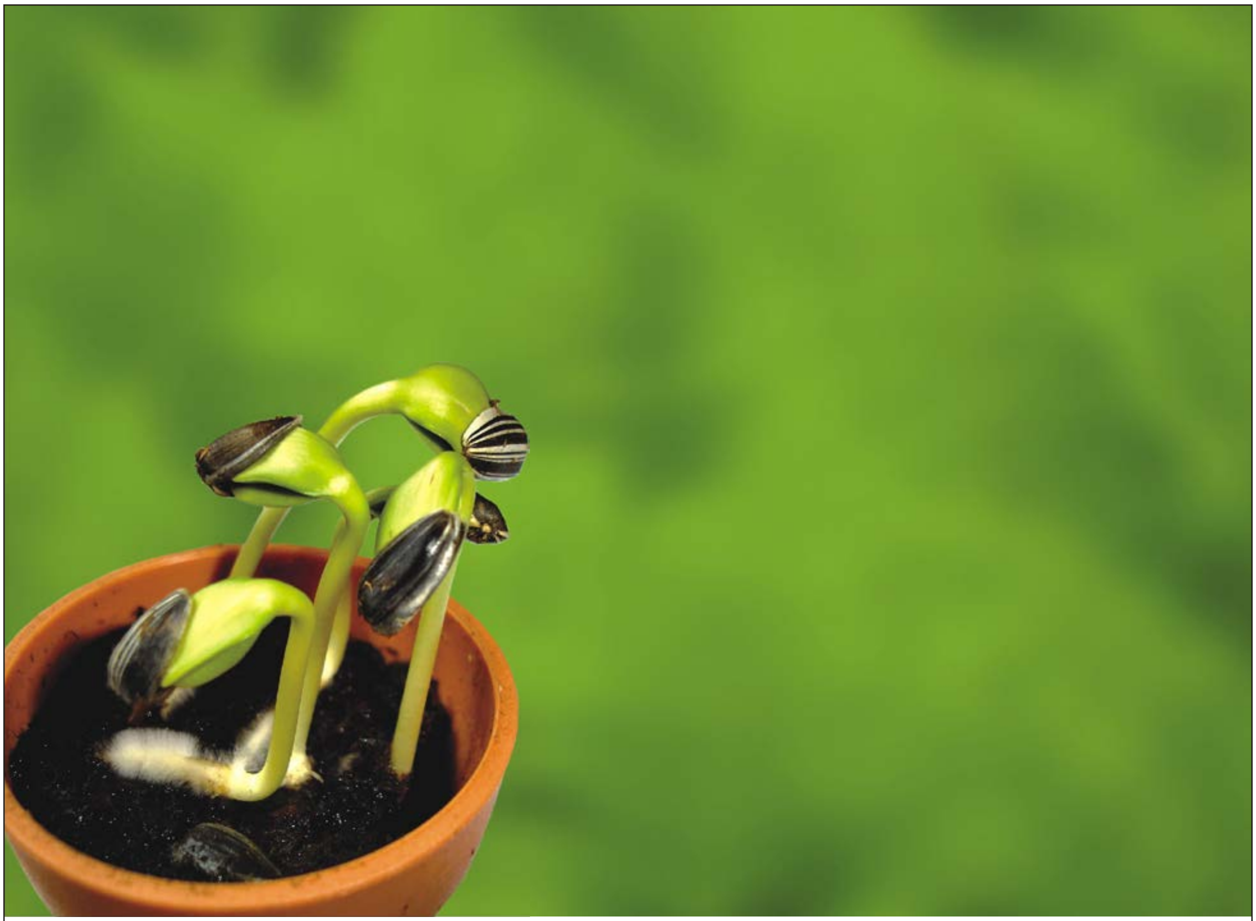

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Genotype×Environment Interaction and Stability for Yield and Its Components in Hybrid Rice Cultivars (*Oryza sativa* L.)

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ABSTRACT

The present investigation was conducted to evaluate 60 hybrid rice cultivars, their parents involving five cytoplasmic male sterile lines and 12 restorer lines along with five checks for their stability across three different agro-climatic zones in Andhra Pradesh, India during kharif 2009. Substantial portion of genotype×environment interaction was significant due to the linear component for panicle weight, number of productive tillers per plant, number of filled grains per panicle, 1000-grain weight and single plant yield indicated significant varibility among the experimentation could be predicted. It was also found that stability in single plant yield was due to plasticity and stability in yield components. From the current study, it is concluded that for yield and its important components the potential parents APMS 6A, IR-80559A, KMR-3R, BR-827-35R, IR-63883-41-3R and IR-21567R were stable. Among the hybrids, superior performing stable hybrids APMS 6 A×IR-24R, APMS 6 A×BR-827-35R, IR-80555A×IR-54742R, IR-80559A×IR-54742R, IR-80559A×KMR-3R and IR-80151A×IR-54742R manifested better performance than rest of hybrids due to having favorable combination of all stability parameters with significantly high mean performance levels over promising hybrid checks KRH-2 and PA-6201 for yield and its important components across the three different environmental conditions. Therefore, these hybrids may be recommended for multi-location trials in India before the commercial release.

Key words: Genetic homeostasis, plasticity, pooled analysis, regression coefficient, stability parameters, variance of deviation from regression

INTRODUCTION

Rice (*Oryza sativa* L.) is considered as one of the most important plants from Poaceae. Today, rice has special position as a source of providing over 75% of Asian population and more than three billion of world populations meal which represents 50 to 80% of their daily calorie intake (Khush, 2005; Amirjani, 2011). This population will increase to over 4.6 billion by 2050 (Honarnejad *et al.*, 2000) which demands more than 50% of rice needs to be produced what is produced present to cope with the growing population (Ashikari *et al.*, 2005; Srividya *et al.*, 2010).

The hybrid rice is being the new answer to the growing hunger of world population; by the way of its elevated yield potential, agronomic performance and disease resistance and release of hybrids is due in many rice growing areas (Cheng *et al.*, 2007). But, before releasing of these hybrids for cultivation, estimation of their adaptability and suitability for those areas is a prime step as hybrids show considerable amount of genotype×environment interaction. The presently cultivated varieties and hybrids though having high seed yield potential, they are erratic in their performance under varied conditions of cultivation. One of the reasons for slow progress in developing rice varieties and hybrids is the prevalence of large genotype×environment interactions which results from differences in the genotypic adaption and the heterogeneous environments (Fukai and Cooper, 1995). Since the advent of hybrid rice technology in the India, the rate of adoption has steadily increased. However, the research on the effects of heterogeneity on performance and stability of rice is limited. This warrants the attention of the plant breeders to evolve superior hybrids that would sustain well in the strainful situation. Young and Virmani (1990) and Panwar *et al.* (2008) also observed varying magnitude of heterosis over environments and stressed the need to evaluate hybrids across environments to identify stable hybrids with high yield that shows least interaction with environment.

