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Society for Advancement of Rice Research

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- To advance the cause of rice research and development in the country.
- To disseminate knowledge on latest development in rice research through publications, seminars, lectures and training programme.
- To provide a platform for exchange of knowledge and information on rice research and developments through organizing workshops, symposia, conferences, etc.
- To provide consultancy in rice production and development.
- To facilitate research and industry collaboration and public private partnership at national level.
- To honour outstanding achievers in rice research and development.
- To cooperate with other organizations having similar aims and objectives.
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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Correlation and Path Analysis for Yield and its Component Traits in Rice (*Oryza sativa* L.)

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Abstract

The materials used in this study consisted of 31 genotypes including two checks i.e. HPR 1156 and HPR 2656. The material was raised in a randomized block design with three replications. Data was recorded on days to 50% flowering, days to 75% maturity, plant height, panicle length, grains/panicle, spikelets/panicle, yield/plant, 1000-grain weight, grain length, grain breadth, L:B ratio, protein content, aroma, yield/plot, reaction to leaf and neck blast. The data were analyzed as per standard statistical procedures. Genotypic correlation was higher in magnitude than the phenotypic correlation coefficient, indicating more genetic association among the various traits. Grain yield/plant exhibited significantly positive association with days to 50% flowering, panicle length, grains/panicle, spikelets/panicle and grain breadth at both genotypic level and phenotypic level. Thus the results indicate that improvement in grain yield/plant can be obtained by laying more emphasis on above characters. Path analysis revealed the highest positive direct effect of grains/panicle on the grain yield followed by L/B ratio, 1000-grain weight, and yield/plant and emphasis may be laid on these characters in future rice breeding programmes.

Key words: Rice, genotypic correlation, phenotypic correlation, path analysis.

Introduction

Rice *(Oryza sativa* L.) is one of the major food crop of world especially of the most Asian countries like China, India, Pakistan, Bangladesh, Vietnam, Korea. Rice is placed on second position in cereal production around the globe. Rice is the most staple food of Asia. More than 90% of the world's rice is grown and consumed in Asia, where 60% of the world's population lives. Rice is grown worldwide over an area 160.6 million hectares with total production of 492.2 million tones. Area under rice in India is 42.2 million hectares with production of 104 million tones (Anonymous 2016). The study of correlation is important to identify traits for which selection can be made. So it is the study of the degree of association between characters which is given by the coefficient of correlation is a useful guide in the plant breeding programmes, as it helps the breeder to concentrate on those characters that are of direct relevance. It is a measure of the degree of association between two traits worked at the same time (Hayes et al. 1995). The extent of observed relationship between two characters is known as simple phenotypic correlation. As such it does not give the true picture of the relationship between two characters because along with genetic values, it includes environmental influence on the covariance between the two characters; the measure is turned as environmental correlation. Johnson et al. (1955) revealed that estimates of genotypic and phenotypic correlation among characters are useful in planning and evaluating breeding programmes.

Path coefficient analysis of yield and its related parameters specifies the cause and measure the relative importance of each variable. The yield potentially of each variety can be exploited if the relative importance of each component is ascertained and is increased to a desired degree by suitable management practices. As yield components vary independently among varieties, study on the relative importance of each component for different varieties is essential. Therefore in addition to determining the inter-relationship among yield components on one hand and between yields and its components causes of association on the other hand, it is important to know the direct effects and the interactions in the form of indirect effects of these traits on the yield.

Materials and Methods

The investigation was carried out on 31 advance breeding lines of Rice and Wheat Research Centre, Malan, and 2 checks namely, HPR-1156 and HPR-2656. These lines were evaluated in Randomized Block Design with three replications. Data was recorded on days to 50% flowering, days to 75% maturity, plant height, panicle length, grains/panicle, spikelets/panicle, yield/plant, 1000-grain weight, grain length, grain breadth, L:B ratio, protein content, aroma, yield/plot, reaction to leaf and neck blast. The data were analyzed as per standard statistical procedures. Phenotypic, genotypic and environmental coefficients of correlation were worked out following the procedure of Al-Jibouri et al. (1958) and Dewey and Lu (1959). The path analysis of important component traits and quality traits with grain yield was done following Dewey and Lu (1959).

Results and Discussion

The estimation of phenotypic correlation (Table 1) showed that days to 50% flowering was significantly and positively correlated with days to 75% maturity (0.574), panicle length (0.529), grain/panicle (0.364), spikelets/panicle (0.399) and yield/plant (0.280) but it was significantly negative correlated with plant height (-0.341), 1000-grain weight (-0.277) and yield/plot (-0.206). Days to 75% maturity showed significantly positive correlation with panicle length (0.603), grains/panicle (0.373), spikelets/panicle (0.384) and L:B ratio (0.300). On the other hand correlation were significantly negative with plant height (-0.229), 1000-grain weight (-0.411), grain breadth (-0.378) and yield/plot (-0.275). Plant height exhibited significantly positive correlation with grain breadth (0.234) but it was significantly negative correlated with panicle length (-0.246). Panicle length showed significantly and positively correlation with grains/panicle (0.668), spikelets/panicle (0.678) yield/plant (0.417) and L:B ratio (0.257) but it was significantly negative correlated with 1000-grain weight (-0.297) and yield/plot (-0.226).

Grains/panicle had significantly positive correlation with spikelets/panicle (0.758) yield/plant (0.521), it was significantly negative correlated with 1000-grain weight (-0.285) and protein content (-0.209). Spikelets/panicle exhibited significantly positive correlation with yield/plant (0.491) but it was significantly negative correlated with 1000-grain weight (-0.424) and yield/plot (-0.341). Yield/plant showed significantly and positively correlation with grain breadth (0.232), and significantly negative with protein content (-0.219).

1000-grain weight showed significantly and positively correlation with grain length (0.238), grain breadth (0.425) and yield/plot (0.353), and it was significantly negative correlated with L/B ratio (-0.197). Grain length had significantly positive correlation with L/B ratio (0.789), and it was significantly negative correlated with grain breadth (-0.361) and protein content (-0.269). Grain breadth showed significantly and negative correlation with L/B ratio (-0.730). Protein content had significant negative correlation with yield/plot (-0.243). In order to increase grain yield, stress should be given on those characters which are positively correlated with yield. 1000-grain

Table 1: Estimation of phenotypic correlation coefficient among various yield, morphological and quality traits in rice genotypes

Traits	Days to 75% maturity	Plant height	Panicle length	Grains / panicle	Spike-lets / panicle	Yield / plant	1000-grain weight	Grain length	Grain breadth	L:B ratio	Protein content	Yield / plot
Days to 50% flowering	0.574*	-0.341*	0.529*	0.364*	0.399*	0.280*	-0.277*	0.020	-0.121	0.133	0.139	-0.206*
Days to 75% maturity		-0.229*	0.603*	0.373*	0.384*	0.158	-0.411*	0.037	-0.378*	0.300*	-0.041	-0.275*
Plant height			-0.246*	-0.060	-0.072	0.148	0.051	-0.112	0.234*	-0.195	-0.181	0.029
Panicle length				0.668*	0.678*	0.417*	-0.297*	0.157	-0.182	0.257*	-0.135	-0.226*
Grains / panicle					0.758*	0.521*	-0.285*	-0.137	0.020	-0.020	-0.209*	0.011
Spikelets / panicle						0.491*	-0.424*	-0.123	-0.037	0.003	-0.180	-0.341*
Yield / plant							-0.006	-0.015	0.232*	-0.082	-0.219*	0.132
1000-grain weight								0.238*	0.425*	-0.197*	-0.118	0.353*
Grain length									-0.361*	0.789*	-0.269*	0.065
Grain breadth										-0.730*	0.051	0.166
L:B ratio											-0.180	-0.063
Protein content												-0.243*

*Significant at 5% level of significance weight had significant positive correlation with grain yield. Similar results were observed by Das et al. (1992), Chandra et al. (2009) and Ratna et al. (2015).

The analysis of the genotypic correlation (Table 2) showed that the days to 50% flowering had significant positive correlation with days to 75% maturity (0.579), panicle length (0.565), grain/panicle (0.393), spikelets/panicle (0.417) and yield/plant (0.317). It was significantly negative with plant height (-0.348), 1000-grain weight (-0.300) and yield/plot (-0.219). Days to 75% maturity showed significantly positive correlation with panicle length (0.650), grains/panicle (0.403), spikelets/panicle (0.404) and L/B ratio (0.325), it was significantly negative with plant height (-0.241), 1000-grain weight (-0.460), grain breadth (-0.495) and yield/plot (-0.299). Plant height showed significantly positive correlation with grain breadth (0.328), and it was significantly negative with panicle length (-0.279), L:B ratio (-0.244) and protein content (-0.196). Panicle length showed significantly positive correlation with grains/panicle (0.754), spikelets/panicle (0.735), yield/plant (0.482), grain length (0.210) and L:B ratio (0.330), and it was significantly negative with 1000-grain weight (-0.327), grain breadth (-0.279) and yield/plot (-0.250). Grains/panicle showed significantly positive correlation with spikelets/panicle (0.818) and yield/plant (0.600), and it was significantly negative with 1000-grain weight (-0.300) and protein content (-0.224). Spikelets/panicle showed significantly positive correlation with yield/plant (0.554), and it was significantly negative with 1000-grain weight (-0.467) and yield/plot (-0.375). Yield/plant showed significantly positive correlation with grain breadth (0.381) and significantly negative with protein content (-0.256). 1000-grain weight showed significantly positive correlation with grain length (0.245), grain breadth (0.549) and yield/plot (0.407), it had negative correlation with L:B ratio (-0.234). Grain length showed significantly positive correlation with L:B ratio (0.848), and it was significantly negative with grain breadth (-0.600) and protein content (-0.333). Grain breadth showed significantly positive correlation with yield/plot (0.226), it was negatively correlated with L:B ratio (-0.920). L:B ratio showed significant negative correlation with protein content (-0.199). Protein content showed significant negative correlation with yield/plot (-0.279).

The values of genotypic correlation coefficient were generally higher than the corresponding phenotypic and environmental correlation coefficient for most of the characters studied suggesting strong inherent relationship between various characters. 1000-grain weight and grain breadth had significant positive correlation with grain yield. Similar results were observed by Rupika et al. (2012) and Lakshmi et al. (2014) for 1000-grain weight and grain breadth.

Table 2: Estimation of genotypic correlation coefficient among various yield, morphological and quality traits in rice genotypes

Traits	Days to maturity	Plant height	Yield per plant	Panicle length	Grains per panicle	Spikelets per panicle	1000-grain weight	Grain length	Grain breadth	L:B ratio	Protein content	Yield per plot
50% flowering	0.579*	-0.348*	0.565*	0.393*	0.417*	0.317*	-0.300*	0.046	-0.160	0.164	0.146	-0.219*
Days to 75% maturity		-0.241*	0.650*	0.403*	0.404*	0.174	-0.460*	0.038	-0.495*	0.325*	-0.043	-0.299*
Plant height			-0.279*	-0.085	-0.093	0.135	0.066	-0.153	0.328*	-0.244*	-0.196*	0.064
Panicle length				0.754*	0.735*	0.482*	-0.327*	0.210*	-0.279*	0.330*	-0.139	-0.250*
Grains/panicle					0.818*	0.600*	-0.300*	-0.132	0.036	-0.016	-0.224*	0.031
Spikelets/panicle						0.554*	-0.467*	-0.083	-0.028	0.049	-0.186	-0.375*
Yield /plant							0.011	-0.035	0.381*	-0.106	-0.256*	0.133
1000-grain weight								0.245*	0.549*	-0.234*	-0.150	0.407*
Grain length									-0.600*	0.848*	-0.333*	0.052
Grain breadth										-0.920*	0.072	0.226*
L:B ratio											-0.199*	-0.056
Protein content												-0.279*

*Significant at 5% level of significance

At the phenotypic level, grains/panicle (0.563) had the highest positive direct effect (Table 3) on the grain yield followed by yield/plant (0.275), 1000-grain weight (0.077), L:B ratio (0.060) and grain breadth (0.008). However, days to 50% flowering (-0.012), days to 75% maturity (-0.170), plant height (-0.158), panicle length (-0.138), spikelets/panicle (-0.772), grain length (-0.070) and protein content (-0.256) had negative direct effects on yield/plot. At the genotypic level, L/B ratio (1.006) had the highest positive direct effect on the grain yield followed by grains/panicle (0.795), 1000-grain weight (0.614), yield/plant (0.359) and days to 50% flowering (0.146). However, days to 75% maturity (-0.442), plant height (-0.052), panicle length (-0.178), spikelets/panicle (-0.904), grain length (-1.133), grain breadth (-0.261) and protein content (-0.318) had negative direct effects on yield/plot. At both genotypic and phenotypic levels grain/panicle, 1000-grain weight, yield/plant, grain length and L:B ratio had highest positive correlation. So, grains/panicle is the most important character as it exhibited high positive direct effect on grain yield at both genotypic and phenotypic level. Similar results were obtained by Meena et al. (2016). Kalyan et al. (2017) reported that number of filled grains/panicle had highest positive effect on grain yield followed by 1000-grain weight. Concurrently, at genotypic level spikelets/panicle had highest indirect effect on grain yield via grains/panicle

Table 3: Estimates of direct and indirect effects at phenotypic and genotypic level for different traits in rice genotypes

