

Table 3: Rice blast disease reaction at PBS, Coimbatore (Artificial screening)

Genotypes	Mean disease score	Mean PDI (%)	Blast disease reaction	Standard error	Standard deviation	Sample variance	Significance (5% / 1 %)
ARBN 97	7.02**	78.07	S	0.547	2.678	7.7.12	1.131/1.535
ARBN 138	6.74**	74.95	MS	0.564	2.671	7.623	1.666/1.582
ARBN 139	6.76**	75.10	MS	0.506	2.479	6.382	1.047/1.421
ARBN 142	0.88**	9.77	R	0.253	1.239	1.536	0.532/0.710
ARBN 144	1.77*	19.71	R	0.564	3.203	5.610	1.353/1.836
ARBN 153	7.56**	83.99	S	0.311	1.523	2.391	0.643/0.873
IR 64	0.61*	6.81	R	0.233	1.142	1.304	0.482/0.654
CB 98002	1.82**	20.29	R	0.560	2.745	7.536	1.159/1.573
CB 98004	5.20**	57.77	MS	0.425	2.083	4.341	0.880/1.194
CB 98006	6.09**	67.55	MR	0.333	1.633	2.667	0.690/0.937
CB 98013	1.38**	15.40	R	0.342	1.676	2.810	0.708/0.961
Columbia 2	1.06**	11.25	R	0.225	1.110	1.210	0.465/0.630
Moroberekan	0.84**	9.33	R	0.175	0.859	0.737	0.363/0.492
Milyang 46	1.17*	13.03	R	0.381	1.865	3.478	0.788/1.069
Tadukan	0.81*	9.03	R	0.451	2.212	4.895	0.634/0.831
Tetep	1.62**	18.07	R	0.590	2.889	3.348	1.220/1.601
IR 50	6.92**	76.88	S	0.419	2.053	4.216	0.867/1.177
TN 1	8.60**	95.55	S	0.359	1.761	3.101	0.744/1.009
White Ponni	8.50**	94.50	S	0.465	2.278	5.188	0.962/1.305
BPT 5204	8.25**	91.70	S	0.567	2.823	7.971	1.192/1.618
ADT 43	3.06**	34.06	R	0.491	2.408	5.797	1.017/1.380
ASD 16	7.21**	80.14	S	0.295	1.445	2.087	0.610/0.828
CO 43	1.85**	20.58	R	0.561	2.749	7.558	1.161/1.575
Pusa Basmati	1.17**	13.01	R	0.382	1.871	3.500	0.790/1.072
Ajaya	2.94**	32.73	R	0.282	1.382	1.911	0.584/0.792
IR 36	6.46**	71.84	MS	0.398	1.949	3.797	0.823/1.117

*-Significant at 5 % level; **-Significant at 1 % level (SES, 2002). Blast disease score: 1-3.0 = R (Resistant). 3.1-5.0 = MR (Moderately Resistant). 5.1-7.0 = MS(Moderately Susceptible). 7.1-9.0 = S (Susceptible)

The analysis of variance has shown (Table 4) significant divergences among the parents for all the characters which can generate potential and promising hybrids. The hybrids also showed significant differences for all the characters. The contribution of lines x testers' interaction was higher for the characters viz., number of tillers per plant, productive tillers per plant, number of filled grains per panicle and grain yield per plant. The contribution of females was higher for plant height, days to 50% flowering, days to maturity and test weight (Table 5). Analysis of variance showed highly significant differences among genotypes for all the characters. The variance due to parents, hybrids and parent - hybrid interactions were highly significant for all the nine characters. Mean squares due to females were larger in magnitude than male parents for all the characters. The magnitude of SCA variance was higher than GCA variance for all the characters except grain yield where the GCA variance was higher (Table 6).

The relative estimates of variances due to specific combining ability (S^2*sca*) effects were predominant for all the characters studied indicating the predominance of non-additive component, except for grain yield per plant for which the variance due to general combining ability (S^2*gca*) effects were more suggesting the preponderance of additive component of genetic variation, indicating both additive and non additive gene variations are important. The ratio of variances