Multi-location testing of genotypes provides an opportunity to plant breeders to identify the adaptability of a genotype to a particular environment and also stability of the genotype over different environments. There are a number of statistical methods for consideration of genotype×environment interaction and its relationship with stability. From all of these methods, regression of mean of each genotype on environmental index is one of the most applicable methods (Tesemma *et al.*, 1998). This method has been suggested by Finlay and Wilkinson (1963) modified by Eberhart and Russell (1966). For determining adaptability and stability of genotypes in this method, parameters like mean genotypes yield, regression coefficient (bi) and variance of deviation from regression (S^2di) are used. In this model various amounts of bi i.e., bi = 1, bi<1 and bi>1 are expressing average, high and low stability, respectively. According to this model, a genotype is encountered as the most stable that its regression coefficient is equal to unit, variance of deviation from regression is the least (non-significant with zero) and its average yield is highest.

Keeping the above in view, the current study determines the stability parameters of 60 hybrids of rice developed and evaluated at three different agro-climatic zones in Andhra Pradesh (A.P).

MATERIAL AND METHODS

The present experiment was carried out with 60 hybrids developed in a line×tester mating design (Kempthorne, 1957) involving five CMS lines as females and 12 restorer lines as the male parents. The hybrids between five female parents and 12 male parents were attempted during winter (rabi) season 2008-2009 at research farm, Directorate of Rice Research (DRR), Hyderabad (A.P) India. The resulting 60 F_1 hybrids along with their 17 parents and five checks (three hybrid checks viz., KRH-2, PA-6201 and DRRH-2 and two varietal checks viz., Jaya and IR-64) were evaluated during rainy (kharif) season 2009 at three different locations viz., Directorate of Rice Research, Hyderabad for Southern Telangana agro- climatic zone; Regional Agricultural Research Station, Warangal for Central Telangana agro-climatic zone and Regional Agricultural Research Station, Karimnagar for Northern Telangana agro-climatic zone. Crossed seeds were treated with Bavistin solution (0.1%) and kept for germination in Petri dishes. Satisfactory germination was observed on the 3rd and 4th day of soaking. The seedlings were transferred to small raised beds covered with a layer of sand, planted in lines and sufficient care was taken to avoid water logging and complete drying up of the nursery beds. The parent (Maintainer lines and Restorer lines) seed was soaked in water for 24 h and then incubated for 48 h. The germinated seeds were transferred to wet beds and proper care was taken to raise a healthy nursery in the first week of June. Top dressing was given with urea and need based plant protection was under taken for raising healthy and vigorous seedlings. Such healthy, strong and vigorous seedlings (One seedling per hill) of 28 days age were transplanted in the main field in the first week of July in a Randomized Block Design (RBD) with three replications by adopting a spacing of 20×15 cm. Fertilizers were applied to the main field at the rate of 100 Nitrogen, 40 Phosphorus and 60 kg^{-1} Murate of potash ha^{-1}. Nitrogen was applied in three split doses. One-fourth as basal, one-half at the time of active tillering stage and one-fourth at panicle initiation stage. Entire Phosphorus and Murate of potash were applied as single dose in the puddle soil. The recommended package of practices and necessary prophylactic measures were adopted to raise a healthy crop.

At flowering and maturity stages, observations were recorded on eight characters days to 50% flowering, panicle length, panicle weight, number of productive tillers per plant, number of filled grains per panicle and spikelet fertility percentage 1000-grain weight and single plant yield from five randomly selected plants in each entry in each replication.

Statistical analysis: The mean values for all the traits across the environments were subjected to stability analysis as suggested by Eberhart and Russell (1966) for various stability parameters i.e., mean (μ), regression coefficient (bi) and deviation from their regression (S^2di) to get the individual genotype response by partitioning the pooled deviation. The significance of the stability parameters i.e., bi, its deviation from unity and deviation from regression were tested by using appropriate t and F tests. Data were analyzed using IndoStat software (IndoStat Inc. Hyderabad, India).

RESULTS AND DISCUSSION

In the present investigation, 82 genotypes including 60 hybrids, 17 parents and five checks were subjected to pooled analysis of variance for the eight characters (Table 1). The pooled analysis of variance revealed that genotype×environment interactions were significant for five characters panicle weight, number of productive tillers per plant, number of filled grains per panicle and 1000-grain weight and single plant yield implying differential response of genotypes under three locations for these characters. Similar reports were earlier made by Hegde and Vidyachandra (1998), Bughio *et al.* (2002), Arumugam *et al.* (2007), Panwar *et al.* (2008) and Ramya and Senthilkumar (2008). The genotype×environment interactions for the remaining three characters days to 50% flowering, panicle length and spikelet fertility percentage were found to be non-significant. Therefore, further analysis of stability was not carried out for these three characters. Significant variation due to environments represented adequate heterogeneity among the

Table 1: Pooled analysis of variance across three environments for yield and its components for stability in rice

Source	d.f	Days to 50% flowering	Panicle length (cm)	Panicle weight (g)	No. of productive tillers/plant	No. of filled grains/panicle	Spikelet fertility (%)	1000-grain weight (g)	Single plant yield (g)
Genotypes (G)	81	100.97**	4.90**	1.09**	7.55**	2717.52**	41.23**	6.46**	96.99**
E+(G×E)	164	1.44	1.56	0.18**	1.10**	514.85**	15.82	0.30*	15.08**
Environments (E)	2	14.52**	51.44**	2.32**	12.00**	5859.23**	91.59**	0.11	201.28**
G×E	162	1.28	0.94	0.16**	0.96*	448.87*	14.88	0.31*	12.78*
E (linear)	1	29.05**	102.88**	4.64**	24.00**	11718.45**	183.17**	0.22	402.55**
G×E (linear)	81	1.49	0.67	0.22**	1.30**	574.19**	16.44	0.39*	16.51**
Pooled Deviation	82	1.06**	1.20**	0.09**	0.61**	319.60**	13.16**	0.22*	8.95**
Pooled Error	486	0.19	0.18	0.04	0.24	68.88	6.61	0.15	3.04