Traits		Days to 50% flowering	Days to 75% maturity	Plant height	Panicle length	Grains /panicle	Spikelets/ panicle	Yield/ plant	1000-grain weight	Grain length	Grain breadth	L:B ratio	Protein content	Correlation with grain yield per plot
Days to 50% flowering	P	**-0.012**	-0.097	0.054	-0.073	0.205	-0.308	0.077	-0.021	-0.001	-0.001	0.008	-0.036	-0.206*
	G	**0.146**	-0.256	0.018	-0.101	0.312	-0.377	0.114	-0.184	-0.052	0.042	0.165	-0.046	-0.219*
Days to 75% maturity	P	-0.007	**-0.170**	0.036	-0.083	0.210	-0.297	0.044	-0.032	-0.003	-0.003	0.018	0.011	-0.275*
	G	0.085	**-0.442**	0.013	-0.116	0.320	-0.365	0.063	-0.283	-0.043	0.129	0.327	0.014	-0.299*
Plant height	P	0.004	0.039	**-0.158**	0.034	-0.034	0.055	0.041	0.004	0.008	0.002	-0.012	0.046	0.029
	G	-0.051	0.107	**-0.052**	0.050	-0.067	0.084	0.048	0.041	0.174	-0.086	-0.245	0.062	0.065
Panicle length	P	-0.006	-0.102	0.039	**-0.138**	0.376	-0.524	0.114	-0.023	-0.011	-0.001	0.015	0.035	-0.226*
	G	0.083	-0.287	0.015	**-0.178**	0.599	-0.664	0.173	-0.201	-0.238	0.073	0.332	0.044	-0.250*
Grains /panicle	P	-0.004	-0.063	0.009	-0.092	**0.563**	-0.585	0.143	-0.022	0.010	0.000	-0.001	0.053	0.011
	G	0.057	-0.178	0.004	-0.134	**0.795**	-0.740	0.216	-0.184	0.150	-0.010	-0.016	0.071	0.031
Spikelets/ panicle	P	-0.005	-0.065	0.011	-0.094	0.426	**-0.772**	0.135	-0.033	0.009	0.000	0.000	0.046	-0.341*
	G	0.061	-0.179	0.005	-0.131	0.650	**-0.904**	0.199	-0.287	0.094	0.007	0.049	0.059	-0.375*
Yield/ plant	P	-0.003	-0.027	-0.023	-0.057	0.293	-0.379	**0.275**	-0.001	0.001	0.002	-0.005	0.056	0.132
	G	0.046	-0.077	-0.007	-0.086	0.477	-0.501	**0.359**	0.007	0.039	-0.100	-0.107	0.081	0.133
1000-grain weight	P	0.003	0.070	-0.008	0.041	-0.161	0.327	-0.002	**0.077**	-0.017	0.003	-0.012	0.030	0.353*
	G	-0.044	0.204	-0.003	0.058	-0.238	0.422	0.004	**0.614**	-0.278	-0.144	-0.236	0.048	0.407*
Grain length	P	0.000	-0.006	0.018	-0.022	-0.077	0.095	-0.004	0.018	**-0.070**	-0.003	0.047	0.069	0.065
	G	0.007	-0.017	0.008	-0.037	-0.105	0.075	-0.012	0.151	**-1.133**	0.157	0.853	0.106	0.052
Grain breadth	P	0.001	0.064	-0.037	0.025	0.011	0.028	0.064	0.033	0.025	**0.008**	-0.044	-0.013	0.166
	G	-0.023	0.219	-0.017	0.050	0.029	0.025	0.137	0.337	0.680	**-0.261**	-0.926	-0.023	0.226*
L:B ratio	P	-0.002	-0.051	0.031	-0.036	-0.011	-0.002	-0.022	-0.015	-0.055	-0.006	**0.060**	0.046	-0.063
	G	0.024	-0.144	0.013	-0.059	-0.012	-0.044	-0.038	-0.144	-0.961	0.241	**1.006**	0.063	-0.056
Protein content	P	-0.002	0.007	0.028	0.019	-0.118	0.139	-0.060	-0.009	0.019	0.000	-0.011	**-0.256**	-0.243*
	G	0.021	0.019	0.010	0.025	-0.178	0.168	-0.092	-0.092	0.378	-0.019	-0.200	**-0.318**	-0.279*

Residual effect at phenotypic level (P)= 0.05643

Residual effect at genotypic level (G)= 0.28292

** Significant at 1% level of significance

Bold values indicate direct effects

followed by yield/plant via grains/panicle; grain length via L:B ratio; 1000-grain weight via spikelets/panicle. At phenotypic level spikelets/panicle had highest indirect effect on grain yield via grains/panicle followed by panicle length via grains/panicle, yield/plant via grains/panicle, 1000-grain weight via spikelets/panicle.

In general, genotypic correlation was higher in magnitude than the phenotypic correlation coefficient, indicating more genetic association among the various traits. Grain yield/plant exhibited significantly positive association with days to 50% flowering, panicle length, grains/panicle, spikelets/panicle and grain breadth at both genotypic level and phenotypic level. Thus the results indicate that improvement in grain yield/plant can be obtained by laying more emphasis on above characters. Correlation coefficient at the genotypic level also showed similar trends as at the phenotypic correlation level.

Path analysis revealed the highest positive direct effect of grains/panicle on the grain yield followed by L:B ratio, 1000-grain weight, yield/plant and days to 50% flowering at genotypic level. However, at phenotypic level grains/panicle had maximum contribution towards the grain yield followed by yield/plant, 1000-grain weight, grain length and L:B ratio. Concurrently, at genotypic level spikelets/panicle had highest indirect effect on grain yield via grains/panicle followed by yield/plant via grains/panicle; grain length via L:B ratio; 1000-grain weight via spikelets/panicle. At phenotypic level spikelets/panicle had highest indirect effect on grain yield via grains/panicle followed by panicle length via grains/panicle, yield/plant via grains/panicle, 1000-grainweightviaspikelets/panicle.

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Genetic diversity analysis for yield traits in rainfed rice (*Oryza sativa* L.) under water stress condition

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Abstract

The present experiment comprised with thirty eight advanced rice cultures and conducted during *Rabi* 2017-18 under rainfed rice ecosystem. They were evaluated for ten yield and yield related traits *viz.,* days to 50% flowering, plant height, number of productive tillers per plant, number of panicles per square metre plot area, panicle length, number of filled grains per panicle, spikelet fertility, grain yield, straw yield and harvest index using D^2 analysis. Based on the analysis, the genotypes were grouped into nine clusters. Maximum number of genotypes (16 genotypes) was grouped in cluster I. Cluster II, III and VII consists of ten, four and three genotypes respectively. Remaining clusters were represented by a single genotype each. Maximum inter cluster distance was observed between cluster III and VI (17.48) followed by between cluster III and IV (17.05) indicating wider genetic diversity between genotypes. Hence these lines may be utilized in further breeding programme for the exploitation of hybrid vigour. The intra cluster distance was maximum in cluster III (7.96) followed by cluster VII (7.23) indicates hybridization involving genotypes within the same clusters may result in good cross combinations. Among the ten traits studied, grain yield contributed maximum divergence (36.13%) followed by days to 50% flowering (29.73%), filled grains per panicle (12.09%) and number of panicles per square metre (9.39%). Hence these altogether contribute more than eighty five per cent towards total divergence. Therefore these characters may be given importance during hybridization programme in rainfed rice ecosystem under water stress condition.

Key words: Genetic diversity, yield traits, rainfed rice, water stress.

Introduction

Rice is an important food crop for about half of the world's population and 90% of it is being produced and consumed in Asia (Rao *et al.,* 2016) and share maximum in grain production. It contributes about 43 per cent of caloric requirement and 20-25% of agricultural income. Rainfed rice accounts for around 45% of the world's rice area and around 40 million ha of rainfed area is concentrated in South and South East Asia alone (Maclean *et al*., 2002). Although more than 1200 rice varieties have been released in India, many of them becoming obsolete due to disparity in consumer preference and inconsistent performance in diverse environments and less than 40 varieties are found in large scale adoption in farmers field with stable performance continue under cultivation after 15 to 20 years of their release. The rice production area in the country are very diverse in hydrology and combined to other soil and climatic factors make a difference in rice yield (Singh *et al.,* 1997).Yield of rainfed lowland rice is drastically reduced by intermittent drought due to unpredictable, and uneven distribution of rainfall during the crop growing period. To reduce yield losses of rice crop in rainfed lowland areas and to increase overall rice production, new rice varieties with greater adaptation to drought are essential. Hence, the development of drought resistant cultivars with a higher yield potential is one of the main objectives of rainfed lowland rice breeding programmes.

The success of any breeding programme depends on the selection of parents for hybridization. The parents involved in the development of varieties should be divergent. The germplasm provides immense scope for wide variability. Genetic divergence is an efficient tool for an effective choice of parents for hybridization programme. Such study also selects the genetically divergent parents to obtain desirable combinations in the segregating generations. Information on nature and degree of genetic divergence would help the plant breeder in choosing the right parents for the breeding programme (Vivekanandan and Subramanian, 1993). An attempt was made in the present investigation to assess the genetic diversity of thirty eight advanced rice cultures for yield traits in rainfed rice ecosystem.

Materials and methods

The experimental material comprised with thirty eight advanced rice cultures which were evaluated in a randomized block design with three replications at Agricultural Research Station, Tamil Nadu Agricultural University, Paramakudi during *Rabi* 2017-18. The experimental site is located at 9” 21’ N latitude, 78” 22’ E longitudes and an altitude of 242 m above mean sea level with average annual rainfall of 840 mm. This site has clay loam soil texture with pH of 8.0. Each genotype was raised in 5x2 m plot keeping 15 x 10 cm spacing. The recommended agronomic practices were followed to raise good crop stand. The data were recorded on ten randomly selected plants from each replication for various quantitative traits studied were *viz,* days to 50% flowering, plant height (cm), number of productive tillers per plant, number of panicles per square metre plot area, panicle length, number of filled grains per panicle, spikelet fertility, grain yield (t/ha), straw yield (t/ha) and harvest index. The genetic distance between the genotypes was worked out using Mahalanobis D^2 analysis (1936) and grouping of varieties into clusters was done following the Tochers method as detailed by Rao, (1952).

Results and Discussion

The analysis of variance revealed significant differences among the genotypes for all the characters studied indicating existence of variability among the genotypes. Based on the relative magnitude of D^2 values, thirty eighty genotypes were grouped into nine clusters (Table 1).

Table 1: Clustering pattern of 38 genotypes

Cluster	No. of genotypes	Name of genotypes
I	16	PM 17003 (G3), CB 14530 (G32), CB 13805 (G38), IR64 dt QTL (G34), PM 17010 (G10), PM 17002 (G2), PM 17018 (G18), PM 17012 (G12), PM 17020 (G20), PM 17011 (G11), PM 17019 (G19), PM 17026 (G26), PM 17005 (G5), PM 17021 (G21), PM 17014 (G14), PM 17017 (G17).
II	10	TM 12039 (G35), CB 13084 (G36), PM 14042 (G28), Anna(R)4(G30), PM 17022 (G22), PM 17023 (G23), PM 17015 (G15), PM 17024 (G24), PM 17025 (G25) and PM 17006 (G6).
III	4	TM 13018 (G31), TM 12077 (G33), PM 17008 (G8) and CB 14756 (G29).
IV	1	PM 17007 (G7)
V	1	PM 17013 (G13)
VI	1	PM 17001 (G1)
VII	3	PM 17009 (G9), TKM 12 (G37) and PM 17016 (G16).
VIII	1	PM 17027 (G27)
IX	1	PM 17004 (G4)

Maximum number of genotypes (16 genotypes) was grouped in Cluster I. Cluster II, III and VII consists of ten, four and three genotypes respectively. Remaining clusters were represented by a single genotype each. The overall composition of the clustering pattern showed that genotypes collected from the same geographic origin were distributed in different clusters. Therefore, the selection of parental material for hybridization programme simply based on geographic diversity may not be rewarding exercise. The choice of suitable diverse parents based on genetic divergence analysis would be more fruitful than the choice made on the basis of geographical distances. Similar findings of non-correspondence of geographic origin with genetic diversity were also reported by Shanmugasundaram*et al.,* (2000), Nayak *et al.,*(2004) and Ranjith *et al.*, (2018).

The intra and inter cluster distance are presented in Table 2. Inter cluster distance was higher than intracluster distance indicating wider genetic diversity among the genotypes. The maximum inter cluster distance was observed between cluster III and VI (17.48) followed by between cluster III and IV (17.05) indicating wider genetic diversity among the genotypes between these groups. The hybrids developed from the selected members of these clusters would produce highly variable population in the segregating generations. The minimum inter cluster distance was found between cluster VI and VII (6.36) followed by between cluster V and IX (6.37). These genotypes in these clusters are genetically very close and hence, hybridization among the varieties will not give fruitful result.

Table 2: Intra (diagonal) and inter cluster average distance of yield traits in 38 genotypes

	I	II	III	IV	V	VI	VII	VIII	IX
I	6.74	9.72	13.12	8.37	8.41	9.29	9.90	9.00	9.62
II		6.42	13.94	14.45	11.95	12.65	13.34	11.86	15.10
III			7.96	17.05	12.51	17.48	16.79	10.39	12.96
IV				0.00	9.84	8.59	9.50	11.45	8.39
V					0.00	12.13	11.35	11.59	6.37
VI						0.00	6.36	11.60	14.04
VII							7.23	12.31	13.21
VIII								0.00	11.53
IX									0.00

The maximum intra cluster distance was observed in cluster III (7.96) followed by cluster VII (7.23). Hence, selection within these clusters may be exercised based on the highest areas for the desirable traits, which would be made use of in improvement through inter-varietal hybridization (Joshi *et al.,* 2008).A perusal of results of cluster means (Table 3) revealed that cluster I with 16 genotypes surprisingly exhibited no highest and lowest values for the all the traits studied. Cluster II with ten genotypes exhibited highest mean value for productive tillers per plant (7.10), straw yield (5.90) and grain yield (2.95). The genotypes in Cluster III had taken more number of days for fifty per cent flowering (96.75) and exhibited highest harvest index (0.39). Cluster IV was characterized by lowest panicle length (17.53) and short stature (59.07); likewise the cluster V had minimum number of productive tillers per plant (5.33), filled grains per panicle (74.33) and harvest index (0.25). The genotype PM 17001 with less number of days for fifty per cent flowering (75.00) and lowest spikelet fertility (78.33) was grouped in cluster VI. The Genotypes PM 17009, TKM 12 and PM 17016 (Cluster VII) had shown tall stature (87.76) and lesser number of panicles per square metre (122.22) but possess lengthy panicles (23.13). The genotype PM17027 showing highest mean values for number of panicles per square metre area (238.00), filled grains per panicle (150.33) and spikelet fertility (94.00) was grouped in cluster VIII.The genotype PM 17004 in Cluster IX exhibited lowest straw (3.30) and grain yield (1.40).