Table 4: Analysis of variance for Line x Tester

Source of variation	Degrees of freedom	Mean squares Days to 50% flowering	Plant height (cm)	Number of tillers per plant	Number of productive tillers per plant	Panicle length (cm)	Filled grains per panicle	1000 grain weight (g)	Days to maturity	Grain yield per plant (g)
Replication	4	8.50	13.49	16.69	16.54	2.09	117.1	1.53	6.5	8.25**
Genotypes	83	757.82**	1229.75**	448.00**	270.37**	21.72**	1108.50**	20.76**	673.54**	152.56**
Crosses	63	823.17**	1171.43**	385.54**	243.55**	23.00**	1020.43**	23.88**	709.55**	169.32**
Parents	19	575.86**	332.01**	98.72**	57.46**	17.90**	1014.66**	11.23**	570.83**	54.93**
Line	3	1907.38**	973.78**	18.73**	24.18**	16.18**	3211.93**	1.12**	1604.40**	4.60**
Testers	15	330.66**	133.77**	120.15**	67.25**	19.32**	632.18**	14.00*	402.15**	54.11**
Lines Vs Testers	1	259.21**	1380.12**	17.22**	10.56**	1.76**	160.02**	0.03	0.36**	218.09**
Parents Vs Hybrids	1	98.20**	21961.45**	11019.48**	6005.42**	13.83**	8440.05**	5.26**	356.17**	951.75**
Error	332	3.53	18.81	9.69	9.94	3.37	44.02	1.01	4.66	3.31

*-significant at 5% level, **-significant at 1% level

Table 5: Analysis of variance for combining ability

Source of variation	Degrees of freedom	Mean squares Days to 50% flowering	Plant height (cm)	Number of tillers per plant	Number of productive tillers per plant	Panicle length (cm)	Filled grains per panicle	1000 grain weight (g)	Days to maturity	Grain yield per plant (g)
Hybrids	63	823.17**	1171.43**	385.54**	243.55**	23.00**	1020.43**	23.88**	709.55**	169.32**
Lines	3	15787.15**	14025.24**	1584.74**	1427.45**	69.91**	1465.10**	277.06**	11886.15**	436.17**
Testers	15	109.35**	938.88**	612.98**	345.90**	39.02**	1511.64**	16.41**	151.45**	274.25**
Lines Vs Testers	45	63.52**	392.02**	229.78**	130.51**	14.53**	827.05**	9.49**	150.48**	116.55**
Error	252	3.57	21.26	11.80	12.49	3.90	45.28	1.28	4.60	3.61
S^2_{gca}	-	4.92	5.05	1.01	0.73	0.05	1.25	0.09	3.62	22.59
S^2_{gca}	-	11.99	74.15	43.60	23.60	2.13	156.35	1.64	29.18	0.34
S^2_{gca}/S^2_{gca}	-	0.41	0.068	0.02	0.03	0.02	0.008	0.05	0.12	0.04

*-significant at 5% level, **-significant at 1% level

Table 6: Magnitude of *gca* and *sca* variances and proportional contribution to total variances due to lines, testers and hybrids for various characters

	Magnitude of *gca* and *sca* variances			Proportional contribution percentage		
Characters	*gca* variance	*sca* variance	*gca*:*sca*	Lines	Testers	Hybrids
Days to 50% flowering	4.92	11.99	0.41:1	91.33	3.16	5.51
Plant height	5.052	74.15	0.07:1	57.01	19.08	23.90
Number of tillers per plant	1.01	43.59	0.02:1	19.57	37.87	42.57
Number of productive tillers per plant	0.73	23.60	0.03:1	27.91	33.82	38.28
Panicle length	0.05	2.13	0.02:1	14.47	40.40	45.13
Filled grains per panicle	1.25	156.35	0.008:1	6.84	35.27	57.89
Days to maturity	3.62	29.18	0.12:1	79.77	5.08	15.15
Thousand grain weight	0.09	1.64	0.05:1	55.25	16.37	28.38
Grain yield per plant	0.34	22.59	0.04:1	12.27	38.56	49.17