*Significant at 5% level ;**Significant at 1% level environments for all the component characters except 1000-grain weight. Partitioning of mean sum of squares in to that of genotypes, environments+(genotypes×environments) and pooled error revealed that genotypes were highly significant for all the characters studied, indicating the presence of genetic variability in the experimental material under investigation. Mean sum of squares due to environments+(genotypes×environments) were significant for the characters panicle weight, number of productive tillers per plant, number of filled grains per panicle,1000-grain weight and single plant yield depicted the distinct nature of environments and genotype× environment interaction on phenotype expression. These findings are in conformity with Young and Virmani (1990), Deshpande and Dalvi (2006), Panwar *et al.* (2008), Ramya and Senthilkumar (2008) and Krishnappa *et al.* (2009). The linear component of genotype× environment interaction was highly significant than non-linear component of genotype× environment interaction for the characters panicle weight, number of productive tillers per plant, number of filled grains per panicle, 1000-grain weight and single plant yield. This indicated significant differences among the genotypes for linear response to environments (bi) behavior of the genotypes could be predicted over environments more precisely and genotype×environment interaction was predominantly outcome of the linear function of environmental components. Hence, prediction of performance of genotypes based on stability parameters would be feasible and reliable. This is in accordance with previous reports on rice by Lohithaswa *et al.* (1999), Panwar *et al.* (2008), Ramya and Senthilkumar (2008) and Krishnappa *et al.* (2009) for yield and its components.

In the present study the mean performance coupled with the regression coefficient (bi) and variance of deviation from regression (S^2di) of each genotype represented its stability (Table 2, 3 and 4). With these conditions, the parents and hybrids were classified and discussed for their adaptability and stability in respect of yield and its component characters studied.

Table 2: Mean performance and stability parameters for panicle weight and number of productive tillers per plant in rice

	Panicle weight (g)			No. of productive tillers per plant		
Parent/Cross	Mean	bi	S^2di	Mean	bi	S^2di
Lines						
IR-80151 A	3.291	-0.164	0.001	8.267	1.657	-0.131
IR-80555 A	3.200	1.985	0.003	8.044	1.310	-0.209
IR-80559 A	3.671	1.759	-0.029	8.356	0.353	-0.241
IR-80561 A	2.847	2.525	-0.039	7.689	0.954	-0.222
APMS 6 A	3.976	0.552	-0.039	8.489	0.203	-0.207
Testers						
IR-66 R	3.231	0.981	0.114	7.911	1.315	0.321
IR-10198 R	3.480	1.220	-0.042	8.311	0.855	-0.240
DR-714 -1- 2R	3.107	2.479	-0.025	7.489	0.349	-0.133
IR-40750R	3.231	0.974	0.065	7.467	0.597	0.195
IR-72R	3.556	1.970	-0.009	8.400	1.361	-0.136
IR-24R	3.527	1.867	0.024	8.244	-0.492	1.041*
IR-21567 R	3.938	1.514	0.036	8.178	-0.641	1.631**
KMR-3 R	3.904	2.195	0.116	8.822	-0.102	-0.207
IR-32809 R	3.242	1.273	-0.015	7.711	0.865	0.732*
IR-63883-41-3R	4.064	-2.031*	-0.040	8.378	-0.646	0.403
IR-54742 R	4.289	-1.524*	-0.042	8.689	0.351	-0.222
BR-827-35 R	4.080	-1.240	0.054	8.622	-0.101*	-0.243
Crosses						
IR-80151A×IR- 66 R	3.982	0.548	-0.034	8.867	2.560	0.034

Table 2: Countinued

	Panicle weight (g)			No. of productive tillers per plant		
Parent/Cross	Mean	bi	S^2di	Mean	bi	S^2di
IR-80151A×IR-10198 R	4.731	1.154	-0.042	10.889	-0.399	-0.100
IR-80151A×DR-714-1-2 R	4.544	2.779	-0.002	11.067	0.449	-0.062
IR-80151A×IR-40750 R	3.642	-0.716	0.026	8.489	-0.712	0.323
IR-80151A×IR-72 R	3.633	4.090	0.337**	8.467	3.611	1.061*
IR-80151A×IR-24 R	4.551	-1.029	-0.024	10.300	2.483	0.234
IR-80151A×IR-21567 R	4.693	3.122**	-0.042	10.356	4.876	-0.124
IR-80151A×KMR-3 R	4.833	-2.019	-0.016	11.667	0.155	-0.063
IR-80151A×IR-32809 R	3.224	-1.254	0.201	8.156	-1.471	1.367*
IR-80151A×IR-63883-41-3 R	4.818	-2.155	0.088	11.222	-1.470	0.924*
IR-80151A×IR-54742 R	5.478	0.558	0.919**	12.156	0.059	0.559
IR-80151A×BR-827-35 R	4.980	-1.709	-0.028	11.933	-0.606	-0.208
IR-80555A×IR-66 R	3.580	1.339	-0.004	8.133	2.419	-0.027
IR-80555A×IR-10198 R	3.844	4.674	0.241	10.267	6.792*	-0.242
IR-80555A×DR-714-1-2 R	4.698	-2.870	0.057	10.800	-1.227	3.663**
IR-80555A×IR-40750 R	3.622	1.146	-0.007	8.444	3.271	-0.225
IR-80555A×IR-72 R	4.127	-0.487	0.384**	9.556	3.532	1.014*
IR-80555A×IR-24 R	4.120	4.213	0.250**	10.522	5.246	0.915*
IR-80555A×IR-21567 R	4.791	-1.540	-0.035	10.244	-0.058	0.399
IR-80555A×KMR-3 R	4.387	-0.424	0.002	11.718	-1.096	-0.036
IR-80555A×IR-32809 R	3.598	-0.219	-0.042	7.711	2.222	0.467
IR-80555A×IR-63883-41-3 R	3.978	3.654	0.092	9.489	3.678	0.120
IR-80555A×IR-54742 R	5.018	-1.536	-0.039	12.333	-1.206	-0.233
IR-80555A×BR-827-35 R	4.642	2.765*	-0.042	12.178	-1.853	0.569
IR-80559A×IR-66 R	3.638	3.242	0.079	7.978	2.361	-0.129
IR-80559A× IR-10198 R	4.151	-2.148	0.071	9.244	-0.956	-0.241
IR-80559A×DR-714-1-2 R	4.184	-2.728	0.679**	9.711	-2.455	0.751*
IR-80559A×IR-40750 R	3.764	0.464	-0.040	8.669	1.511	-0.157
IR-80559A×IR-72 R	4.273	2.286	0.014	10.911	5.233*	-0.236
IR-80559A×IR-24 R	4.404	2.970	0.038	10.711	3.263	0.271
IR-80559A×IR-21567 R	4.673	3.578	0.082	11.644	4.941	1.005*
IR-80559A×KMR-3 R	5.038	-0.636	0.026	11.933	-0.455	-0.188
IR-80559A×IR-32809 R	4.007	5.815*	-0.042	10.356	4.116	0.669
IR-80559A×IR-63883-41-3 R	4.193	1.374	0.083	11.067	-3.316	-0.093
IR-80559A×IR-54742 R	5.013	0.151	-0.011	13.756	2.177	1.875**
IR-80559A×BR-827-35 R	4.507	0.470	0.037	11.778	-2.150	1.643**
IR-80561A×IR-66 R	3.529	-0.342	-0.041	7.756	1.565	0.022
IR-80561A×IR-10198 R	3.580	2.713	-0.017	9.622	3.080	1.125*
IR-80561A×DR-714-1-2 R	3.156	-0.600*	-0.042	7.889	-0.715	1.033*
IR-80561A×IR-40750 R	3.351	3.928	0.320**	9.000	2.729	1.479**
IR-80561A×IR-72 R	3.193	2.713	-0.017	8.711	2.656	0.950*
IR-80561A×IR-24 R	3.404	0.902	-0.025	8.282	1.541	-0.121
IR-80561A×IR-21567 R	4.160	-1.166	-0.025	11.356	-2.069	0.126
IR-80561A×KMR-3 R	4.707	-0.783	-0.009	11.867	-1.660*	-0.240
IR-80561A×IR-32809 R	4.458	-0.987	-0.036	11.533	1.061	-0.065
IR-80561A×IR-63883-41-3 R	3.576	-2.865*	-0.041	9.867	-2.271	0.248
IR-80561A×IR-54742 R	4.880	-0.766	-0.040	12.622	0.061	0.933*