Table 3: Cluster mean of different yield characters in 38 rice genotypes

Cluster	Days to 50% flowering	Plant Height (cm)	Productive tillers per plant	No. of panicles per sq.metre	Panicle length (cm)	Filled grains / panicle	Spikelet fertility (%)	Straw yield (t/ha)	Grain yield (t/ha)	Harvest Index
I	81.25	64.36	6.56	179.54	18.89	97.35	91.85	5.28	2.17	0.30
II	79.80	67.28	7.10	205.33	18.60	79.93	93.42	5.90	2.95	0.34
III	96.75	64.72	6.42	148.08	19.30	134.17	93.94	4.40	2.63	0.39
IV	78.00	59.07	6.33	154.67	17.53	99.00	89.63	3.80	1.50	0.28
V	88.00	73.00	5.33	159.00	18.33	74.33	83.83	5.83	1.93	0.25
VI	75.00	74.33	6.00	164.00	21.93	110.00	78.33	5.40	2.30	0.30
VII	76.56	87.76	5.78	122.22	23.13	111.78	88.27	5.76	2.26	0.29
VIII	86.00	68.13	6.33	238.00	19.33	150.33	94.40	5.80	2.40	0.29
IX	90.00	59.20	6.33	153.33	18.30	95.00	93.33	3.30	1.40	0.30

None of the clusters contained genotypes with all the desirable traits which could be directly selected and utilized. All the minimum and maximum cluster mean values were distributed in relatively distant clusters. However the cluster II and VIII recorded desirable mean value for maximum number of productive traits *viz.*, productive tillers per plant, number of panicles per square metre area, filled grains per panicle, spikelet fertility, straw yield and grain yield. Similar results were also reported by Banumathy *et al.*(2010) and Rai *et al.* (2014), thereby underlining the fact that the hybridization between genotypes of different clusters is necessary for the development of desirable genotypes. The crossing between the entries belonging to cluster pairs having large inter cluster distance and possessing high cluster means for one or other characters to be improved may be recommended for isolating desirable recombinants in the segregating generations in rice. However, caution should be exercised in selecting very diverse genotypes, because the frequency of heterotic crosses and magnitude of heterosis for yield and its components were found to be higher in crosses between parents with intermediate divergence than the extreme one (Arunachalam *et al*., 1984 and Datta *et al*., 2004) The selection on diverse parents for hybridization programme should be done after considering the inter-cluster distances and mean performance of genotypes for different characters. The lines belonging to diverse clusters and showing high mean performance in desirable direction for different traits may be chosen as parents.

The contribution of each trait to total divergence is presented in table 4. Among the traits studied, grain yield contributed maximum divergence (36.13%) followed by days to 50% flowering (29.73%), filled grains per panicle (12.09%) and number of panicles per square metre (9.39%). The minimum percentage of contribution was observed in productive tillers per plant (0.28%) followed by harvest index (1.14%), straw yield (2.42%), plant height (2.70%), panicle length (2.84%) and spikelet fertility (3.27%). The traits *viz.*, grain yield, days to 50% flowering, filled grains per panicle and number of panicles per square metre contributed more than eighty five per cent towards total divergence. Hence, these characters should be given importance during hybridization and selection in the segregating population under water stress condition.

Table 4: Percentage of contribution of each character towards total divergence

Character	No. of Times Ranked First	Contribution (%)
Days to 50% flowering	209	29.73
Plant Height (cm)	19	2.70
Productive tillers per plant	2	0.28
No. of panicles per sq.metre	66	9.39
Panicle length (cm)	20	2.84
Filled grains / panicle	85	12.09
Spikelet Fertility	23	3.27
Straw yield (kg/ha)	17	2.42
Grain yield (kg/ha)	254	36.13
Harvest Index	8	1.14
Total	**703**	**100**

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Combining ability analysis in rice (*Oryza sativa* L.)

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Abstract

Combining ability in rice was carried out by using ten parents, their forty five hybrids. The magnitudes of mean sum of square due to *sca* were greater than the *gca* for most of the traits indicating the predominance of non-additive type of gene action. The estimates of gca effects of parents indicated that there were four parents NAUR-1, GNR-3, NVSR-303-6 and GAR-13 to be good general combiners for grain yield and some of yield contributing characters. The best specific crosses for grain yield per plant involved the combinations of either poor x poor, good x poor and poor x good effects.

Key words: Combining ability, gene action, Diallel, Zn and Fe Content.

Introduction

Knowledge about combining ability would help in choosing parents for effective improvement in segregating population and at the same time elucidates the nature and magnitude of various types of gene action involved in quantitative traits. Hence, a study on combining ability of ten parents was undertaken.

Materials and Methods

The experimental material consisted of 56 genotypes including 10 parents, 1 Check and their 45 crosses. The crossing was done by using diallel fashion. The flowers were hand emasculated and pollinated at the Main Rice Research Centre, Navsari Agricultural University, Navsari during *summer* 2015. Three complete sets of 56 genotypes were evaluated during *kharif* 2015 by using randomized block design replicated three times at Main Rice Research Center, Navsari Agricultural University, Navsari. The parents and F_1's were represented by single row plot of 10 plants placed at 20 cm x 10 cm. All the agronomical practices and plant protection measures were followed as and when required to raise a healthy crop of rice. The mean values of 56 entries were subjected to combining ability analysis by employing method-II, model-1 (fixed effect) of Griffing (1956[b]).

Result and Discussion

The analysis of variance for combining ability showed that gca and sca variances were highly significant for all the characters indicating that both additive as well as non additive types of gene action were involved in the inheritance of these traits under the study (Table 1). The magnitudes of mean sum of square due to sca were greater than the gca for most of the traits indicating the predominance of non-additive type of gene action. This was supported by low magnitude of σ^2gca/ σ^2sca ratios. The findings are in confirmation with reports of Salim *et al.* (2010), Patil *et al.* (2011), Padmavathi *et al.* (2012), Sanghera and Hussain (2013), Adilakshmi and Upendra (2014) and Tiwari and Jatav (2014) in rice.

Nature and magnitude of combining ability effects provide guidelines in identifying the better parents and their utilization. The summary of general combining ability effects of the parents (Table 2) revealed that among parents, NAUR-1, GNR-3, NVSR-303-6 and GAR-13 were recognized as good general combiners for grain yield per plant and quality traits. NAUR-1 was good general combiner for productive tiller per plant, panicle length, grains per panicle and straw yield per plant. GNR-3 was good general combiner for productive tiller per plant, grains per panicle, test weight and iron content. NVSR-303-6 was found good general combiner for straw yield per plant, protein content and iron content. GAR-13 was found good general combiner for traits like grains per panicle and protein.

In case of specific combining ability effects, none of the one way hybrids excluding reciprocal crosses exhibited favorable sca effects for all the characters. In the present

Table 1: Analysis of variances for combining ability for the yield and yield contributing traits in rice

Source of Variations	df	Days to 50% flowering	Plant height (cm)	Productive tillers per plant	Panicle length (cm)	Grains per panicle	Grain yield per plant (g)
GCA	9	24.98*	102.35**	3.37**	10.12**	4145.20**	156.90**
SCA	45	27.53**	74.09**	1.63**	4.88**	3023.34**	59.62**
Error	108	10.74	23.12	0.26	0.68	75.53	2.08
σ^2 **GCA**		1.19	6.60	0.26	0.79	339.14	12.90
σ^2 **SCA**		16.79	50.96	1.37	4.20	2947.81	57.54
σ^2gca/σ^2sca		0.07	0.13	0.19	0.19	0.11	0.22

Source of Variations	df	Straw yield per plant (g)	Test weight (g)	Protein content (%)	Iron content (ppm)	Zinc content (ppm)	Amylose content (%)
GCA	9	153.40**	21.58**	1.08**	208.44**	15.44**	0.77**
SCA	45	115.89**	16.22**	1.09**	84.75**	17.41**	1.50**
Error	108	3.68	0.90	0.02	0.33	0.16	0.26
σ^2 **GCA**		12.48	1.72	0.09	17.34	1.27	0.04
σ^2 **SCA**		112.21	15.32	1.07	84.42	17.25	1.24
σ^2gca/σ^2sca		0.111	0.11	0.08	0.20	0.07	0.03

* Significant at 5 % and **Significant at 1 %

Table 2: Estimates of general combining ability effects of parents for different characters in rice.

Parents	Days to 50% flowering	Plant height (cm)	Productive tillers per plant	Panicle length (cm)	Grains per panicle	Grain yield per plant (g)
NAUR-1	0.35	-1.01	0.88**	2.04**	10.91**	4.26**
GNR-3	-1.18	-0.19	0.92**	-0.56*	22.49**	6.58**
IET-24762	3.38**	5.09**	-0.38**	1.07**	10.33**	-2.66**
GAR-13	-0.22	1.86	-0.33*	0.05	23.28**	2.49**
IET-24765	-1.09	-1.47	0.01	-0.78**	-25.99**	-2.06**
IET-24767	0.27	-2.55	0.01	-0.13	-19.10**	-1.57**
IET-24772	1.26	-5.54**	-0.03	-0.31	1.97	-3.56**
Gurjari	-1.12	1.34	-0.18	-0.54*	-27.66**	-1.29**
NVSR-303-6	-0.45	0.19	-0.77**	0.13	-1.17	2.03**
IET-23825	-1.19	2.28	-0.13	-0.97**	4.93*	-4.22**
SE (gj)	0.89	1.317	0.14	0.22	2.38	0.39
SE ((gi-gj)	1.38	1.96	0.21	0.34	3.55	0.58

Parents	Straw yield per plant (g)	Test weight (g)	Protein content (%)	Iron content (ppm)	Zinc content (ppm)	Amylose content (%)
NAUR-1	6.24**	0.36	-0.63**	-1.09**	-1.16**	0.20
GNR-3	-0.14	2.47**	0.01	1.64**	-1.04**	-0.04
IET-24762	-1.56**	-1.57**	-0.36**	2.34**	2.01**	0.48**
GAR-13	-2.20 **	-1.06**	0.26**	-7.26**	-1.74**	0.26
IET-24765	3.75**	-0.90**	0.18**	1.58**	-0.43**	-0.15
IET-24767	-3.57**	-0.88**	0.14**	-1.14**	1.11**	-0.38**
IET-24772	0.84	-0.80**	-0.16**	1.33**	0.07	-0.24
Gurjari	0.46	1.71**	0.12**	-4.01**	0.71**	0.01
NVSR-303-6	2.21**	-0.36	0.13**	8.34**	0.13	-0.04
IET-23825	-6.02**	1.04**	0.32**	-1.73**	0.34**	-0.10
SE (gj)	0.52	0.26	0.04	0.15	0.11	0.14
SE ((gi-gj)	0.78	0.38	0.06	0.23	0.16	0.20

* Significant at 5 % and **Significant at 1 %

study positive specific combining ability is desirable for all the characters except days to 50% flowering and plant height. Significant specific combining ability in favorable direction was observed in variable crosses, for days to 50% flowering (13), plant height (9), productive tillers per plant (16), panicle length (11), grains per panicle (30), grain yield per plant (18), straw yield per plant (18), test weight (22), protein content (24), iron content (19), zinc content (16) and amylose content (12) . The results are in agreement with findings of Patil *et al.* (2011), Varpe *et al.* (2011), Chandirakala *et al.* (2012). High sca effects denote undoubtedly a high heterotic response, but this may be due to poor performance of the parents in comparison with their hybrids. With the same amount of heterotic effect, the sca effect may be less, where the mean performance of the parents was higher but this estimate may also be biased (Ziauddin *et al*. 1979). This suggested that the selection of cross combination based on heterotic response would be more realistic rather than on the basis of sca effects. Adilakshmi and Upendra (2014), Tiwari and Jatav (2014), Nagaraju *et al.* (2015) and Patel *et al.* (2015) also reported similar results.

For days to 50% flowering, the gca and sca effects of the parents and hybrid in negative direction were considered to be desirable as the earliness is preferred over the late varieties. The gca effects of the parents varied from -1.19 (IET-23825) to 3.38 (IET-24762). Six parents *viz.,* IET-23825, GNR-3, Gurjari, IET-24765, NVSR-303-6 and GAR-13 showed negative gca effect for this trait indicating good general combiner for earliness. Estimates of specific combining ability effect ranged from -12.16 for cross combination (GNR-3 x Gurjari) to 10.20 for cross combination (IET-24762 x NVSR-303-6). Total 13 crosses showed significant sca effects for this trait but only five crosses showed significant negative sca effects in desirable direction. The cross combination GNR-3 x Gurjari showed minimum desirable sca effect (-12.16) followed by GNR-3 x NVSR-303-6 and GAR-13 x IET-24772 for days to 50% flowering.

For plant height the gca effects of the parents varied from IET-24772 (-5.54) to IET-24762 (5.09). Five parents *viz.,* IET-24772, IET-24767, IET-24765, NAUR-1 and GNR-3 showed negative gca effect for plant height indicating good general combiner for short plant stature, while the estimates of sca effect ranged from -22.44 for the cross (GNR-3 x IET-23825) to 13.35 for the cross (IET-24762 x GAR-13). Nine crosses showed significant negative desirable sca effects. The cross combination GNR-3 x IET-23825 followed by IET-24765 x IET-23825 and NAUR-1 x IET-24762 depicted significant negative desirable sca effect for plant height.

The estimates of gca effect for productive tillers per plant was found to be significant for the five parents, of which two exhibited significant positive effects in desirable direction (Table 2). The parents, GNR-3 (0.92) showed the highest significant positive gca effect followed by NAUR-1 (0.88) and were found to be good general combiners for more tiller per plant. With regards to sca effects of the crosses, 16 crosses had positive sca effects, and were classified as better specific cross combinations for more number of productive tillers per plant. The sca effect ranged from -1.04 for the cross combination (IET-24767 x IET-23825) to 2.10 (IET-24762 x Gurjari) (Table 3). Cross combination IET-24762 x Gurjari (2.10) exhibited the maximum positive sca effect followed by the cross combination IET-24767 x NVSR-303-6 (1.85) and GNR-3 x IET-24772 (1.72).

For the trait panicle length the gca effect was found to be significant for the six parents, of which two parents namely NAUR-1 (2.04) and IET-24762 (1.07) showed gca effect in positive direction and were classified as better general combiner for longer panicle length. While, the sca effects of hybrids were concerned, 11 hybrids had positive and significant estimates and were categorized as better specific cross combinations for longer panicles. The sca effect ranged from -2.99 (NAUR-1 x GNR-3) to 4.25 (Gurjari x IET-23825). The top hybrids, which exhibited high positive sca effect were Gurjari x IET-23825 (4.25), IET-24765 x IET-23825 (3.29), IET-24762 x IET-23825 (3.11) and IET-24767 x IET-23825 (3.11).