Table 7: General combining ability (*gca*) effects of lines and testers

Lines / Testers	DFL	PH	NOTP	NOPTP	PL	NOFLP	DM	TW	GYP
IR 50	**-17.54 ****	**-11.13 ****	**5.29 ****	**5.68 ****	0.04	-5.13 **	-15.61 **	**1.67 ****	-0.64 **
White ponni	7.81 **	18.31 **	-0.82 *	-0.43	**0.75 ****	1.97 **	5.48 **	0.40 **	0.01
TN 1	-4.51 **	0.93	0.98 *	-0.73	0.54 **	-1.56 *	-2.71 **	0.59 **	**3.12 ****
BPT 5204	14.25**	-8.12**	-5.46 **	-4.53 **	-1.33 **	**4.72 ****	12.84 **	-2.66 **	-2.49 **
ARBN 97	1.41 **	1.55	4.29 **	3.27 **	-0.41	0.86	0.59	0.76 **	4.06 **
ARBN 138	3.16 **	-0.43	2.14 **	0.02 ns	0.90 *	6.61 **	2.54 **	1.04 **	2.08 **
ARBN 139	4.46 **	-9.20 **	-2.56 **	-2.88 **	-0.29	3.15 *	5.04 **	-0.03 ns	0.81
ARBN 142	0.96 *	-10.80 **	-2.16 **	-2.33 **	-0.66	3.71 *	1.79 **	-0.67 **	-0.80
ARBN 144	0.76	-6.35 **	1.34 ns	3.32 **	-0.31	-7.09 **	-1.16 *	-0.94 **	-0.61
ARBN 153	-0.69	**-11.60 ****	-7.26 **	-6.33 **	-1.86 **	-15.85 **	-0.96 *	-0.79 **	-3.36 **
IR 64	-0.44	0.80	**11.19 ****	**9.92 ****	2.50 **	**22.10 ****	-0.26	**2.26 ****	**9.41 ****
CB 98002	0.32	0.95	-1.16 ns	0.12 ns	-0.14	1.11	1.44 **	-0.16	-0.73
CB 98004	-0.46	9.53 **	-2.91 **	-0.33 ns	2.26 **	5.16 **	0.21	0.46	-1.51 **
CB 98006	-0.54	8.15 **	-2.76 **	-1.88 *	0.53	0.63	0.84	0.04	0.48
CB 98013	-1.99 **	2.00	6.59 **	4.02 **	-0.46	2.55	-1.46 **	-0.52 *	1.34 **
Columbia 2	-0.89 *	0.86	-7.11 **	-4.98 **	0.13	-11.19 **	-0.96 *	-0.71 **	-7.63 **
Milyang - 46	**-6.04 ****	-2.50 *	9.19 **	4.47 **	1.69 **	4.26 **	-2.01 **	0.00	2.51 **
Moroberekan	2.01 **	4.00 **	-3.86 **	-3.38 **	0.09	-5.05 **	2.24 **	1.00 **	-2.96 **
Tadukkan	-0.69	11.75 **	-5.86 **	-3.08 **	-1.11 *	-7.95 **	-0.11	-0.66 **	-2.05 **
Te-tep	-1.28 **	1.25	0.84	0.02	-2.87 **	-2.99 *	**-7.80 ****	-1.07 **	-1.03 *
SE (g) of lines	0.211	0.516	0.384	0.395	0.221	0.752	0.240	0.127	0.212
Se (g) of testers	0.422	1.031	0.768	0.790	0.441	1.505	0.479	0.253	0.425

*,**Means significant at 5% and 1% probability level, respectively. Bold representation indicates top 2 rankings

(S^2gca/S^2sca) due to general and specific combining ability effects ranged from 0.008 to 0.41. Similar results indicating the predominance of non-additive gene action for the above mentioned traits were reported earlier by (Radhidevi *et al.*, 2002; Annadurai and Nadarajan, 2001; Sarker *et al.*, 2002; Ganesh *et al.*, 2004). The presence of greater non-additive genetic variance for all the characters offers the scope for exploitation of hybrid vigour through heterosis breeding.

These observations suggest that a breeding method that can incorporate both additive and non additive genetic components would be a useful strategy. Recurrent selection method, which provides better opportunity for selection, recombination and accumulation of desired genes, should help to increase fixable as well as non-fixable types of gene effects.

The selection of parents based on *per se* performance may not always result in producing superior segregants. Dhillon (1975) pointed out that combining ability of parents gives useful information on the choice of parents in terms of expected performance of their progenies. In the present investigation, among the lines, IR 50 was found to be a good general combiner for six traits viz., days to 50% flowering (negative), plant height (negative) and days to maturity (negative direction). For the other traits like number of tillers per plant, number of productive tillers per plant and 1000 grain weight the same line IR 50 was found to be the good general combiner. The varieties White ponni, BPT 5204 and TN 1 recorded higher *gca* values for panicle length, filled grains per panicle and grain yield per plant respectively.