Table 2: Countinued

	Panicle weight (g)			No. of productive tillers per plant		
Parent/Cross	Mean	bi	S^2di	Mean	bi	S^2di
IR-80561A×BR-827-35 R	4.829	1.492	-0.015	11.956	1.402	0.198
APMS 6A×IR-66 R	3.536	1.290	-0.020	8.622	0.803	-0.206
APMS 6A×IR-10198 R	4.240	5.048	0.122*	10.800	6.054	2.904**
APMS 6A×DR-714-1-2 R	4.620	3.109	-0.001	11.053	1.789	0.517
APMS 6A×IR-40750 R	3.729	2.203	0.154*	8.933	3.000	3.346**
APMS 6A×IR-72 R	3.742	4.430	0.005	9.844	3.729	0.179
APMS 6A×IR-24 R	4.860	1.963	-0.033	12.533	0.301	-0.234
APMS 6A×IR-21567 R	4.153	1.753	0.629**	10.456	1.773	1.451**
APMS 6A×KMR-3 R	4.927	0.229	-0.036	12.311	-0.354	-0.188
APMS 6A×IR-32809 R	4.338	2.351	-0.025	10.289	1.401	0.332
APMS6A×IR-63883-41-3 R	4.567	2.936	-0.023	10.244	2.967	-0.220
APMS 6A×IR-54742 R	5.278	0.730	-0.042	12.156	-1.006*	-0.243
APMS 6A×BR-827-35 R	4.878	0.897	0.025	12.311	0.102	-0.207
Checks						
PA-6201	4.269	0.445	0.075	10.578	1.150	0.262
KRH-2	4.238	0.797	-0.030	10.333	-0.150*	-0.240
DRRH-2	4.171	0.508	-0.015	9.756	0.799	0.080
JAYA	3.947	2.391	-0.033	8.622	-2.212	-0.205
IR-64	3.418	1.420	-0.038	9.333	0.757	-0.188
C.D (p = 0.05)	0.580			1.352		

*Significant at 5% level ;**Significant at 1% level

Table 3: Mean performance and stability parameters for number of filled grains per panicle and 1000-grain weight in rice

	No. of filled grains per panicle			1000-grain weight (g)		
Parent/Cross	Mean	bi	S^2di	Mean	bi	S^2di
Lines						
IR-80151 A	139.756	0.655	-67.908	21.909	-6.519	-0.145
IR-80555 A	143.711	1.492	-49.161	20.733	-14.373	0.084
IR-80559 A	148.578	0.948	-56.752	23.064	0.288	-0.138
IR-80561 A	127.287	2.204	6.851	21.240	-1.070	-0.085
APMS 6 A	193.689	1.834	3.711	19.711	20.772	-0.100
Testers						
IR-66 R	125.622	2.386	-3.742	22.491	13.399*	-0.152
IR-10198 R	142.289	-0.214	158.605	23.691	4.713	-0.142
DR-714-1-2 R	133.178	-0.621	-49.286	20.633	6.747	-0.131
IR-40750 R	133.778	1.522	83.029	23.051	13.226	-0.149
IR-72 R	145.489	1.971	7.265	23.566	6.041	-0.066
IR-24 R	149.622	0.286	58.118	23.853	-0.536	-0.151
IR-21567 R	144.600	1.271	5.047	24.053	9.482	-0.152
KMR-3 R	159.711	1.195	39.230	22.766	6.469	-0.103
IR-32809 R	132.333	-0.227	71.269	23.336	-10.185	-0.138
IR-63883-41-3 R	148.629	0.420	197.968*	25.372	4.547	3.880**
IR-54742 R	151.800	1.002	-9.622	26.907	-9.596*	-0.152
BR-827-35 R	141.756	0.530	136.759	26.404	-0.707	-0.041