Higher number of grains per panicle is a desirable feature in rice since it is related to higher grain yield. Therefore, the parents and hybrids with positive gca and sca effects, respectively are preferable for this trait. The estimates of gca effect of parents showed that eight parents showed significant gca effects out of these significant parents only five parents have significant positive gca effects, parents GAR-13 (23.28) and GNR-3 (22.49) showed the highest significant positive gca effect followed by, NAUR-1 (10.91), IET-24762 (10.33) and IET-23825 (4.94) and were found to be good general combiners for higher number of grains per panicle (Table 2). In case of sca effects of crosses, 30 crosses exhibited significant and positive desirable sca effects and were grouped as better specific cross combinations for more number of grains per panicle. The sca effect ranged from-81.19 (IET-24762 x Gurjari) to 66.32 (IET-24762 x IET-24765) (Table 3). The cross

Table 3: Estimation of specific combining ability effect for days to 50% flowering, plant height and productive tillers per plant, panicle length, grains per panicle and grain yield per plant in rice.

Crosses	Days to 50% flowering	Plant height (cm)	Productive tillers per plant	Panicle length (cm)	Grains per panicle	Grain yield per plant (g)
NAUR-1xGNR-3	-2.53	1.17	0.14	-2.99**	-1.07	-12.23**
NAUR-1xIET 24762	-2.85	-13.90**	0.31	-0.09	-45.84**	3.30*
NAUR-1xGAR-13	0.71	-11.80**	-0.39	1.32*	-73.19**	4.65**
NAUR-1xIET-24765	0.03	9.71*	0.32	-2.91**	-1.24	9.82**
NAUR-1xIET-24767	-0.88	-11.66**	1.06*	0.77	43.12**	1.25
NAUR-1xIET-24772	6.48*	12.92**	0.36	2.68**	40.71**	6.86**
NAUR-1xGurjari	1.78	-2.76	-0.55	-1.02	40.61**	-0.33
NAUR-1xNVSR-303-6	-1.64	5.92	1.23**	2.11**	41.39**	-3.24*
NAUR-1xIET-23825	-0.02	7.50	0.06	-1.32*	14.22*	0.95
GNR-3xIET-24762	-4.53	4.34	1.20*	-0.69	25.40**	3.57**
GNR-3xGAR-13	3.08	1.97	-0.10	2.85**	-31.72**	12.01**
GNR-3xIET-24765	3.50	9.49*	0.82*	0.55	53.42**	6.86**
GNR-3xIET-24767	6.15*	-1.41	0.16	-0.22	27.67**	-7.51**
GNR-3xIET-24772	4.25	8.63*	1.72**	-0.37	17.20*	-0.48
GNR-3xGurjari	-12.16**	4.08	0.20	0.97	55.16**	8.96**
GNR-3xNVSR-303-6	-10.90**	5.30	1.12**	-0.75	9.47	1.88
GNR-3xIET-23825	2.84	-22.44**	-0.17	1.14	23.84**	12.75**
IET-24762xGAR-13	-4.63	13.35**	-0.40	-2.10**	14.84*	5.44**
IET-24762xIET-24765	-2.62	0.34	0.85*	-0.94	66.32**	15.61**
IET-24762xIET-24767	10.03**	0.49	0.12	-1.98**	61.16**	1.24
IET-24762xIET-24772	8.74**	-7.38**	0.29	-1.93*	16.03*	0.20
IET-24762xGurjari	-0.32	-5.13	2.10**	-0.31	-81.19**	-12.80**
IET-24762xNVSR-303-6	10.20**	-4.04	-0.43	-0.51	49.90**	-15.26**
IET-24762xIET-23825	-4.81	-0.59	0.26	3.11**	41.39**	-2.73*
GAR-13xIET-24765	-3.00	2.71	-0.85*	-0.59	59.97**	-5.37**
GAR-13xIET-24767	2.37	10.53*	0.88*	-1.57*	37.74**	-1.45
GAR-13xIET-24772	-7.89**	-11.28*	1.11*	2.67**	38.27**	10.24**
GAR-13xGurjari	-0.02	-1.29	-0.13	0.83	34.43**	-6.55**
GAR-13xNVSR-303-6	7.10*	-3.14	0.78*	-0.43	49.75**	2.54*
GAR-13xIET-23825	-1.29	-12.23**	1.35**	-0.01	29.17**	-2.03
IET-24765xIET-24767	4.58	4.52	1.14*	0.32	-6.31	-8.98**
IET-24765xIET-24772	4.27	-8.02*	-0.42	0.97	-35.97**	2.09
IET-24765xGurjari	1.18	1.62	0.45	0.92	-20.97**	1.92
IET-24765xNVSR-303-6	-1.62	-3.89	0.44	1.92*	-21.43**	-0.05
IET-24765xIET-23825	-1.28	-15.24**	1.08*	3.29**	43.85**	-3.51**
IET-24767xIET-24772	-7.76**	-3.54	0.78	-1.87*	-19.27*	2.07
IET-24767xGURJARI	1.94	-2.15	0.06	1.01	-11.74	2.54*
IET-24767xNVSR-303-6	-6.45*	-9.00*	1.85**	-0.25	-47.26**	8.62**
IET-24767xIET-23825	-2.32	6.64	-1.04*	3.11**	-11.10	-2.80*
IET-24772xGurjari	2.19	4.23	0.49	0.26	14.82*	-3.18*
IET-24772xNVSR-303-6	-4.37	-4.08	-0.78	-1.60*	39.84**	-9.95**
IET-24772xIET-23825	-1.33	-1.30	0.78	2.16**	43.96**	-4.79**
GurjarixNVSR-303-6	-0.43	2.96	0.09	-1.51*	61.38**	12.49**
GurjarixIET-23825	5.12*	-5.85	1.32**	4.25**	24.14**	5.80**
NVSR-303-6xIET-23825	7.05*	10.83*	0.05	-0.74	32.29**	5.08**
SE (Sij)	3.02	4.43	0.47	0.76	8.00	1.33
SE (Sij- Skl)	4.23	6.21	0.66	1.06	11.21	1.86

* Significant at 5 % and **Significant at 1 %

combinations (IET-24762 x IET-24765) 66.32 exhibited the maximum positive sca effect followed by (Gurjari x NVSR-303-6) 61.38 and (IET-24762 x IET-24767) 61.16 (Table 3).

The estimates of gca effect for the grain yield per plant of parents was ranged from -4.218 for IET-23825 to 6.58 for GNR-3. The parents, GNR-3 exhibited maximum significant gca effect in positive direction (6.58), followed by NAUR-1 (4.26), GAR-13 (2.49) and NVSR-303-6 (2.03) and were considered as good general combiners for higher grain yield per plant (Table 2). Estimates of sca effect ranged from -15.26 (IET-24762 x NVSR-303-6) to 15.61 (IET-24762 x IET-24765). Total 18 hybrids showed significant and positive sca effect (Table 3). The top hybrids showed significant and positive effect were (IET-24762 x IET-24765) 15.61 followed by (GNR-3 x IET-23825) 12.75 and (Gurjari x NVSR-303-6) 12.49 and these were appeared as good specific cross combinations in positive direction for obtaining higher grain yield per plant.

The estimates of gca effect for straw yield of parents was ranged from -6.02 for IET-23825 to 6.24 for NAUR-1. Among the all parents, three parents showed significant positive gca effects, parents NAUR-1 (6.24) had highest gca effects followed by IET-24765 (3.75) and NVSR-303-6 (2.21) and these were considered as good general combiners for obtaining higher straw yield per plant (Table 2). The estimates of sca effect ranged from -22.02 (GNR-3 x IET-23825) to 23.81 (GNR-3 x NVSR-303-6). Total 18 hybrids showed significant and positive sca effect. The hybrids which showed significant and positive effect was (GNR-3 x NVSR-303-6) 23.81 followed by (GNR-3 x IET-24765) 19.66 and (NAUR-1 x IET-24765) 16.80 and were appeared as good specific cross combinations for obtaining higher straw yield per plant (Table 3).

In case of test weight, the estimates of gca effect of parents ranged from -1.57 for the parent IET-24762 to 2.47 for GNR-3. Among the all parents, total three parents GNR-3 (2.47), Gurjari (1.71) and IET-23825 (1.04) showed significant positive gca effect and were considered as to be good general combiners for the development of rice varieties with more test weight. Range of sca effect of hybrids varied from -5.76 for cross combinations (IET-24772 x Gurjari) to 5.95 for the cross combinations (NAUR-1 x IET-24762). Total 22 hybrids showed significant and positive sca effect. The cross combination (IET-24772 x Gurjari) -5.76 was classified as better specific combination for the development of rice varieties with fine grain while cross combination (NAUR-1 x IET-24762) 5.95 was considered as better specific combination for development of variety with coarse grain.

For the protein content the estimates of gca effect of parents ranged from -0.63 for NAUR-1 to 0.32 for IET-23825 (Table 2). Among the all parents, six parents showed significant positive gca effects, parents IET-23825 (0.32) had highest gca effects followed by GAR-13 (0.26) and IET-24765 (0.18) these were considered as good general combiners for high protein content. The estimates of sca effect for protein content was ranged from -2.36 (Gurjari x NVSR-303-6) to 1.37 (NAUR-1 x GAR-13). Total 24 hybrids showed significant and positive sca effect. The top three hybrids which showed significant and positive effect was (NAUR-1 x GAR-13) 1.37 followed by (IET-24762 x IET-24765) 1.27 and (NAUR-1 xIET-24765) 1.22 and were appeared as good specific cross combination for obtaining higher protein content.

The range of gca effects for the iron content of parents were -4.01 for the parent Gurjari to 8.34 for the parent NVSR-303-6. Total five parents have significant positive gca effects were NVSR-303-6 (8.34), IET-24762 (2.34), GNR-3 (1.66), IET-24765 (1.58) and IET-24772 (1.33) and were considered as good general combiners for the development of bio fortified rice varieties. The values of sca effect varied from -14.72 for the cross (NAUR-1 x NVSR-303-6) to 15.32 for the cross (NAUR-1 x GNR-3). 19 hybrids showed positive and significant sca effect and were came out as better specific cross combinations for higher iron content. The top ranking three crosses with high sca effect were (NAUR-1 x GNR-3) 15.32 followed by cross (IET-24762 x IET-24767) 12.91 and (GNR-3 x IET-24765) 12.67.

The gca effect for the zinc content was found to be significant for eight parents but only four had significant positive effect. The range of gca effects for parents was -1.74 for GAR-13 to 2.01 for IET-24762. The parents IET-24762 (2.01), IET-24767 (1.11) Gurjari (0.71) and IET-23825 (0.34) had significant positive gca effects, these were considered as good general combiner for higher zinc content, while the estimates of sca effect for this trait was ranged from -5.80 (Gurjari x IET-23825) to 10.03 (NVSR-303-6 x IET-23825). 16 hybrids showed positive and significant sca effect and were came out as better specific combinations for higher zinc content. The hybrids which showed significant and positive effect was NVSR-303-6 x IET-23825 (10.03) followed by GAR-13 x Gurjari

(8.89) and GNR-3 x IET-24762 (8.18) were appeared as good specific cross combinations for obtaining higher zinc content.

Out of ten parents, only one parents exhibited significant positive gca effects for amylose content. The variation for the gca effects was from -0.38 (IET-24767) to 0.48 (IET-24762). The parents IET-24762 (0.48) are considered as the good general combiner for more amylose content. The values of sca effect varied from -2.75 for the cross (NAUR-1 x GNR-3) to 2.49 for the cross (GNR-3 x NVSR-303-6). 12 hybrids showed positive and significant sca effect and were categorized as better specific combinations for higher amylose content. The top ranking three crosses with high sca effect were (GNR-3 x NVSR-303-6) 2.49 followed by cross (NAUR-1 x IET-23825) 1.97 and (GNR-3 x IET-24767) 1.82.

From the foregoing discussion, it can be concluded that the crosses having best specific combination for grain yield per plant would have obtained either through poor x poor, poor x good and good x poor parental combinations. A character with preponderance of additive genetic variance would lead to the improvement of a character through selection in segregating generations. The presence and magnitude of various components of non-additive gene effect could be justified with heterosis breeding and in the present investigation yield and yield attributing traits were under the control of non-additive type of gene action hence, for the further improvement in yield and quality traits heterosis breeding may be rewarding. Further the parents NAUR-1, GNR-3, NVSR-303-6 and GAR-13 had good general combining ability for the grain yield and some of the yield attributing traits so, these parents may given due consideration for the further breeding programme. The crosses GNR-3 x GAR-13, GNR-3 x IET-23825, GNR-3 x Gurjari, Gurjari x NVSR-303-6 and NAUR-1 x IET-24765 could be exploited fully in future rice breeding programme by adopting heterosis breeding.

Table 4: Estimation of specific combining ability effect for straw yield per plant, test weight and protein content, iron content, zinc content and amylose content in rice.