Among the testers, IR 64 was the good general combiner for six traits viz., number of tillers per plant, number of productive tillers per plant, panicle length, filled grains per panicle, 1000 grain weight and grain yield per plant. The testers Milyang-46, ARBN 153 and Te-tep recorded higher *gca* values (negative direction) for days to 50% flowering, plant height and days to maturity. The

Table 8: Top five hybrids related with *per se* performance and GCA status

Character	Five superior hybrids	Mean value	GCA status
Days to 50% flowering	IR 50 X IR 64	76.40	Low x Low
	IR 50 X CB98013	76.40	Low x Low
	IR 50 X CB98004	76.40	Low x Low
	IR 50 X ARBN 153	78.60	Low x Low
	IR 50 X TADUKAN	78.60	Low x Low
Plant height (cm)	BPT 5204 X ARBN 153	73.40	Low x Low
	IR 50 X ARBN 142	76.40	Low x Low
	IR 50 X ARBN 153	76.40	Low x Low
	BPT 5204 X ARBN 144	80.40	Low x Low
	BPT 5204 X Moroberekan	80.40	Low x High
Number of tillers per plant	TN 1 X Milyang 46	56.00	High x High
	IR 50 X CB98013	54.20	High x High
	IR 50 X TETEP	50.00	High x Low
	IR 50 X IR 64	49.40	High x High
	TN 1 X IR 64	47.00	High x High
Number of productive tillers per plant	IR 50 X IR 64	42.60	High x High
	IR 50 X TETEP	42.20	High x Low
	IR 50 X CB98013	41.40	High x High
	IR 50 X ARBN 144	39.60	High x High
	BPT 5204 X IR 64	38.00	Low x High
	TN 1 X Milyang 46	38.00	Low x High
Panicle length (cm)	BPT 5204 X CB 98004	27.70	Low x High
	IR 50 X IR 64	26.84	Low x High
	TN 1 X Moroberekan	26.80	High x Low
	TN 1 X Milyang 46	26.60	High x High
	White ponni X Moroberekan	26.40	High x Low
Filled grains per panicle	TN 1 X IR 64	162.40	Low x High
	BPT 5204 X IR 64	160.60	High x High
	BPT 5204 X CB 98002	148.20	High x Low
	BPT 5204 X CB 98004	145.40	High x High
	TN 1 X ARBN 97	143.80	Low x Low
Days to maturity	TN 1 X Tetep	96.20	Low x Low
	IR 50 X IR 64	107.20	Low x Low
	IR 50 X Milyang 46	107.80	Low x Low
	IR 50 X CB98013	109.20	Low x Low
	IR 50 X ARBN 153	110.40	Low x Low
Test weight (g)	TN 1 X IR 64	23.84	High x Low
	IR 50 X IR 64	23.66	High x Low
	TN 1 X Moroberekan	23.53	High x Low
	IR 50 X ARBN 153	22.42	High x Low
	White ponni X ARBN 97	22.28	High x High
Grain yield per plant (g)	TN 1 X IR 64	46.35	High x High
	BPT 5204 X IR 64	43.08	Low x High
	IR 50 X IR 64	41.09	Low x High
	BPT 5204 X CB 98006	36.53	Low x Low
	IR 50 X Milyang 46	35.60	Low x High

parents with high *gca* effect can be utilized in the hybridization programme for selection of superior recombinants in segregating progenies as suggested by Rojas and Sprague (1952).

The knowledge of combining ability coupled with *per se* performance of parents would be of great value in selecting suitable parents for hybridization program. In the present study, association between *per se* performance and *gca* effects was evident for most of the traits except number of tillers and number of productive tillers per plant (Table 7, 8).

Among the lines, IR 50 exhibited high *per se* performance along with high *gca* effects for days to flowering, days to maturity and plant height in the negative direction. The varieties BPT 5204 and TN I recorded high *gca* along with high *per se* performance for filled grains per panicle and grain yield per plant respectively.

Among the testers, IR 64 recorded high *per se* performance along with high *gca* effects for panicle length, filled grains per panicle, 1000 grain weight and grain yield per plant. Earlier studies also indicated that the parallelism between *per se* performance and *gca* effects does not always existed (Radhidevi *et al*., 2002; Suresh and Reddy, 2002; Selvaraj *et al*., 2006).

Generally parents with high order of *per se* performance for characters resulted in hybrids with high expression (Gilbert, 1958). None of the hybrid showed superior mean performance for all the traits studied. However, the hybrid IR 50×IR 64 ranked first by recording first two high mean values for 5 characters in viz., days to flowering, number of tillers per plant, panicle length, days to maturity (early) and test weight followed by TN 1×IR 64 for 3 characters with top rank viz., filled grains per panicle, test weight and grain yield per plant. The remaining hybrids showed superior performance for either one or two characters only (Table 8).

The hybrids with high mean performance for more number of traits can be utilized in hybrid breeding programmes. Hybrids with high mean performance for number of productive tillers, panicle length, test weight and grain yield per plant were observed (Radhidevi *et al*., 2002; Suresh and Reddy, 2002).