Table 3: Countinued

	No. of filled grains per panicle			1000-grain weight (g)		
Parent/Cross	Mean	bi	S^2di	Mean	bi	S^2di
Crosses						
IR-80151A×IR-66 R	149.000	1.344	404.404**	23.218	9.367	1.097**
IR-80151A×IR-10198 R	188.422	-0.586	181.133	23.893	-3.743	-0.136
IR-80151A×DR-714-1-2 R	187.178	-1.684	173.957	22.733	17.430	-0.144
IR-80151A×IR-40750 R	139.911	-1.294	-41.897	23.069	-18.807*	-0.147
IR-80151A×IR-72 R	134.511	2.663	944.531**	23.353	-22.862*	-0.057
IR-80151A×IR-24 R	166.267	-2.247	26.204	23.631	9.916	-0.149
IR-80151A×IR-21567 R	197.578	5.424	54.480	24.173	26.793*	-0.152
IR-80151A×KMR-3 R	192.000	-2.729	77.585	26.603	-8.471	0.211
IR-80151A×IR-32809 R	136.911	-1.031*	-68.203	22.384	-37.711	0.226
IR-80151A×IR-63883-41-3 R	188.422	-1.091	85.246	24.147	7.874	-0.142
IR-80151A×IR-54742 R	224.911	-1.827	-16.139	27.438	19.111	-0.137
IR-80151A×BR-827-35 R	209.156	-2.738	222.524**	25.089	-2.905	-0.151
IR-80555A×IR-66 R	132.067	2.043*	-68.504	23.349	-5.825	0.190
IR-80555A×IR-10198 R	153.444	4.360	534.849**	24.384	10.519	0.501*
IR-80555A×DR-714-1-2 R	186.822	-1.876	1123.985**	22.487	16.896	-0.107
IR-80555A×IR-40750R	136.778	2.076	-42.981	23.282	-12.967	0.065
IR-80555A×IR-72 R	154.111	1.546	1206.560**	23.800	-16.698	0.124
IR-80555A×IR-24 R	169.711	2.753	-65.403	24.336	2.032	-0.151
IR-80555A×IR-21567 R	203.436	-3.480	-4.658	23.389	20.704	0.322
IR-80555A×KMR-3 R	187.400	-1.952	-7.391	23.547	17.603	-0.132
IR-80555A×IR-32809 R	123.111	1.457	478.689*	23.376	-22.165	-0.135
IR-80555A×IR-63883-41-3 R	163.267	3.728	1730.808**	24.240	11.083	-0.074
IR-80555A×IR-54742 R	216.133	-0.105	-63.396	25.938	17.095	-0.145
IR-80555A×BR-827-35 R	181.867	2.545	-14.568	25.122	1.127	-0.150
IR-80559A×IR-66 R	131.356	0.648	61.012	23.787	-1.851	-0.070
IR-80559A×IR-10198 R	136.533	-1.050	200.129*	24.267	-4.909	-0.152
IR-80559A×DR-714-1-2 R	149.822	-0.784	125.486	23.922	-5.096	-0.066
IR-80559A×IR-40750 R	134.578	0.255	-67.302	23.744	-7.518	0.826*
IR-80559A×IR-72 R	183.444	3.426	201.742*	24.422	4.260	-0.132
IR-80559A×IR-24 R	172.400	1.983	8.735	24.182	2.516	0.843*
IR-80559A×IR-21567 R	197.356	5.058	1227.297**	24.081	4.933	-0.149
IR-80559A×KMR-3 R	223.978	1.403	332.817*	24.331	-3.356	0.809*
IR-80559A×IR-32809 R	187.978	3.748	865.486**	24.118	6.974	-0.151
IR-80559A×IR-63883-41-3 R	172.111	-1.034	1854.342**	25.220	22.358	-0.063
IR-80559A×IR-54742 R	205.644	2.184	91.075	27.352	6.229	0.108
IR-80559A×BR-827-35 R	184.111	-0.936	-61.474	26.031	-0.952	0.022
IR-80561A×IR-66 R	124.578	1.186	-43.685	22.389	-0.661	-0.151
IR-80561A×IR-10198 R	154.667	2.768	355.167	23.213	-4.165	-0.132
IR-80561A×DR-714-1-2 R	136.067	-0.444	-64.902	21.267	-18.447	0.025
IR-80561A×IR-40750 R	138.711	2.184	893.102**	22.224	-14.626	-0.071
IR-80561A×IR-72 R	134.711	1.506	-33.993	23.833	-2.285	-0.133
IR-80561A×IR-24 R	134.778	1.521	-13.101	22.998	8.812	-0.124
IR-80561A×IR-21567 R	162.067	-2.178	103.134	23.227	-11.947	0.244
IR-80561A×KMR-3 R	212.711	-0.197	1348.332**	23.476	-10.472	0.018
IR-80561A×IR-32809 R	190.267	-0.006	-23.194	23.742	8.198	-0.151

Table 3: Countinued

	No. of filled grains per panicle			1000-grain weight (g)		
Parent/Cross	Mean	bi	S^2di	Mean	bi	S^2di
IR-80561A×IR-63883-41-3 R	150.202	-0.885*	-67.767	23.789	-6.877	0.412
IR-80561A×IR-54742 R	185.778	-0.064*	-68.668	26.949	-2.764	-0.150
IR-80561A×BR-827-35 R	196.733	1.986	2613.786**	25.380	13.410	-0.152
APMS 6A×IR-66 R	133.889	0.915	-61.664	22.871	-9.045	-0.081
APMS 6A×IR-10198 R	199.178	7.060	-16.201	22.789	0.725	0.048
APMS 6A×DR-714-1-2 R	201.067	2.656	-9.823	21.433	-25.037	-0.133
APMS 6A×IR-40750 R	149.978	0.626	134.968	23.264	5.336	-0.127
APMS 6A×IR-72 R	171.089	4.323	1399.202**	23.429	4.836	-0.056
APMS 6A×IR-24 R	217.600	1.409	-64.702	23.491	6.432	0.348
APMS 6A×IR-21567 R	177.156	3.008	1607.641**	23.229	6.940	0.178
APMS 6A×KMR-3 R	216.931	2.164	-5.313	22.536	20.615	-0.128
APMS 6A×IR-32809 R	177.067	3.966	41.975	23.369	1.898	0.481*
APMS6A×IR-63883-41-3 R	189.356	3.044	-57.783	23.740	14.097	0.046
APMS 6A×IR-54742 R	231.000	-1.296	24.600	25.036	-0.580	1.269**
APMS 6A×BR-827-35 R	238.044	-0.830	-56.435	25.022	2.652	-0.094
Checks						
PA-6201	168.133	1.947	31.373	23.629	1.945	-0.152
KRH-2	173.222	1.276	252.741*	23.196	-7.440	-0.135
DRRH-2	156.711	1.114	162.483	23.751	3.263	-0.141
JAYA	139.656	2.380	-59.613	26.460	-11.891	-0.037
IR-64	130.667	2.006	30.203	25.189	7.400	-0.134
C.D (p = 0.05)	23.094			1.092		