Crosses	Straw yield per plant (g)	Test weight (g)	Protein content (%)	Iron content (ppm)	Zinc content (ppm)	Amylose content (%)
NAUR-1xGNR-3	6.83**	2.37**	-0.74**	15.32**	5.06**	-2.75**
NAUR-1xIET 24762	-0.74	5.95**	0.65**	1.37**	6.70**	1.38**
NAUR-1xGAR-13	-0.50	0.69	1.37**	-9.21**	1.36**	0.93*
NAUR-1xIET-24765	16.80**	-0.98	1.22**	-10.43**	1.94**	0.69
NAUR-1xIET-24767	-0.52	-0.28	-1.52**	2.53**	2.03**	0.57
NAUR-1xIET-24772	4.95**	3.44**	-0.45**	-0.23	2.27**	0.10
NAUR-1xGurjari	-5.38**	2.26**	0.12	-3.89**	-4.87**	1.19*
NAUR-1xNVSR-303-6	0.44	-0.70	-0.49**	-14.72**	-5.29**	1.24**
NAUR-1xIET-23825	4.48*	-2.93**	-1.79**	-1.33*	5.06**	1.97**
GNR-3xIET-24762	0.53	4.97**	-0.14	8.55**	8.18**	-0.36
GNR-3xGAR-13	10.93**	-0.07	0.96**	-7.07**	-3.26**	0.18
GNR-3xIET-24765	19.66**	-2.02*	0.95**	12.67**	-4.07**	1.60**
GNR-3xIET-24767	-6.45**	0.10	-0.17	-8.55**	0.85*	1.82**
GNR-3xIET-24772	-6.27**	5.41**	0.38**	-0.23	3.44**	-0.64
GNR-3xGurjari	-7.96**	-3.48**	-1.78**	-0.64	-1.06**	1.10*
GNR-3xNVSR-303-6	23.81**	-1.76*	0.60**	-9.46**	-2.58**	2.49**
GNR-3xIET-23825	-22.02**	-3.56**	-0.04	-9.83**	-3.06**	1.55**
IET-24762xGAR-13	-1.52	2.17*	-0.40**	4.43**	-5.33**	-0.09
IET-24762xIET-24765	12.86**	1.26	1.27**	1.92**	0.64*	-0.25
IET-24762xIET-24767	6.39**	-0.35	-0.76**	12.91**	-0.64*	-2.03**
IET-24762xIET-24772	-5.52**	-0.76	0.42**	-4.04**	-2.06**	0.49
IET-24762xGurjari	-14.78**	-3.33**	-0.96**	4.43**	-1.67**	-1.08*

Crosses	Straw yield per plant (g)	Test weight (g)	Protein content (%)	Iron content (ppm)	Zinc content (ppm)	Amylose content (%)
IET-24762xNVSR-303-6	-1.28	3.60**	-0.29*	-10.80**	0.06	0.29
IET-24762xIET-23825	1.83	-0.76	0.82**	-10.96**	-2.20**	0.02
GAR-13xIET-24765	-4.53**	-1.09	-2.29**	6.01**	-0.69*	-0.03
GAR-13xIET-24767	12.53**	-0.39	-0.70**	10.04**	0.33	0.52
GAR-13xIET-24772	-7.43**	3.87**	-1.12**	5.55**	-0.45	1.05*
GAR-13xGurjari	-11.90**	3.75**	0.70**	1.35*	8.89**	-0.19
GAR-13xNVSR-303-6	-8.58**	0.62	1.08**	0.57	-1.79**	-0.14
GAR-13xIET-23825	12.73**	4.18**	0.53**	-2.93**	6.64**	-0.75
IET-24765xIET-24767	-8.33**	5.31**	0.01	-14.37**	-2.63**	-0.06
IET-24765xIET-24772	-8.61**	5.56**	-0.30*	11.19**	0.44	0.13
IET-24765xGurjari	7.11**	3.99**	0.34**	-4.80**	4.83**	-0.12
IET-24765xNVSR-303-6	-17.84**	-0.19	0.50**	-8.28**	-3.69**	-1.05*
IET-24765xIET-23825	-10.33**	3.07**	0.77**	0.47	-3.43**	-0.33
IET-24767xIET-24772	6.28**	5.24**	1.10**	-9.85**	-2.40**	0.02
IET-24767xGURJARI	-3.83*	1.56*	0.34**	5.46**	-4.02**	-0.55
IET-24767xNVSR-303-6	9.28**	-0.09	0.74**	-10.23**	-1.45**	0.49
IET-24767xIET-23825	1.11	3.37**	0.75**	-8.03**	5.59**	-1.11*
IET-24772xGurjari	13.12**	-5.76**	0.96**	2.21**	-1.08**	-0.36
IET-24772xNVSR-303-6	-10.14**	-1.89*	1.00**	4.19**	-2.07**	0.35
IET-24772xIET-23825	10.25**	1.79*	0.08	-9.85**	-3.76**	-1.58**
GurjarixNVSR-303-6	-12.52**	1.53*	-2.36**	-1.60**	-2.02**	-1.56**
GurjarixIET-23825	10.51**	1.58*	1.02**	1.60**	-5.80**	0.82*
NVSR-303-6xIET-23825	5.54**	2.46**	0.84**	5.06**	10.03**	-1.12*
SE (Sij)	1.77	0.88	0.13	0.53	0.37	0.47
SE (Sij- Skl)	2.47	1.23	0.18	0.74	0.52	0.66

* Significant at 5 % and **Significant at 1 %

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Correlation and path coefficient analysis using a set of diverse genotypes of *Oryza* spp.

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Abstract

Considering the component traits is the important factor in selection for improvement of grain yield. Fifty-nine rice genotypes were field evaluated for yield traits in three consecutive crop seasons. Analysis of variance indicated the existence of significant differences among the genotypes for yield and its component characters during three seasons. The character association studies revealed that single plant grain yield had significant positive association with days to maturity, number of total tillers per plant, number of productive tillers per plant, panicle length, panicle weight, spikelet fertility, thousand grain weight, biomass per plant, biological yield per plant, harvest index and per day productivity indicating that these characters are very important for yield improvement and simultaneous selection of these characters will ultimately result in high yield. Path coefficient analysis revealed that number of filled grains per panicle exerted the highest positive direct effect on single plant grain yield followed by biological yield per plant, per day productivity, days to 50% flowering, thousand grain weight and plant height indicating that the selection for these characters was likely to bring about an overall improvement in grain yield.

Key words: Rice, Correlation, Path analysis, Grain yield

Introduction

Study of character association helps the breeder in fixing selection criteria for grain yield in parental lines, such that selections will be effective in isolating the plants with desired combination of characters. Various morphological and physiological plant characters contribute to yield and heading date. Yield contributing components are interrelated with each other and show a complex chain of relationship. Several workers have studied the correlation coefficients in rice and contradictory associations have been reported for almost all the character pairs which may be due to the experimental material and genotypic backgrounds in the studies. Interrelationship and relative contribution of each component trait towards yield is elucidated through path analysis. The path coefficient analysis which was initially developed by Wright (1921) and described by Dewey and Lu (1959) allows partitioning of correlation coefficient into direct and indirect effects of various traits towards dependent variable and thus helps in assessing the cause-effect relationship as well as effective selection. This is used in plant breeding programs to determine the nature of the relationships between yield and yield components that are useful as selection criteria to improve the crop yield. If the cause and effect relationship is well defined, it is possible to present the whole system of variables in the form of a path-diagram. In agriculture, path analysis has been used by plant breeders to assist in identifying traits that are useful as selection criteria to improve crop yield (Dewey and Lu, 1959). The present investigation was undertaken for screening and detecting trait association of rice genotypes belonging to different maturity groups.

Materials and Methods

Fifty-eight lines along with a check variety Prasanna (early maturing variety) were evaluated during *Rabi* 2014-2015, *Kharif* 2015 and *Rabi* 2015-2016 to estimate the genetic variability parameters among the genotypes for yield, and the extent of association between yield and its component characters including direct and indirect effects. The experiment was laid out in a Randomized Complete Block Design with three replications at Indian Institute of Rice Research, Hyderabad, Rajendranagar, during three seasons.

Estimation of Correlation Coefficients: Correlation coefficients were calculated using the formulae suggested by Karl Pearson (1920). Correlation coefficients were estimated based on pooled data of three seasons.

$$r_{xy} = \frac{\mathrm{cov}(xy)}{S_x \bullet S_y}$$

Where,

r_{xy}	=	correlation between x and y
Cov (xy)	=	covariance for characters x and y
S	=	Standard deviation
r	=	correlation coefficient
xy	=	two independent variables

Path Coefficient Analysis: The direct and indirect effects both at genotypic and phenotypic level were estimated by taking grain yield as dependent variable, using path coefficient analysis suggested by Wright (1921) and Dewey and Lu (1959). Direct and indirect effects were estimated based on pooled data of three seasons for 59 lines.

Results and Discussion

Crop yield is the end product of the interaction of a number of often interrelated attributes. A thorough understanding of the interaction of characters among themselves had been of great use in plant breeding. The efficiency of selection for yield mainly depends on the direction and magnitude of association between yield and its component characters and also among themselves. Character association provides information on the nature and extent of association between pairs of metric traits and helps in selection for the improvement of the character. Pooled genotypic correlations were worked out on single plant grain yield and yield contributing characters in fifty-nine genotypes. Results of pooled genotypic correlation analysis were presented in Table 1.

Days to 50 % flowering showed positive significant association at genotypic level with days to maturity, panicle length, panicle weight, number of filled grains per panicle, number of unfilled grains per panicle, number of total grains per panicle, biomass per plant and biological yield per plant. The similar findings were reported by Hasan *et al.* (2013), Patel *et al*. (2014) and Ravi *et al.* (2014) for days to maturity, Soni *et al*. (2013) for panicle length, panicle weight and biological yield per plant, Ratna *et al*. (2015) for number of filled grains per panicle and Patel *et al*. (2014) for biomass per plant. It showed positive non-significant association at genotypic level with spikelet fertility and single plant grain yield. Panwar (2006) and Mishra *et al*. (2014) for spikelet fertility, Golam *et al.* (2015) and Mishu *et al.* (2016) reported similarly for single plant grain yield. This trait showed negative significant association at genotypic level with plant height, thousand grain weight, harvest index and per day productivity. It expressed negative non–significant association at genotypic level with number of total tillers per plant, number of productive tillers per plant and sterility percentage. Similar results were reported by Chandra *et al.* (2009) and Ravi *et al.* (2014) for plant height, Bhadru *et al* (2012) for thousand grain weight and per day productivity, Madhavilatha (2002) and Ratna *et al*. (2015) for number of productive tillers per plant and Mishu *et al.* (2016) for sterility percentage.

Plant height (cm) showed positive significant association at genotypic level with panicle length, spikelet fertility, thousand grain weight, and biomass per plant and biological yield per plant. Ganapati *et al*. (2014), Patel *et al*. (2014), Golam *et al*.(2015) and Moosavi *et al.* (2015) showed positive significant association or panicle length, Soni *et al*. (2013) and Mishra *et al*. (2014) for spikelet fertility and thousand grain weight, Patel *et al*. (2014) for biomass per plant and Soni *et al*. (2013) for biological yield per plant. Positive non-significant association at genotypic level with panicle weight and per day productivity was observed in case of plant height. These results are in accordance with Bhadru *et al.* (2012) for per day productivity. Plant height also showed negative significant association at genotypic level with number of total tillers per plant, number of productive tillers per plant, number of unfilled grains per panicle, sterility percentage and harvest index. It expressed a negative non-significant association at genotypic level with number of filled grains per panicle, number of total grains per panicle and single plant grain yield. Similarly, negative association of these traits were reported by Golam *et al.* (2015) for number of total tillers per plant and number of productive tillers per plant, Panwar (2006) and Ganapati *et al*. (2014) for harvest index, Dilruba *et al*. (2014) and Ratna *et al*. (2015) for filled grains per panicle, Seyoum *et al.* (2012) and Rahman *et al.* (2014) for single plant grain yield.

Number of productive tillers per plant showed positive significant association at genotypic level with spikelet fertility, harvest index, per day productivity and single plant grain yield as reported by Hasan *et al*. (2013), Soni *et al*. (2013) and Mishra *et al*. (2014) for spikelet fertility, Ramanjaneyulu *et al*. (2014) for harvest index, Bhadru *et al*. (2012) for per day productivity, Rashid *et al.* (2014),

Table 1: Pooled genotypic correlation coefficient analysis of single plant grain yield and yield contributing characters in rice

	DFF	DM	PH(cm)	TN	PTN	PL(cm)	PW(g)	FG	UFG	TGP	SF (%)	SP (%)	TGW(g)	BM(g)	BY(g)	HI	PP(g)	SPY(g)
DFF	**1**	0.96**	-0.34**	-0.10	-0.10	0.22**	0.50**	0.74**	0.48**	0.72**	0.01	-0.01	-0.44**	0.60**	0.40**	-0.74**	-0.44**	0.01
DM		**1**	-0.37**	-0.04	-0.04	0.16*	0.55**	0.76**	0.50**	0.74**	0.05	-0.05	-0.47**	0.58**	0.46**	-0.63**	-0.32**	0.15**
PH(cm)			**1**	-0.69**	-0.61**	0.15*	0.13	-0.03	-0.27**	-0.07	0.44**	-0.44**	0.26**	0.38**	0.19*	-0.48**	0.04	-0.12
TN				**1**	0.94**	-0.52**	-0.75**	-0.80**	-0.78**	-0.82**	0.51**	-0.51**	0.07	-0.22**	0.09	0.51**	0.49**	0.49**
PTN					**1**	-0.61**	-0.75**	-0.72**	-0.69**	-0.74**	0.45**	-0.45**	-0.07	-0.18*	0.12	0.53**	0.51**	0.51**
PL(cm)						**1**	0.72	0.55**	0.38**	0.54**	-0.06	0.06	0.48**	0.62**	0.60**	-0.16*	0.28**	0.38**
PW(g)							**1**	0.87**	0.88**	0.90**	-0.22**	0.22**	0.19**	0.73**	0.58**	-0.60**	-0.07	0.20**
FG								**1**	0.76**	0.99**	0.00	-0.00	-0.33**	0.53**	0.32**	-0.74**	-0.37**	-0.05
UFG									**1**	0.83**	-0.65**	0.65**	-0.12	0.22**	0.05	-0.38**	-0.39**	-0.19*
TGP										**1**	-0.10	0.10	-0.30**	0.50**	0.28**	-0.70**	-0.38**	-0.08
SF (%)											**1**	-1.00**	-0.17*	0.21**	0.23**	-0.33**	0.16*	0.19**
SP (%)												**1**	0.17*	-0.21**	-0.23**	0.33**	-0.16*	-0.19**
TGW(g)													**1**	0.09	0.27**	0.45**	0.56**	0.42**
BM(g)														**1**	0.90**	-0.63**	0.23**	0.49**
BY(g)															**1**	-0.27**	0.59**	0.82**
HI																**1**	0.52**	0.28**
PP(g)																	**1**	0.88**
SPY(g)																		**1**

DFF -days to 50% flowering, DM-days to maturity, PH- plant height, PL-panicle length, PW-panicle weight, FG- number of filled grains/panicle, UFG-number of unfilled grains/panicle, TGP- number of total grains/panicle, TGW- thousand grain weight, SPY-single plant grain yield TN- number of tillers plant, PTN-number of productive tillers/plant, SF- spikelet fertility, SP- sterility percentage, BM- biomass /plant, BY -biological yield /plant, HI -harvest index, PP -productivity/day

* Significant at 5 per cent level; ** Significant at 1 per cent level

and Golam *et al*. (2015) for single plant grain yield and Mishra *et al.* (2014) for biological yield per plant. Number of productive tillers per plant showed negative significant association at genotypic level with panicle length, panicle weight, number of filled grains per panicle, number of unfilled grains per panicle, number of total grains per panicle, sterility percentage and biomass per plant. It expressed negative non-significant association at genotypic level with thousand grain weight. Similar results were reported by Babu *et al*. (2012), Rahman *et al*. (2014) and Ratna *et al*. (2015) for panicle length and Naseer *et al*. (2015) for total grains per panicle, Satyavathi *et al.* (2001) for number of filled grains per panicle and Golam *et al*. (2015) for thousand grain weight.