Thus, a high order of expression of a character by a hybrid might be attributed by the high degree of expression of either one or both of its parents in respect to the traits concerned. The *sca* is the deviation from the predicted value of hybrid on the basis of *gca* of their respective parents. The *sca* effect may be due to non-additive gene action.

In the present study, the first five top ranking hybrids that exhibited maximum *sca* effects are presented in Table 9. The ranking based on *sca* effects of the hybrids showed reasonable deviation from that based on the magnitude of heterosis for most of the traits. This could be expected, since the *sca* effects are only estimates. The large *sca* effect need not necessarily result in exceptional performance of a cross.

The *sca* effects along with *per se* performance of hybrids gave an idea about the practical utility of hybrid combinations for heterosis breeding. Out of 64 hybrids, significant negative *sca* effects were recorded for days to 50% flowering, plant height and days to maturity respectively. Negative *sca* for the above mentioned characters were reported earlier by Sampoornam and Thiyagarajan (1998) Radhidevi *et al*. (2002) and Suresh and Reddy, (2002). Totally, 16 hybrids for number of tillers and productive tillers, six hybrids for panicle length, 10 hybrids for test weight, 19 hybrids for filled grains per panicle, 10 hybrids for 1000 grain weight and 18 hybrids for yield per plant recorded significantly positive *sca* effects. Similar type of postive *sca* effects were reported by Ramalingam *et al*. (1997), Sampoornam and Thiyagarajan (1998) and Radhidevi *et al*. (2002).

Among the top five ranking hybrids, the hybrid White ponni/Tadukan showed higher *sca* for days to flowering, plant height, days to maturity and filled grains per panicle. The hybrid TN 1/ARBN 97 showed higher *sca* effects for number of tillers, number of productive tillers and panicle

Table 9: Hybrids with high *sca* effects

Character	Five superior hybrids	*sca* value	GCA status
Days to 50% flowering	White ponni X Tadukan	-8.51**	High x Low
	BPT 5204 X IR 64	-6.20**	High x Low
	TN 1 X CB98002	-5.81**	Low x Low
	BPT 5204 X Columbia 2	-5.35**	High x Low
	BPT 5204 X ARBN 153	-4.72**	High x Low
Plant height (cm)	White Ponni X ARBN 142	-19.21**	High x Low
	BPT 5204 X CB 98006	-11.93**	Low x Low
	TN1 X CB 98004	-10.96**	Low x High
	IR 50 X Tadukan	-10.32**	Low x High
	White Ponni X Tadukan	-9.96**	High x Low
Number of tillers per plant	TN 1 X Milyang 46	14.67**	High x High
	IR 50 X CB98013	12.71**	High x Low
	IR 50 X TETEP	11.16**	High x Low
	TN1 X ARBN 97	10.17**	High x High
	White ponni X CB 98004	9.97**	Low x Low
Number of productive tillers per plant	IR 50 X Tetep	10.92**	High x Low
	TN 1 X ARBN 97	9.88**	Low x High
	White ponni X CB 98004	8.38**	Low x Low
	White ponni X ARBN 153	6.78**	Low x Low
	IR 50 X CB 98013	6.12**	High x High
Panicle length (cm)	BPT 5204 X CB 98004	3.45**	Low x High
	TN 1 X Moroberekan	2.86**	High x Low
	TN 1 X ARBN 97	2.56**	High x Low
	White ponni X Moroberekan	2.28**	High x Low
	BPT 5204 X Tetep	2.25**	Low x Low
Filled grains per panicle	White ponni X Tadukan	20.88**	High x Low
	IR 50 X ARBN 153	18.48**	Low x Low
	TN 1 X ARBN 97	18.41**	Low x Low
	BPT 5204 X CB 98002	16.28**	High x Low
	BPT 5204 X Columbia 2	15.98**	High x Low
Days to maturity	TN 1 X Tetep	-20.85**	Low x Low
	White ponni X ARBN 142	-9.03**	High x Low
	White ponni X Tadukan	-6.93**	High x Low
	White ponni X ARBN 144	-6.28**	High x Low
	IR 50 X IR 64	-4.49**	Low x Low
Test weight (g)	BPT 5204 XCB 98004	3.58**	Low x Low
	TN 1 X Moroberekan	2.16**	High x Low
	TNI X CB98002	1.79**	High x Low
	IR 50 X ARBN 153	1.75**	High x Low
	White ponni X ARBN 139	1.59**	High x Low
	BPT 5204 X CB 98006	10.57**	Low x Low
Grain yield per plant (g)	BPT 5204 X IR 64	7.94**	Low x High
	IR 50 X IR 64	7.49**	Low x High
	White ponni X ARBN 153	6.88**	Low x Low
	TN 1 X IR 64	5.85**	High x High

length. The hybrids TN 1/Tetep and BPT 5204 recorded higher *sca* effects for test weight and grain yield per plant (Table 9).