* Significant at 5% level ; ** Significant at 1% level

Table 4: Mean performance and stability parameters for single plant yield in rice

	Single plant yield (g)		
Parent/Cross	Mean	bi	S^2di
Lines			
IR-80151 A	17.062	0.611	-2.783
IR-80555 A	18.236	1.081	-2.960
IR-80559 A	19.896	0.937	-2.553
IR-80561 A	15.564	1.229	-0.095
APMS 6 A	19.533	0.665	-2.251
Testers			
IR-66 R	16.689	1.945	-2.913
IR-10198 R	18.511	0.573	-2.580
DR-714-1-2 R	16.289	-0.099	-2.308
IR-40750 R	15.489	1.004	-2.589
IR-72 R	17.827	1.276	-2.382
IR-24 R	18.889	0.601	0.601
IR-21567 R	19.064	1.355	6.156
KMR-3 R	20.644	-0.088	-2.977
IR-32809 R	15.404	1.185	-2.707
IR-63883-41-3 R	19.369	0.288	3.953
IR-54742 R	20.764	0.049*	-3.025

Table 4: Countinued

	Single plant yield (g)		
Parent/Cross	Mean	bi	S^2di
BR-827-35 R	20.273	-0.131	-2.414
Crosses			
IR-80151A×IR- 66 R	23.453	3.279	1.509
IR-80151A×IR-10198 R	30.131	-0.535	4.654
IR-80151A×DR-714-1-2 R	30.953	-0.740	-2.585
IR-80151A×IR-40750 R	20.240	-1.669	0.029
IR-80151A×IR-72 R	21.129	2.811	125.415**
IR-80151A×IR-24 R	30.769	-0.910	-2.218
IR-80151A×IR-21567 R	28.327	4.873	2.194
IR-80151A×KMR-3 R	31.051	-0.452	7.119
IR-80151A×IR-32809 R	17.333	-1.026	0.296
IR-80151A×IR-63883-41-3 R	30.494	-0.407	6.022
IR-80151A×IR-54742 R	32.711	-0.632	-1.273
IR-80151A×BR-827-35 R	31.536	-1.073	-0.972
IR-80555A×IR-66 R	19.524	2.880	-2.483
IR-80555A×IR-10198 R	24.178	4.886	77.182**
IR-80555A×DR-714-1-2 R	30.109	-1.792	0.26
IR-80555A×IR-40750R	19.342	3.372	2.92
IR-80555A×IR-72 R	22.124	4.116	21.516**
IR-80555A×IR-24 R	26.691	3.695	35.330**
IR-80555A×IR-21567 R	30.878	-0.847	0.633
IR-80555A×KMR-3 R	30.160	-1.641*	-2.844
IR-80555A×IR-32809 R	15.653	1.595	-1.857
IR-80555A×IR-63883-41-3 R	23.247	4.899	7.552
IR-80555A×IR-54742 R	33.284	0.331	-2.199
IR-80555A×BR-827-35 R	30.133	1.592	-2.823
IR-80559A×IR-66 R	18.418	3.083	-2.676
IR-80559A×IR-10198 R	23.538	-1.333	35.927**
IR-80559A×DR-714 -1-2 R	23.971	-0.499	34.182**
IR-80559A×IR-40750 R	18.758	1.712	-0.398
IR-80559A×IR-72 R	27.969	2.444	-1.167
IR-80559A×IR-24 R	28.567	1.154	0.343
IR-80559A×IR-21567 R	30.220	2.728	13.560*
IR-80559A×KMR-3 R	32.819	-0.138	-1.602
IR-80559A×IR-32809 R	26.800	4.407	-1.459
IR-80559A×IR-63883-41-3 R	29.147	-0.282	33.627**
IR-80559A×IR-54742 R	33.067	1.547	-3.016
IR-80559A×BR-827-35 R	30.484	-0.849	18.867**
IR-80561A×IR-66 R	18.118	2.379*	-3.018
IR-80561A×IR-10198 R	22.704	3.823	-2.204
IR-80561A×DR-714-1-2 R	18.378	-2.090	-2.219
IR-80561A×IR-40750 R	21.173	4.303	26.789**
IR-80561A×IR-72 R	20.238	1.000	39.153**
IR-80561A×IR-24 R	20.753	1.522	13.277*
IR-80561A×IR-21567 R	28.562	-1.232	-2.687
IR-80561A×KMR-3 R	31.726	-0.942	-1.586

Table 4: Countinued

	Single plant yield (g)		
Parent/Cross	Mean	bi	S^2di
IR-80561A×IR-32809 R	30.236	-0.368	6.873
IR-80561A×IR-63883-41-3R	25.449	-1.545	-2.411
IR-80561A×IR-54742 R	31.224	-0.627	1.744
IR-80561A×BR-827-35 R	31.780	0.595	1.392
APMS 6A×IR-66 R	19.827	2.566	2.278
APMS 6A×IR-10198 R	29.022	5.516	12.132*
APMS 6A×DR-714-1-2 R	30.956	1.480	-2.962
APMS 6A×IR-40750 R	22.309	1.622	32.388**
APMS 6A×IR-72 R	24.558	4.828	-1.014
APMS 6A×IR-24 R	33.904	0.660	-2.761
APMS 6A×IR-21567 R	28.040	0.974	8.271
APMS 6A×KMR-3 R	31.484	0.342	-1.615
APMS 6A×IR-32809 R	27.553	1.777	-2.654
APMS 6A×IR-63883-41-3 R	29.101	2.316	-2.114
APMS 6A×IR-54742 R	34.333	-0.577*	-2.973
APMS 6A×BR-827-35 R	33.692	-0.150	-2.069
Checks			
PA-6201	27.116	0.252	-0.584
KRH-2	27.404	0.325	-0.484
DRRH-2	26.360	0.061	-1.070
JAYA	22.651	0.320	-1.504
IR-64	22.051	-0.191	1.570
C.D (p = 0.05)	4.850		