Panicle length (cm) had a positive significant association at genotypic level with number of filled grains per panicle, number of total grains per panicle, thousand grain weight, biomass per plant, biological yield per plant and single plant grain yield and a positive non-significant association at genotypic level with panicle weight and sterility percentage. The similar findings were reported by Patel *et al.* (2014) and Ramanjaneyulu *et al.* (2014) for number of total grains per panicle, Ganapati *et al*. (2014) for number of filled and unfilled grains per panicle, Patel *et al.* (2014) for thousand grain weight and biomass per plant, Soni *et al*. (2013) for biological yield per plant, Sindhumole *et al.* (2015) and Mishu *et al*. (2016) for single plant grain yield, Nandeshwar (2010) and Moosavi *et al*. (2015) for panicle weight and Mishu *et al.* (2016) for sterility percentage. It also showed negative significant association at genotypic level with harvest index and a negative non-significant association at genotypic level with spikelet fertility. Similar results were reported by Nandeshwar (2010) for spikelet fertility.

Panicle weight (g) showed positive significant association at genotypic level with filled grains per panicle, unfilled grains per panicle, total grains per panicle, sterility percentage, thousand grain weight, and biomass per plant, biological yield per plant and single plant grain yield as reported in the association studies of Ranwake and Amarasighe (2014) for total grains per panicle and filled grains per panicle, Soni *et al.* (2013) for thousand grain weight and biological yield per plant, Nandeshwar (2010), Bhadru *et al.* (2011), Awaneet and Senapati (2013), Soni *et al.* (2013) and Ranwake and Amarasighe (2014) for single plant grain yield. This trait showed negative significant association at genotypic level with spikelet fertility and harvest index.

Number of total grains per panicle showed positive significant association with biomass per plant and biological yield per plant. It showed positive non-significant association at genotypic level with sterility percentage. It showed negative significant association at genotypic level with thousand grain weight, harvest index and per day productivity. Spikelet fertility (%) showed positive significant association at genotypic level with biomass per plant, biological yield per plant, per day productivity and single plant grain yield. The results are in accordance with Soni *et al.* (2013) for biological yield per plant and Hasan *et al.* (2013), Soni *et al.* (2013) and Naseer *et al.* (2015) for single plant grain yield. This trait showed negative significant association at genotypic level with the traits, sterility percentage, thousand grain weight and harvest index. The results are in accordance with Divya *et al.* (2015) for sterility percentage.

Thousand grain weight (g) showed positive significant association with harvest index, biological yield per plant, per day productivity and single plant grain yield. It showed positive non-significant association at genotypic level with biomass per plant. The results are in similarity with Patel *et al.* (2014) Rahman *et al.* (2014), Naseer *et al*. (2015), Roy *et al*. (2015) and Mishu *et al.* (2016) for single plant grain yield. Biomass per plant (g) was in positive significant association at genotypic level with biological yield per plant, per day productivity and single plant grain yield as that of studies by Patel *et al*. (2014) for harvest index and Patel *et al*. (2014) and Ramanjaneyulu *et al*. (2014) for single plant grain yield. Harvest index had a positive significant association at genotypic level with per day productivity and single plant grain yield. Similarly, Panwar (2006), Soni *et al.* (2013), Patel *et al*. (2014) and Ramanjaneyulu *et al.* (2014) reported for single plant grain yield. Per day productivity (g) showed positive significant association at genotypic level with single plant grain yield as reported by Bhadru *et al*. (2012) for single plant grain yield.

Genotypic correlations revealed that single plant grain yield had significant positive association with days to maturity, number of total tillers per plant, number of productive tillers per plant, panicle length, panicle weight, spikelet fertility, thousand grain weight, biomass per plant, biological yield per plant, harvest index and per day productivity. It showed positive non- significant association with days to 50% flowering at genotypic level. The trait showed negative significant association with number of unfilled grains per panicle and sterility percentage and negative non-significant association with plant height, number of filled grains per panicle and number of total grains per panicle at genotypic level. Pleiotropy or linkage may also be the genetic reasons for this type of negative association. According to NeWall and Eberhart (1961), when two characters show negative genotypic correlation it would be difficult to exercise simultaneous selection for these characters in the development of a variety. Hence, under such situations, judicious selection programme might be formulated for simultaneous improvement of such important developmental and component characters.

Single plant grain yield showed positive significant association with days to maturity, number of total tillers per plant, number of productive tillers per plant, panicle length, panicle weight, spikelet fertility, thousand grain weight, biomass per plant, biological yield per plant, harvest index and per day productivity. Similar kind of association was reported by Ravi *et al.* (2014) and Golam *et al.* (2015) for days to maturity, Ramanjaneyulu *et al.* (2014) and Golam *et al*. (2015) for number of total tillers per plant and number of productive tillers per plant, Soni *et al.* (2013) and Ranwake and Amarasighe (2014) for panicle length and panicle weight, Soni *et al.* (2013) for spikelet fertility and biological yield per plant, Rahman *et al.* (2014), Naseer *et al*. (2015) and Mishu *et al.* (2016) for thousand grain weight, Patel *et al*. (2014) and Ramanjaneyulu *et al*. (2014) for biomass per plant, Panwar (2006), Soni *et al.* (2013) and Patel *et al*. (2014) for harvest index and Bhadru *et al*. (2012) for per day productivity. Hence, these characters could be considered as criteria for selection for higher yield as these were mutually and directly associated with grain yield.

Correlation gives the relation between two variables whereas path coefficient analysis allows separation of the direct effect and their indirect effects through other attributes by partitioning the correlations (Wright, 1921). Based on the data recorded on the genotypes across three seasons in the present investigation, the pooled genotypic correlations were estimated to determine direct and indirect effects of single plant grain yield and yield contributing characters. If the correlation coefficient between a casual factor and the effect is almost equal to its direct effect, it explains the true relationship and a direct selection through this trait may be useful. If the correlation coefficient is positive, but the direct effect is negative or negligible, the indirect effects appear to be the cause of that positive correlation. In such situation the other factors are to be considered simultaneously for selection. However, if the correlation coefficient is negative but direct effect is positive and high, a restriction has to be imposed to nullify the undesirable indirect effects in order to make use of direct effect. Results of pooled genotypic path coefficient of single plant grain yield and yield contributing characters discussed here under which were presented in Table 2 and Figure 1.

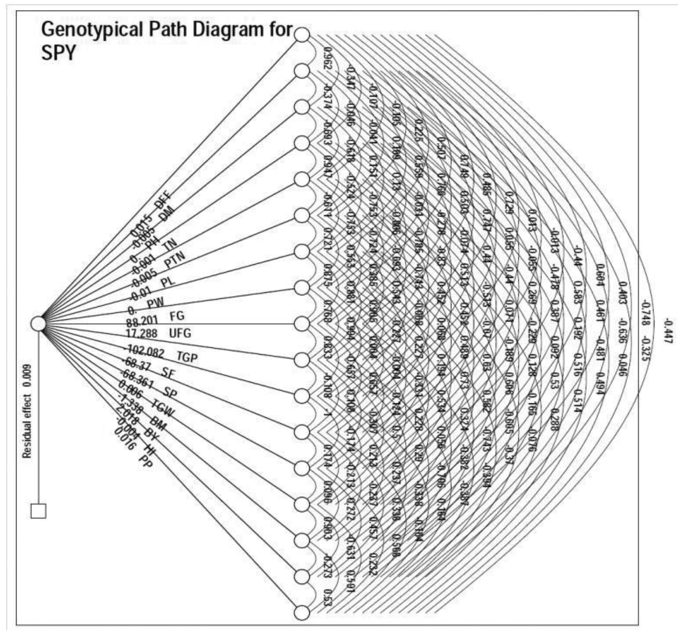

Figure 1: Pooled genotypical path diagram of single plant grain yield

The direct contribution of Days to 50% flowering to single plant grain yield was positive (0.0151) at genotypic level. These results are in agreement with Mohanty *et al.* (2012), Nikhil *et al*. (2014), Ravi *et al.* (2014), Golam *et al*. (2015) and Ratna *et al* (2015). This trait exhibited positive non-significant correlation with single plant grain yield due to indirect positive influence through number of total tillers per plant, number of productive tillers per plant, number of filled grains per panicle, sterility percentage, biological yield per plant and harvest index at genotypic level. The direct effect of Plant height on single plant grain yield was positive at genotypic level. These results are in agreement with Hasan *et al*. (2013), Nagaraju *et al.* (2013), Dilruba *et al.* (2014), Golam *et al.* (2015) and Naseer *et al*. (2015). This trait expressed negative non-significant correlation with single plant grain yield due to indirect positive influence on single plant grain yield through days to maturity, number of total tillers per plant, number of productive tillers per plant, number of total grains per panicle, sterility percentage, thousand grain weight, biological yield per plant, harvest index and per day productivity at genotypic level.

Table 2: Pooled genotypic path coefficient of single plant grain yield and yield contributing characters in rice

Character	DFF	DM	PH (cm)	TN	PTN	PL (cm)	PW(g)	FG	UFG	TGP	SF (%)	SP (%)	TGW(g)	BM(g)	BY(g)	HI	PP(g)	SPY(g)
DFF	**0.02**	0.00	0.00	0.00	0.00	0.00	0.00	66.07	8.38	-74.44	-0.87	0.87	0.00	-0.81	0.81	0.00	-0.01	0.01
DM	0.01	**0.00**	0.00	0.00	0.00	0.00	0.00	67.53	8.69	-76.22	-3.76	3.76	0.00	-0.78	0.93	0.00	-0.01	0.1562**
PH (cm)	-0.01	0.00	**0.00**	0.00	0.00	0.00	0.00	-2.74	-4.80	7.54	-30.08	30.08	0.00	-0.52	0.39	0.00	0.00	-0.13
TN	0.00	0.00	0.00	**0.00**	-0.01	0.01	0.00	-71.11	-13.57	84.68	-35.10	35.10	0.00	0.31	0.19	0.00	0.01	0.4919**
PTN	0.00	0.00	0.00	0.00	**-0.01**	0.01	0.00	-63.86	-11.98	75.84	-30.88	30.88	0.00	0.25	0.26	0.00	0.01	0.5107**
PL (cm)	0.00	0.00	0.00	0.00	0.00	**-0.01**	0.00	48.81	6.66	-55.47	4.67	-4.67	0.00	-0.84	1.22	0.00	0.00	0.3886**
PW(g)	0.01	0.00	0.00	0.00	0.00	-0.01	**0.00**	77.14	15.23	-92.37	15.49	-15.49	0.00	-0.98	1.18	0.00	0.00	0.2062**
FG	0.01	0.00	0.00	0.00	0.00	-0.01	0.00	**88.20**	13.28	-101.48	-0.30	0.30	0.00	-0.71	0.65	0.00	-0.01	-0.06
UFG	0.01	0.00	0.00	0.00	0.00	0.00	0.00	67.76	**17.29**	-85.05	44.95	-44.94	0.00	-0.31	0.11	0.00	-0.01	-0.1904*
TGP	0.01	0.00	0.00	0.00	0.00	-0.01	0.00	87.68	14.40	**-102.08**	7.36	-7.36	0.00	-0.67	0.58	0.00	-0.01	-0.08
SF (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	-11.37	10.99	**-68.37**	68.36	0.00	-0.28	0.48	0.00	0.00	0.1960**
SP (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.39	11.37	-10.99	68.37	**-68.36**	0.00	0.28	-0.48	0.00	0.00	-0.1960**
TGW(g)	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	-29.16	-2.15	31.30	11.87	-11.86	**0.01**	-0.13	0.55	0.00	0.01	0.4219**
BM(g)	0.01	0.00	0.00	0.00	0.00	-0.01	0.00	47.10	3.95	-51.04	-14.53	14.53	0.00	**-1.34**	1.82	0.00	0.00	0.4962**
BY(g)	0.01	0.00	0.00	0.00	0.00	-0.01	0.00	28.59	0.97	-29.56	-16.19	16.18	0.00	-1.21	**2.02**	0.00	0.01	0.8206**
HI	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	-65.49	-6.60	72.09	23.11	-23.11	0.00	0.84	-0.55	**0.00**	0.01	0.2883**
PP(g)	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	-32.67	-6.81	39.48	-11.24	11.24	0.00	-0.31	1.19	0.00	**0.02**	0.8864**

Genotypic residual effect = 0.0088

BOLD values are direct effects

DFF -days to 50% flowering, DM-days to maturity, PH- plant height, PL-panicle length, PW-panicle weight, FG- number of filled grains/panicle, UFG-number of unfilled grains/panicle, TGP- number of total grains/panicle, TGW- thousand grain weight, SPY-single plant grain yield TN- number of tillers plant, PTN-number of productive tillers/plant, SF- spikelet fertility, SP- sterility percentage, BM- biomass /plant, BY -biological yield /plant, HI -harvest index, PP -productivity/day

The direct effect of thousand grain weight (g) on single plant grain yield was positive at genotypic level. These results are in agreement with Dilruba *et al.* (2014), Rahman *et al*. (2014), Ratna *et al*. (2015), Naseer *et al*. (2015) and Golam *et al.* (2015). It expressed positive significant correlation with single plant grain yield due to indirect positive effects of this trait *via* days to maturity, plant height, and number of productive tillers per plant, number of total grains per panicle, spikelet fertility, and biological yield per plant and per day productivity at genotypic level. The direct effect of per day productivity on single plant grain yield was positive at genotypic level. These results are in agreement with Bhadru *et al*. (2012). Perday productivity showed positive significant correlation with single plant grain yield due to indirect positive effects of this trait *via* days to maturity, number of total grains per panicle, sterility percentage, thousand grain weight and biological yield per plant at genotypic level. Whereas, days to 50% flowering, number of total tillers per plant, number of productive tillers per plant, panicle length, number of filled grains per panicle, spikelet fertility, biomass per plant and harvest index showed negative indirect effect at genotypic level.