An examination of *gca* effects of parents and the *sca* effects of the resultant hybrids revealed that, it may not be possible to find a definite trend for all the traits in all the hybrids. However, in the present study when both the parents possessed significant positive *gca* effects, positive *sca* effects were discernible in the hybrids involving them in at least a few hybrids (data not shown).

Selection of hybrids combining superior *per se* performance, *sca* and heterosis is desirable in breeding programme to get satisfactory results. In the present investigation, among the top five ranking hybrids, IR 50/IR 64 was identified as a superior hybrid as it recorded higher magnitude of standard heterosis for maximum number of characters viz., days to flowering, number of tillers per plant, number of productive tillers per plant, panicle length, test weight and grain yield per plant. It also expressed superior performance (lesser) for duration. It also had high *sca* for most of the important traits viz., grain yield per plant and days to maturity. This hybrid also involved parents with high *gca* effects. The other promising hybrids which showed superior mean performance, *sca* effects and standard heterosis for most of the characters studied are TN 1/ARBN 97, White ponni/Taddukan, TN 1/IR 64, BPT 5204/IR 64, BPT 5204/ CB 98006 and IR 50/Milyang 46. Parents with high x high *gca* effects indicating the presence of additive x additive type of gene action between favourable alleles contributed by the two parents which was considered to be of fixable nature (Subbarao and Aruna, 1997). Thus these hybrids would be very much useful for further testing.

The magnitude of heterosis is a prerequisite for development of any hybrid. Before selecting a cross on the basis of *per se* performance it would be worthwhile to evaluate them for hybrid vigour for various characters. Knowledge on the extent of heterosis would help in the choice of the best crosses for commercial exploitation.

IR 50/CB 98013 was the most promising combination since it showed highly significant negative relative heterosis for days to 50% flowering. IR 50/CB 98013 recorded highly significant negative heterobeltiosis and IR 50/CB 98013 and IR 50/IR 64 recorded higher standard heterosis over ASD 16. Negative heterosis for days to 50% flowering is a desirable feature as confers earliness. Negative heterosis for this trait was reported by Thirumeni and Subramanian (2000) and Radhidevi *et al.* (2002).

Negative heterosis for plant height is highly desirable as it confers resistance to lodging. White ponni/ARBN 142 had shown highly significant negative relative heterosis and heterobeltiosis. BPT 5204/ARBN 153 had shown the highest value of negative standard heterosis over ASD 16.

Days to maturity determines the earlier harvest of the produces and earlier marketing. Highest value of significant positive relative heterosis, heterobeltiosis and standard heterosis was recorded by the hybrid TN 1/Te-tep over the standard check ASD 16. Positive heterosis for this trait had been reported earlier by Joshi *et al.* (2004). Test weight is one of the most important components of yield that influences the yield conspicuously. The highest value of relative heterosis (BPT 5204/CB 98013), heterobeltiosis (TN 1/Moroberekan) and standard heterosis (TN 1/IR 64) was recorded over the standard check ASD 16. The present observations are in accordance with the findings of Yolanda and Vijendra Das (1996), Seetharamiah *et al.* (1999) and Thirumeni and Subramanian (2000).

Most of the hybrids recorded positive significant standard heterosis values for grain yield per plant. IR 50/IR 64 recorded highest heterosis values for relative heterosis and TN 1/IR 64 recorded high heterobeltiosis and standard heterosis over the standard check ASD 16. The present observations are in accordance with the findings of Souframanien *et al.* (1998) and Radhidevi *et al.* (2002). The hybrids with higher standard heterosis were listed in Table 10.

The mean values, ranges of performance and heterosis of the 64 F_1 hybrids was given in Table 11. The degree of heterosis showed variation from trait to trait. For heterobeltiosis (heterosis over the better parent), No. of tillers/plant showed the highest heterosis (50.62%), followed by no.