*Significant at 5% level; ** Significant at 1% level

Panicle weight is positively associated with grain yield and is known to contribute grain yield *via* more number of filled grains per panicle. Regarding this trait, the results indicated that the genotype×environment interaction was due to both linear and non-linear components. Only the non-linear component of genotype×environment was significant for the panicle weight alone was considered in the interpretation for stability (Hegde and Vidyachandra, 1998). Among parents, the lines APMS 6A (3.976 g) and IR-80559A (3.671 g) recorded maximum panicle weight with minimum deviation from regression line and regression coefficient value was around unity, hence they are considered to be widely adaptable to differing environmental conditions. The testers IR-54742R (4.289 g) and IR-63883-41-3R (4.064 g) displayed the highest panicle weight which were on par with the best check, PA-6201 (4.269 g) supplemented with less than unit regression coefficient (bi) values and non-significant S^2di values, so specifically adapted to the poor environments while the testers BR-827-35R (4.080 g), IR-21567R (3.938 g) and KMR-3R (3.904 g) exhibited higher panicle weight with unit regression coefficient (bi) value and non-significant deviation from regression line and are rated as widely adaptable. Among the hybrids, nine hybrids APMS 6A×IR-54742R (5.278 g), IR-80559A×KMR-3R (5.038 g), IR-80555A×IR-54742R (5.018 g), IR-80559A×IR-54742R (5.013 g), IR-80151A×BR-827-35 R (4.980 g), APMS 6A×KMR-3R (4.927 g), APMS 6A×BR-827-35 R (4.878 g), IR-80561A×IR-54742R (4.880 g) and APMS 6A×IR-24R (4.860 g) exhibited significantly higher panicle weight than the best check PA-6201 (4.269 g) along with non-significant deviation from regression and unit regression coefficient (bi) values and hence, possess the average stability and are widely adaptable over three locations. Three hybrids IR-80151A×IR-21567R (4.693 g), IR-80555A×BR-827-35R (4.642 g) and IR-80559A ×IR-32809R (4.007g) were statistically on par with the best check PA-6201 (4.269 g) and recorded non-significant S^2di values and hence, are adaptable for favourable environments since exhibiting less than average stability (Table 2).

Number of productive tillers per plant is known to directly contribute towards grain yield can be exploited. More number of productive tillers more will be the yield and vice versa. Both linear and non-linear components of genotype×environment interactions were found to be significant for this trait. These present findings were in agreement with earlier investigations of Ramya and Senthilkumar (2008) and Krishnappa *et al.* (2009) while significance of non-linear component was reported by Rajanna and Arumugam *et al.* (2007). The highest number of productive tillers were obtained from the lines APMS 6A (8.489) and IR-80559A (8.356) and testers KMR-3R (8.822), IR-54742R (8.689), IR-72R (8.400), IR-63883-41-3R (8.378) and IR-10198R (8.311) manifested non-significant deviation from regression with average stability due to around unit bi values, so these parents are widely adaptable. The tester BR-827-35R (8.622) alone expressed less than one bi value displaying more than average stability and non-significant S^2di value and hence, found to be adaptable to poor environments. Nine hybrids APMS 6A×IR-24R (12.533), IR-80555A×IR-54742R (12.333), APMS 6A×BR-827-35R (12.311), APMS 6A×KMR-3R (12.311), IR-80555A×BR-827-35 R (12.178), IR-80151A×IR-54742R (12.156), IR-80561A×BR-827-35 R (11.956), IR-80559A ×KMR-3R (11.933) and IR-80151A×BR-827-35R (11.933) possessed significantly higher number of productive tillers per plant than the best check PA-6201 (10.578) accompanied by responsiveness around unity and non- significant S^2di values are considered to be stable for wider environments. The hybrids APMS6A×IR-54742R (12.156) and IR-80561A×KMR-3R (11.867) recorded less than one regression line (bi) values expressing more than average stability and higher mean than the best check PA-6201 and hence, are adapted specifically to poor environments with non-significant S^2di values. The parameters more than unity regression coefficient (bi) value, higher mean than the best check PA-6201 (10.578) and non-significant S^2di value were realized from the hybrid IR-80559A×IR-72R (10.711) and hence, is adapted to favourable environments (Table 2).

With regard to most important yield contributing trait number of filled grains per panicle, both linear and non-linear components of genotype×environment interactions were found to be significant which were in conformity with the observations made earlier by Ramya and Senthilkumar (2008). Whereas significance of non-linear component was reported by Lohithaswa *et al.* (1999) and Deshpande and Dalvi (2006). The line APMS 6A (193.689) scored higher number of filled grains per panicle over the best check KRH-2 (173.222). This line possessed unit regression line slope value (bi) exhibiting non-significant S^2di values and is adaptable to wider environments. Eleven cross combinations APMS 6A×BR-827-35R (238.044) APMS 6A×IR-54742R (231.000) IR-80151A×IR-54742R (224.911) APMS 6A×IR-24R (217.600) APMS 6A×KMR-3R (216.931) IR-80555A×IR-54742R (216.133) IR-80559A×IR-54742R (205.644) IR-80555A×IR-21567R (203.436) APMS 6A×DR-714-1-2R (201.067) APMS 6A×IR-10198R (199.178) and IR-80151A×IR-21567R (197.578) possessed significantly higher number of filled grains per panicle over the best check KRH-2 (173.222). And were found to be stable for wider environments on account of their non-significant deviation from regression with average stability. However, the hybrids IR-80561A×IR-54742R (185.778) and IR-80561A×IR-63883-41-3R (150.202) which were on par with the best check KRH-2 (173.222) exhibited non-significant S^2di values and regression coefficient value (bi) of less than one expressing more than average stability and considered to be specifically adaptable to poor environments (Table 3).