The association of different component characters among themselves and with yield is quite important for devising an efficient selection criterion for yield. The total correlation between yield and component characters may be some times deceptive, as it might be an over-estimate or under-estimate because of its association with other characters. Hence, indirect selection by correlated response may not be productive always. When many characters are affecting a given character, splitting the total correlation into direct and indirect effects as proposed by Wright (1921) would give more meaningful interpretation to the cause of association between the dependent variable like yield and independent variables like yield components. This kind of information will be helpful in formulating the selection criteria, indicating the selection for these characters is likely to bring about an overall improvement in single plant grain yield directly.

Path coefficient analysis revealed that number of filled grains per panicle exerted the highest positive direct effect on single plant grain yield followed by biological yield per plant, per day productivity, days to 50% flowering, thousand grain weight and plant height indicating that the selection for these characters was likely to bring about an overall improvement in single plant grain yield directly. Therefore, it is suggested that preference should be given to these characters in the selection programme to isolate superior lines with genetic potentiality for high yield in rice genotypes. Negative direct effect on grain yield was exhibited by days to maturity, number of total tillers per plant, number of productive tillers per plant, panicle length, panicle weight, spikelet fertility, sterility percentage, and biomass per plant and harvest index.

In conclusion, a perusal of genetic variability parameters along with trait association revealed that number of total tillers per plant, number of productive tillers per plant, biomass per plant, biological yield per plant and per day productivity across all the three seasons, which indicate preponderance of additive gene action, hence these traits could be used for selection in crop improvement. Character association and path analysis indicated that thousand grain weight, biological yield per plant and per day productivity displayed significant positive correlation as well as positive direct effect on single plant grain yield. The positive direct effect of these traits on yield resulted in strong genetic correlation. Hence, these traits were considered as important attributes in formulating selection criterion for achieving desired targets.

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Breeding strategy for improvement of rice maintainer lines through composite population for short term diversity

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Abstract

Hybrids commercially grown in the country gives 15-20% yield advantage over the best inbred varieties. There is a need to increase the magnitude of heterosis level to 20-30% besides improving grain quality and other desirable traits like plant type, number of productive tillers, flowering duration, desirable plant height, grain type, yield, maintenance ability, disease and insect pest resistance etc. In present study we developed base composite populations suitable to local conditions using original gene pool obtained from International Rice Research Institute (IRRI) by adding 10 component lines for above mentioned different traits. More than 950 productive segregants selections were made and stabilized through pedigree method for desirable traits. The developed lines are superior for different traits. This indicates population improvement strategy is bringing the superior allele into one line in short period of time from different genotypes. This method is very useful to increase diversity in hybrid rice parental lines within known time.

Key words: Hybrid rice, parental line improvement, composite population, diversity

Introduction

More-than half of Indian population and many parts of the world especially in Asia depends mainly on rice for their calorie requirements. Now-a-days food security is main concern with available resources like declining of land, labour, agricultural inputs with changing climate (Arunachalam, 1981). Also food security must be achieved with lesser environment pollution. To meet above challenge one of the practical and feasible options is exploitation of heterosis in food crops (Donghui *et al.*, 2014). Heterosis is superiority or inferiority of F_1 over its parent for different traits. The utility of heterosis was first practically exploited in maize and in case of rice it was first utilized by China. In India, although first hybrids developed during 90's and now area under rice hybrids is less than 3 m ha till date. The main reason for less popularization hybrid rice is due to magnitude of heterosis level is only 15-20% and amenable to many pest and diseases along with nutrition and quality concern (Arunachalam and Katiyar, 1982). In order to increase the rice productivity and area under hybrids of our country, it is very much essential to increase heterosis level to 25-30%. To achieve this goal we have to improve the hybrids parental line performance through diversifying its genetic background. The highly commercialized hybrids analysis shows parents are more diverse (Melchinger and Gumber, 1998). Hence, it is very much essential to select more diverse parental lines viz., CMS line, maintainers and restorer. But, right now our breeding program depends only on very narrow genetic base parental line stocks. Recombination breeding and genetic male sterility (GMS) facilitated population improvement are the two most important breeding approaches which are being used for genetic improvement of parental lines (maintainers and restorers) of hybrid rice to create variability and to exploit higher heterosis in hybrids. The required objective can be achieved within short period of time through GMS based composite population facilitated with recurrent selection (Arunachalam, 1981) since, conventional breeding approach have its own drawbacks to create variations for all traits within a stipulated time. Recurrent selection breeding approach is applicable where natural crossing mating system is available. In rice, GMS provides opportunities to natural crossing and recurrent selection provides for continuous recombination, accumulation of favourable genes, broadening of the genetic base and breaking of undesirable linkages.

In the present study, parental line (maintainer) was diversified through genetic male sterility facilitated composite population with recurrent selections for different traits like plant type, number of productive tillers, flowering duration, desirable plant height, floral traits, disease and insect pest resistance etc.

Materials and methods

Two IRRI Philippines bred maintainer composite populations viz., IR 71590-CP-140 (ME) and IR 71591-CP-141 (M) belonging to medium early and medium maturity group respectively, were used as base population.

For development of new Indian Institute of Rice Research (IIRR) bred maintainer composite population, genetically diverse and indigenously bred maintainers were used with several desirable traits viz., plant type, number of productive tillers, flowering duration, desirable plant height, grain type, yield, maintenance ability, floral traits, disease and insect pest resistance as component lines. In the first generations of gene pool development 8-10 component lines were crossed with GMS plants selected from the respective base populations. The breeding procedure is according to developed at IRRI using male sterility facilitated recurrent selection (Figure 1). This method involves genetic male sterility in the background of maintainer and component lines are diverse with desirable traits.

Results and discussion:

Population improvement is a medium to short term breeding approach for development of genotype of interest (Arunachalam and Katiyar, 1982). In each breeding cycle, individual plants are selected and best performing individuals are recombined. As against quick fixation of genes during selfing generations of recombination breeding, the genetic male sterility facilitated recurrent selection provides for continuous recombination, accumulation of favourable genes, broadening of the genetic base and breaking of undesirable linkages.

At IRRI, two composite populations of maintainer viz., IR 71590-CP-140 and IR 71591-CP-141 were developed by genetic male sterility facilitated recurrent selection (Table 1). By using IRRI bred populations as GMS source, at IIRR, Hyderabad, two maintainer composite populations (DRCP-104 & DRCP-105) were developed (Table 2) by adding 10 component lines to genetic male sterility composite population through producing F_2 for each component lines individually with GMS line as female. After producing F_2 with each component line, was mixed

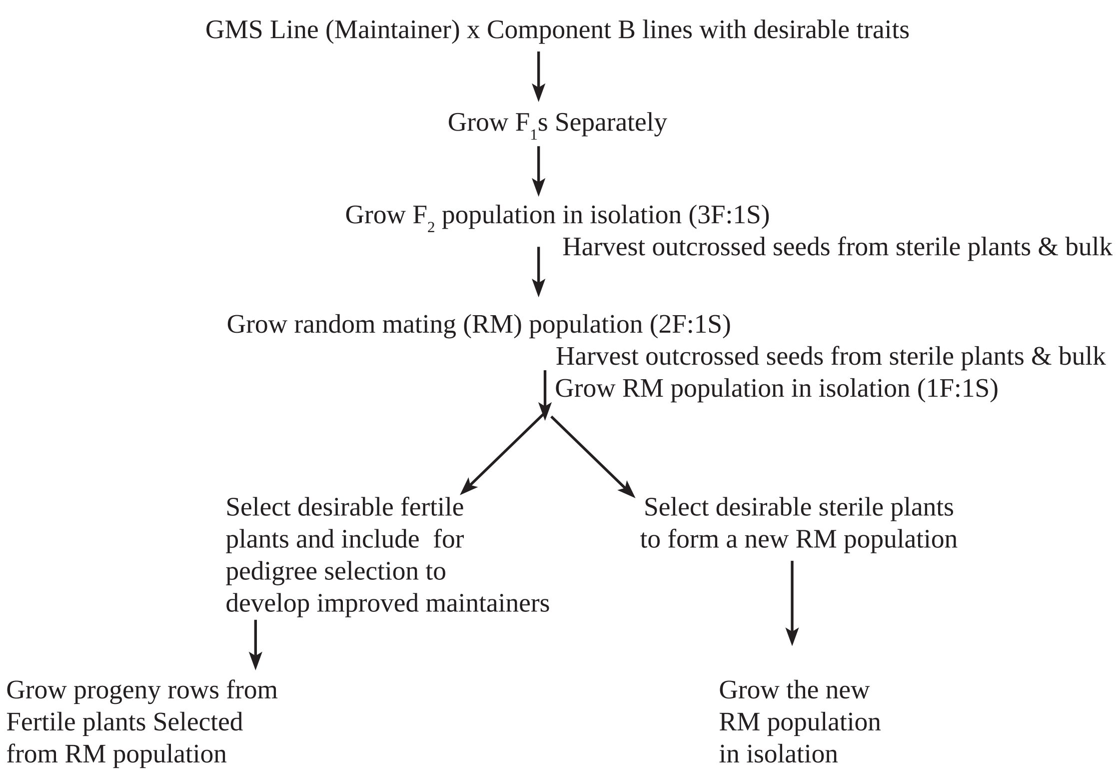

Figure 1: Schematic representation used to develop new random mating maintainer composite populations facilitated with recurrent selection at IIRR

in equal or varied quantity of seeds depends on trait of interest in order to maintain genetic heterogygosity or variability over a period of time (Xiao *et al*., 1996). This is called as composite population. In the subsequent season onwards, isolation was maintained at field condition after planting to avoid any contamination from other field or pollen source and to select productive segregants for trait of interest.

Table 1: Composition of original populations developed at IRRI

Name of populations	Male sterility source	No. of lines	Special attributes
IR 71590-CP-140(ME)	**IR 70413 (ms)**	**4**	Good grain quality, high yield potential, multiple disease and insect resistance, high GCA, good maintenance ability.
IR 71591-CP-141(M)	**IR 58025B (ms)**	**7**	

In our study, the main selection criteria used were semi-dwarf plant stature, moderate to heavy panicle, synchronous tillering, high rate of stigma exsertion, medium to long slender grains, sturdy culm and different maturity group (Figure 2). Large number of productive segregants selected from the populations is being handled by pedigree method (Arunachalam and Srivastava, 1980). Newly bred genetically diverse parental lines were first tested for its maintainer ability/reaction. The details of the newly developed populations were given in the Table 2.

Table 2: Maintainers Gene pools developed at IIRR, Hyderabad

Maturity group	No. of gene pools	No. of component lines added	No. of Lines developed	Special attributes
Medium	1	10	460	Better grain quality (LS, MS grains); Good maintenance ability; Improved plant type traits; High out-crossing ability (Stigma exsertion); Multiple disease and insect pest resistance; Better combining ability for yield and yield contributing traits, productive tillers, plant type, intermediate plant height, desirable flowering duration and synchronous tillering ability.
Medium Early	**1**	**8**	**510**	
Total	**2**	**18**	**970**	

Figure 2: Field view of composite population newly developed at IIRR

Some of the key points taken in to consideration while developing new populations are (i) Constituting populations based on maturity group, (ii) Growing populations in isolation, (iii) Continuous recombination and breakage of undesirable linkages, (iv) Accumulation of favourable alleles, (v) Flexibility in reconstituting the populations, (vi) Maintain heterogeneity of pollen by supplementary pollination, (vii) Fertile and productive segregants are handled by pedigree method, (viii) Seeds set on sterile plants are bulked to constitute next population, (ix) Bulking of seeds of selected fertile plants which segregate for male sterility to develop new population and (x) Introduction of new lines and reconstitution of populations.

The greatest advantage of the composite population is that, recombination and transgressive segregants. To achieve this, we have grown more-than three thousand plants in isolation with supplementary pollination. When the crop is grown in isolation, there may be chances for a high frequency of selfing too. Then population become less variable and selection in that population become less effective or phenotypically similar after 6-8 generations. After this process, the selected individual genotypes have traits of all component lines with genotypically uniform. The population can be regenerated again after adding up desired component line after tested for trait of interest (Katiyar and Arunachalam, 1981).

In order to broaden the genetic base of maintainers and also to increase the frequency of favourable alleles for wide range of desirable traits this novel method of genetic male sterility facilitated population improvement is a boon to hybrid rice breeders as this method allows for continuous recombination, helps to break the unwanted linkages thus widening the genetic base of the parental lines of hybrid rice.

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Seed storage protein evaluation of few rice varieties used by tribal people of Chhattisgarh

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Abstract

Seed storage protein profiling of seven local rice varieties namely Jeeraphul, Karheni, Sighar, Ratua, Lusari, Chhindmauri, Kalinga collected from Pratappur, Chhattisgarh were analyzed in the present study. Albumin was observed to be notably lowest in all rice varieties (1.2 mg/g to 14.4 mg/g of seed flour) where as glutelin fraction was found to be the highest (19.6 mg/g to 67.6 mg/g of seed flour) in all varieties. The percentage yield of prolamin is high in Lusari and Ratua i.e. 58.5 mg/ g of seed flour where as Karheni and Sighar varieties were found to have least prolamin i.e. less than 2 mg/g of seed flour. Seed storage protein profile analysis revealed polymorphic prolamin banding pattern in Kalinga and Karheni rice varieties where as similar globulin and glutelin profiles observed among all the studied varieties.