Table 10: Hybrids with desirable standard heterotic expression for different traits

Character	Five superior hybrids	Standard heterosis	GCA status
Days to 50% flowering	IR 50 X IR 64	-3.05*	Low x Low
	IR 50 X CB98013	-3.05*	Low x Low
	IR 50 X Milyang 46	-3.05*	Low x Low
	IR 50 X ARBN 142	3.30*	Low x Low
	IR 50 X ARBN 144	4.06**	Low x Low
Plant height (cm)	BPT 5204 X ARBN 153	-7.09*	Low x Low
	BPT 5204 X CB 98013	6.84*	Low x Low
	IR 50 X CB98013	7.34*	Low x Low
	IR 50 X Tetep	7.34*	Low x Low
	IR 50 X Tadukan	9.11**	Low x High
Number of tillers per plant	TN 1 X Milyang 46	211.11**	High x High
	IR 50 X CB98013	201.11**	High x High
	IR 50 X Tetep	177.78**	High x Low
	IR 50 X IR 64	174.44**	High x High
	TN1 X IR 64	161.11**	High x High
Number of productive tillers per plant	IR 50 X IR 64	180.26**	High x High
	IR 50 X Tetep	177.63**	High x Low
	IR 50 X CB98013	172.37**	High x Low
	IR 50 X ARBN 144	160.53**	High x High
	TN 1 X ARBN 97	150.00**	Low x High
	BPT 5204 X IR 64	150.00**	Low x High
Panicle length (cm)	BPT 5204 X CB 98004	22.57**	Low x High
	IR 50 X IR 64	18.76**	Low x High
	TN 1 X Moroberekan	18.58**	High x Low
	TN 1X Milyang 46	17.70**	High x High
	White ponni X Moroberekan	16.81**	High x Low
Filled grains per panicle	TN1 X IR 64	46.80**	Low x High
	BPT 5204 X IR 64	45.21**	High x High
	BPT 5204 X CB 98002	34.00**	High x Low
	BPT 5204 X CB 98004	31.46**	High x High
	BPT 5204 X ARBN 97	30.02**	High x Low
Days to maturity	TN 1 X Tetep	-11.90**	Low x Low
	IR 50 X ARBN 97	2.93*	Low x Low
	IR 50 X ARBN 138	2.93*	Low x High
	IR 50 X CB 98006	2.93*	Low x Low
	IR 50 X Tetep	3.30**	Low x Low
Test weight (g)	IR 50 X IR 64	21.59**	High x High
	TNI X IR 64	22.49**	High x High
	TNI X Moroberekan	20.91**	High x Low
	IR 50 X ARBN 153	15.20**	High x Low
	TN 1 X ARBN 97	14.49**	High x High
Grain yield per plant (g)	TN 1 X IR 64	70.30**	High x High
	BPT 5204 X IR 64	58.30**	Low x High
	IR 50 X IR 64	50.99**	Low x High
	BPT 5204 X CB 98006	34.22**	Low x Low
	IR 50 X Milyang 46	30.81**	Low x High

Table 11: Mean values, ranges of performance and heterosis among the 64 F_1 hybrids

	Performance		MP heterosis (%)[1]		BP heterosis (%)[2]		Std. heterosis[3]	
Trait	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Days to 50 % flowering	97.39**	76.4 to 119.8	-2.6**	-17 to 14	-9.99**	-27.1 to 1.7	23.60**	-3.0 to 52.3
Plant height	95.90**	73.4 to 140.6	17.0**	4.5 to 50	9.14**	-19.8 to 42.0	21.40**	-7.0 to 78.0
No. of tillers/plant	31.16**	17.0 to 56.0	67.7**	-22.0 to 198	50.62**	-31.8 to 184	73.09**	-5.56 to 211
No.of productive tillers/plant	25.58**	14.4 to 42.6	57.2**	-18.5 to 167	42.88**	-21.0 to 160	68.28**	-5.26 to 180
Panicle length	23.21**	17.6 to 27.7	1.55	-22.9 to 18.7	2.56*	-28.0 to 15.4	3.15**	-22.1 to 22.5
No.of Filled grains/panicle	126.10**	94.0 to 162.4	9.15**	-30.1 to 52.2	1.16	-38.01 to 48.0	14.00**	-15.0 to 46.8
Days to maturity	127.56**	96.0 to 146.0	1.65*	-25.7 to 14.7	-7.02**	-30.0 to 9.26	16.81**	-11.9 to 34.2
1000 grain weight	19.76**	15.7 to 23.8	18.30*	-21.3 to 19.0	21.59**	-24.24 to 16.2	21.68**	-21.0 to 22.4
Grain yield/plant	27.97**	15.37 to 46.40	9.26**	-31.6 to 71.9	11.40**	-42.31 to 78.9	12.76**	-42.3 to 80.3