Grain weight (1000-grain weight) of a genotype serves as an indicator to the end product i.e., grain yield. The results showed that the genotype×environment interaction was mainly due to both linear and non-linear components supported by Krishnappa *et al.* (2009) for this component, while significance of non-linear component was observed by Arumugam *et al.* (2007). Among the parents, the testers IR-54742R (26.907 g) and BR-827-35R (26.404 g) exhibited significantly higher 1000-grain weight over the best hybrid check DRRH-2 (23.751 g). The tester BR-827-35R was stable with unit regression showing average stability and minimum deviation from regression, while the tester IR-54742R was found to be adaptable to poor environments with more than the average stability. Among the hybrids, eleven hybrids IR-80151A×IR-54742R (27.438 g) IR-80559A×IR-54742R (27.352 g), IR-80151A×KMR-3R (26.603 g), IR-80561A×IR-54742R (26.949 g), IR-80559A ×BR-827-35R (26.031 g), IR-80555A×IR-54742R (25.938 g), IR-80561A×BR-827-35R (25.380 g), IR-80559A×IR-63883-41-3R (25.220 g), IR-80555A×BR-827-35R (25.122 g), IR-80151A×BR-827-35R (25.089 g) and APMS 6A×BR-827-35R (25.022 g) were significantly higher than the best hybrid check, DRRH-2 (23.751 g) and recorded unit regression (bi) values and hence, they are considered to be widely adaptable to different environments by possessing the least variance of deviation from regression. However, the hybrid IR-80151A×IR-21567R (24.173 g) had non-significant deviation from regression, regression coefficient (bi) above one and on par with the best hybrid check DRRH-2, so it was having responsiveness to better environments while the hybrids IR-80151A×IR-72R (23.353 g) and IR-80151A×IR-40750R (23.069 g) were on par with best hybrid check DRRH-2 (23.751 g) and exhibited bi values less than one and are adaptable specifically to poor environments (Table 3).

Single plant yield is the most important trait in the development of rice hybrids. Identification of a hybrid with high grain yield and average stability is of immense value. A perusal of stability parameters for single plant yield indicated that both linear and non-linear components of genotype×environment interaction were found to be significant in the current study. Similar results were reported by Young and Virmani (1990), Panwar *et al.* (2008) and Krishnappa *et al.* (2009) while contradicting these results indicated only significance of non-linear component was reported by Hegde and Vidyachandra (1998), Lohithaswa *et al.* (1999) and Arumugam *et al.* (2007) and non-linear component of the interaction was not significant reported by Deshpande and Dalvi (2006). All the parents except the tester IR-54742R possessed unit regression values (bi) and non-significant S^2di values, thus displaying average stability and are adaptable to wider environments, while the tester IR-54742R (20.764 g) recorded regression coefficient value (bi) of less than one with minimum deviation from regression and considered to be adaptable to poor environments. Among the parents, none could significantly higher single plant yield than the best check KRH-2 (27.404 g). Six promising potential hybrids APMS 6A×IR-24R (33.904 g), APMS 6A×BR-827-35R (33.692 g), IR-80555A×IR-54742R (33.284 g), IR-80559A×IR-54742R (33.067 g), IR-80559A× KMR-3R (32.819 g) and IR-80151A×IR-54742R (32.711g) manifested significantly higher single plant yield than the promising checks KRH-2 (27.404 g) and PA-6201 (27.116 g) along with non-significant deviation from regression line (S^2di) and around unit bi values expressing average stability among the 60 hybrids. Hence, they are considered to be "well buffered" for single plant yield as these can adjust their genotype state in response to the changing environmental conditions which is referred to as "genetic homeostasis". As many as other 22 hybrids possessed unit regression coefficient (bi) values with non-significant deviation from regression and higher mean single plant yield than promising checks KRH-2 (27.404 g) and PA-6201 (27.116 g). These hybrids were; IR-80561A×BR-827-35R (31.780 g), IR-80561A×KMR-3R (31.726 g), IR-80151A×BR-827-35R

(31.536 g), APMS 6A×KMR-3R (31.484 g), IR-80561A×IR-54742R (31.224 g), IR-80151A×KMR-3R (31.051 g), APMS 6A×DR-714-1-2R (30.956 g), IR-80151A×DR-714-1-2R (30.953 g), IR-80555A×IR-21567R (30.878 g), IR-80151A×IR-24R (30.769 g), IR-80151A×IR-63883-41-3R (30.494 g), IR-80561A×IR-32809R (30.236 g), IR-80555A×BR-827-35R (30.133 g), IR-80151A×IR-10198R(30.131 g), IR-80555A×DR-714-1-2R (30.109 g), APMS 6A×IR-63883-41-3R (29.101 g), IR-80559A×IR-24R (28.567 g), IR-80561A×IR-21567R (28.562 g), IR-80151A×IR-21567R (28.327 g), APMS 6A×IR-21567R (28.040 g), IR-80559A×IR-72R (27.969 g) and APMS 6A×IR-32809R (27.553 g). However, the hybrids APMS 6A×IR-54742R (34.333 g) significantly higher than best check KRH-2 (27.404 g) and IR-80555A×KMR-3R (30.160 g) on par with best check KRH-2 (27.404 g) responded non-significantly for S^2di and were expressing less than one bi values and are proposed specifically for poor environments (Table 4).

Any generalization regarding the stability of a genotype for all the traits is quite difficult. As many as hybrids had average stability to the environments for yield and its component characters. Eberhart and Russell (1966) suggested that, if the traits associated with high yield show stability, the selection of genotype only for yield could be effective. A non-significant correlation between the deviation from regression (S^2di) and mean performance or regression coefficient (bi) indicated that these stability parameters might be under the control of different genes located on different chromosomes (Reddy and Chaudhary, 1991; Singh *et al*., 1995). Earlier, Grafius (1956) and Bradshaw (1965) also reported that plasticity in one or more component characters might allow stability in the final character. It is inferred that alleles that confer broader adaptation might be involved to achieve yield and stability across environments. It is also clear that most of the high yielding hybrids exhibited stability for yield components panicle weight, number of productive tillers per plant, number of filled grains per panicle and 1000-grain weight over all the environments (Table 2, 3 and 4). This might be due to plasticity in their traits and phenotypic stability could be the result of their high plasticity due to its heterogeneous composition.

CONCLUSION

From the present investigation it is concluded that among the parents, identified superior performing parents APMS 6A, IR-80559A, KMR-3R, BR-827-35R, IR-63883-41-3R and IR-21567R were stable over three locations for yield and its important components can be used for developing stable hybrids. Even though as many as stable hybrids were identified among the hybrids, the most high yielding potential stable hybrids were APMS 6A×IR-24R, APMS 6A×BR-827-35R, IR-80555A ×IR-54742R, IR-80559A×IR-54742R, IR-80559A×KMR-3R and IR-80151A×IR-54742R across the three different environmental conditions since they possessed favorable combination of all stability parameters or ideal stability values with significantly desired mean performance levels over both promising checks KRH-2 and PA-6201 for yield and its important components. To get more realistic information on stability, the identified promising stable cross combinations could recommended for multi-location trials in India before the commercial release.

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