*,**Significant at p = 0.05 and p = 0.01, respectively. [1]-Mid-parent heterosis. [2]-Better-parent heterosis. [3]-Standard heterosis

of productive tillers / plant (42.88 %), 1000 grain weight (21.59 %) and grain yield / plant (11.40%). Days to flowering (-9.99 %) and days to maturity (-7.02 %) exhibited significant negative heterosis. However, better-parent heterosis of filled grains/panicle was not statistically significant although it ranged from -38 to 48%, depending on the crosses. Mid-parent heterosis for yield varied from-31.9 to 71.9 % in the hybrids. Better-parent heterosis for yield ranged between -42.31 and 78.9%. Days to 50 % flowering, when compared with other traits, exhibited a low level of heterosis. Standard heterosis was obtained by using the standard check (ASD 16) as control, which is a ruling variety for grain yield in Tamilnadu, India. Standard heterosis for yield varied from -42.3 to 80.3% in the hybrids.

Resistance to rice varieties to blast is governed mostly by dominant genes, but in few cases by recessive genes (Marchetti *et al*., 1987; Padmanabhan *et al*., 1973). An inhibitor gene was also reported by Woo (1965). Twenty six hybrids which excelled in yield parameters were screened in natural condition including the high yielding hybrids for partial leaf blast disease at Hybrid Research Evaluation Centre, Gudalur, India. Most of the hybrids were resistant except the combinations IR 50/ARBN 138 and TN 1/ARBN 138 which was susceptible. The hybrids IR 50/ARBN 97 and TN 1/ARBN 97 was moderately resistant for leaf blast reaction. The resistance in the hybrids might be due to the dominance reaction (Table 12). The parents had one or more resistance genes and the resistant gene expresses its dominance in the F_1 generation. Kiyosawa and Shiyomi (1970) reported that resistance of Toride 1 was controlled by a dominant gene *Pi-z (t)*. Yamada *et al*. (1976) identified a single resistant gene for blast fungus in nine cultivars. Padmanabhan *et al*. (1973) indicated that three dominant genes govern the resistance of the variety Zenith of which the two are complementary (*Pi-z* and *Pi-a*). The two complementary genes found in Zenith and in S.67 were allelic or same. Inheritance of resistance in Te-tep and Tadukan was found to be tri-genic. An inhibitory gene was found in the variety C.I. 5309. Kiyosawa (1981) identified 13 genes for complete resistance, none of which were recessive. Some studies, however, have identified recessive genes for blast resistance. Marchetti *et al*. (1987) identified a single recessive gene in the cultivar Gulfrose.

Two hybrids recorded moderate resistance reaction. Parlevliet (1988) described moderate resistance as an incomplete quantitative resistance based on minor genes. It is characterized by

Table 12: Disease reaction of high yielding hybrids to leaf blast incidence under natural screening at HRE,Gudalur

Hybrids	Score	Disease reaction
IR 50 X ARBN 97	5	MR
IR 50 X ARBN 138	9	S
IR 50 X IR 64**	3	R
IR 50 X CB 98013	3	R
IR 50 X Milyang-46**	3	R
IR 50 X Tetep	3	R
IR 50 X Tadukan	3	R
White Ponni X CB 98006	3	R
White Ponni X CB 98013	3	R
White Ponni X CB 98006	3	R
White Ponni X IR 64	3	R
White Ponni X Moroberekan	3	R
TN 1 X ARBN 97	5	MR
TN 1 X ARBN 138	9	S
TN 1 X CB 98006	3	R
TN 1 X CB 98013	3	R
TN 1 X IR 64**	3	R
TN 1 X Milyang 46	3	R
TN 1 X Moroberekan	3	R
TN 1 X Tadukan	3	R
BPT 5204 X IR 64**	3	R
BPT 5204 x CB98006**	3	R
BPT 5204 X CB 98013	3	R
BPT 5204 X Moroberekan	3	R
BPT 5204 X Tadukan	3	R
BPT 5204 X Tetep	3	R

** - indicating the crosses with high heterotic value for grain yield per plant

compatibility between the pathogen and plant with the reduced incidence of the disease. Genetic studies indicate that the partial resistance is under oligo or polygenic control and can be affected by the environment. Several researchers had also reported the role of minor genes in conferring disease resistance (Babugee and Gnanamanickam, 2000).

In conclusion, Incorporation of resistance to leaf blast is one of the important objectives of hybrid rice breeding without compromising the yield. For the success of such a breeding programme it is essential to know the variability in the disease expression of the resistant parents under varying environmental conditions and to know their genetic constitution.

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