Key words: Rice, Seed storage protein, Prolamin

Introduction

Chhattisgarh is responsible for more than 70% of the Country's rice production and popularly known as Rice bowl of India (Rahman et al., 2006). Many rice varieties have been documented from this region that are consequence of centuries of rice farming by native communities through adaptation and selection to a variety of micro-ecosystem conditions. Cereals are the major source of energy, protein, vitamins and minerals for the world's largest population (McKevith 2004). In addition, rice protein is hypoallergenic and rich in lysine (Wang et al., 2014). Therefore, rice protein is commonly used in baby foods of limited formula for children with food sensitivity. Rice seed storage protein is a significant source of energy and nutrition, the second most copious ingredient of rice after starch (Chen et al., 2018). The major classes of seed storage protein in rice have been classified according to their relative solubility into four fractions: albumin, globulin, prolamin and glutelin. Many reviews and research papers have been published in the recent years on rice seed storage proteins and they have confirmed that storage globulin constitute major endosperm storage protein in rice. The rice proteins are usually not soluble in dilute salt solutions and categorised as glutelins, but they actually belong to the 11–12S globulin family (Shewry and Halford 2002).

Rice protein is considered to be of high-quality as it contains eight out of ten essential amino acids. Rice has elevated level of lysine in comparison to wheat and maize, which provides high digestibility and dietary quality (Santos et al., 2013). The identification of protein rich rice genotypes not only revolutionized plant breeder's but also increase the nutritional quality of the diet in poor tribal communities where rice act as the staple food. The present study is an attempt to determine the contents of four seed storage protein fractions (albumin, globulin, prolamin and glutelin) among few rice varieties of Chhattisgarh.

Materials and Methods

Plant materials: Seven local rice varieties such as Jeeraphul, Karheni, Sighar, Ratua, Lusari, Chhindmauri, Kalinga were collected from Pratappur, Surajpur district of Chhattisgarh (Figure 1). Whole seeds were crushed to fine powder that is used as the raw material in this study.

Extraction, Quantification and electrophoresis of various seed storage proteins: The protein extraction was performed at room temperature. Rice flour (200 mg) of different varieties successively extracted with (i) 500 ul of deionized water, (ii) 1 M NaCl (iii) 80% alcohol and (iv) 0.01 M NaOH for the extraction of four major seed storage

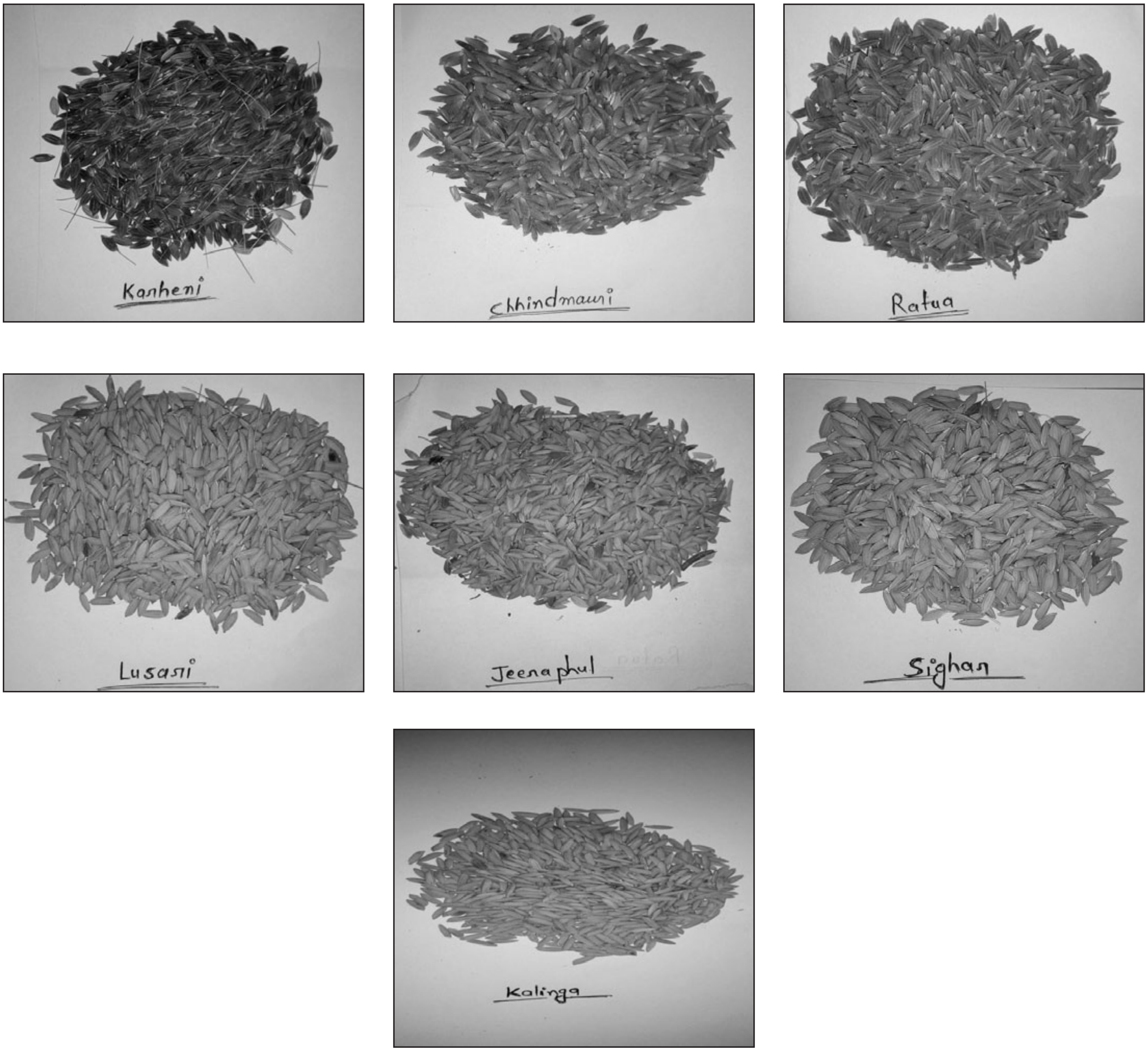

Figure 1: Photographs of collected rice varieties

proteins i.e. albumin, globulin, prolamin and glutelin respectively (Figure 2). Protein concentrations were estimated by Lowry method using BSA as standard (Lowry et al., 1951). The percentage yields were calculated as per the formula: (Protein fraction/ Total seed storage protein X 100) (Khanzada et al., 2016). Seed storage protein profile was done by Laemmli's discontinuous buffer system (Laemmli 1970) on a vertical gel containing 4% stacking gel and 12 % resolving gel of 29.2 % acrylamide / 0.8 % N,N'-methylene- bis-acrylamide (BIS). 5 µl each of protein were mixed separately with 5 µl of sample buffer (1.25 ml 1M Tris-HCl, 2.5 ml glycerol, 2 ml 10% SDS,0.2 ml 0.5% BPB final volume make up to 10 ml). These mixtures were boiled at 100°C for 2 minutes and then loaded on to the wells of a polyacrylamide gel. Protein gels were stained with 50% methanol, 10% acetic acid, and 0.25% Coomassie brilliant blue. The molecular weight of protein bands determined manually by calculating the Rm (relative mobility) and considering BSA as the standard.

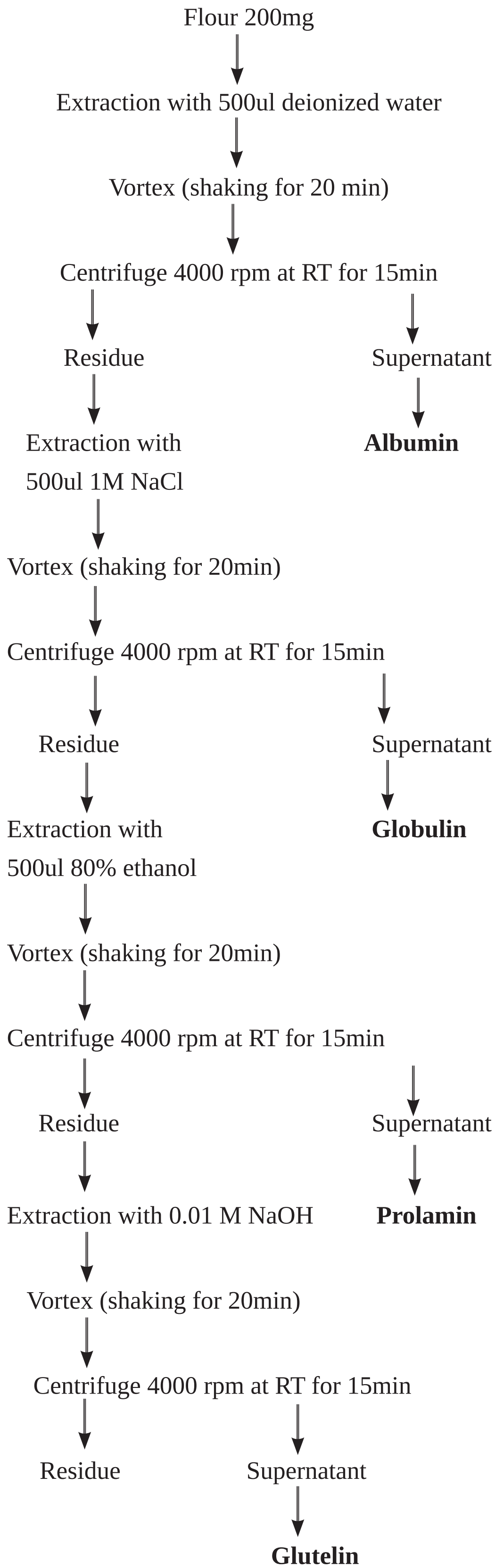

Figure 2: Flow chart for rice seed storage protein extraction

Results and Discussion

The collected local rice varieties varied in their protein contents. Variation in kernel color, grain size and protein content of all rice varieties are summarized in Table 1. The color of seeds in different rice varieties are red, light red and white.

Table 1: Grain colour, size and total seed storage protein of the collected rice varieties

S. No	Rice varieties (Local name)	Seed color	Grain size mm	Total seed storage protein (mg/g of seed flour) (Albumin+ Globulin + Prolamin + Glutelin)
1	Lusari	Light red	5.0	89.65
2	Karheni	White	7.0	1.85
3	Sighar	White	6.2	24.73
4	Chhindmauri	White	6.0	72.75
5	Kalinga	White	4.8	59.25
6	Ratua	White	6.8	122.1
7	Jeeraphul	White	6.3	88.6

Fractionation of seed storage protein based on their solubility: The storage proteins are generally categorized in four types due to their solubility: albumin- H_2O soluble, globulin- NaCl soluble, prolamin- alcohol soluble and glutelin- NaOH soluble protein. Albumin was found to be significantly low in all rice varieties except Ratua (14.4 mg/ g of seed flour). Globulin yield is low in Karheni and Jeeraphul (0.8 mg/ g of seed flour) where as Chhindmauri , Lusari and Kalinga contain 3.2, 5.95 and 6.75 mgof globulin/g of seed flour. . The percentage yield of prolamin is high in Lusari and Ratua i.e. 49.24 and 47.91 % respectively, where as Karheni and Sighar varieties were found to have least prolamin i.e. less than 2 mg/g of seed flour (Table 2). Glutelin fraction was found to be the highest in all varieties except Sighar i.e. 19.6 mg/ g of seed flour (Table 2). Ratua variety identified with the highest levels of albumin, prolamin and glutelin protein fractions (Table 2).

Seed storage protein is a distinctive quantitative trait usually affected by environment (Shewry, 2007). The combination of conventional breeding and marker assisted selection will provide a more proficient move towards improving the storage protein content of the rice grain than traditional breeding (Zhang et al., 2008).There are reports that prolamin and glutelin constitute 80-85% of rice total seed protein and are the good pointer of high protein content (Vithyashini and Wickramasinghe 2015). Glutelin protein is repoted to be rich in essential amino acids and recognized as easily digestible protein (Resurreccion *et al.*, 1993). The present study revealed that out of the seven studied local rice varieties six are glutelin rich.

Polymorphism of storage proteins in different rice varieties

There were differences in protein banding patterns between the local rice varieties. As shown in Figure 5, similar prolamin band was observed for Jeeraphul, Sighar and Lusari respectively. However, marked difference observed in the prolamin banding pattern of Kalinga and Karheni rice varieties. The prolamin band with aproximate size of 14 kDa was found in all studied varieties except Karheni. All the rice varieties showed monomorphic globulin (approximate size of 26kDa) and glutelin (approximate size of 22kDa) profile (Figure 3 and 4). Jin et al. (2006) have reported that 80% of rice varieties had similar seed storage patterns, suggesting that storage protein polymorphism in rice cannot be used to distinguish different ecotypes. In contrast the present study showed different patterns of prolamin seed storage proteins.

Table 2: Comparison of the concentrations and total percent yield of the major seed storage proteins

S.No.	Rice varieties	Albumin		Globulin		Prolamin		Glutelin	
		mg/g	% Yield	mg/g	% yield	mg/g	% yield	mg/g	%yield
1	Lusari	1.2	1.33	5.95	4.40	**58.5**	42.94	**24**	26.77
2	Karheni	ND	--	0.8	43.24	1.05	46.75	ND	--
3	Sighar	3.2	12.93	ND	--	1.93	7.80	19.6	79.25
4	Chhindmauri	1.8	2.47	3.2	4.39	**29.25**	40.20	**38.5**	52.92
5	Kalinga	1.6	2.70	6.75	11.79	6.8	11.47	**44.1**	74.43
6	Ratua	**14.4**	11.79	ND	--	**58.5**	47.91	**49.2**	40.29
7	Jeeraphul	1.4	1.58	0.8	0.90	18.8	21.21	**67.6**	76.29

Bold font indicates high values of seed storage proteins observed in samples, ND – Not Detectable, -- Not Measurable

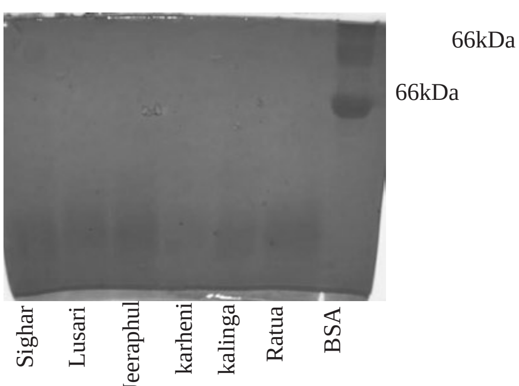

Figure 3: SDS-PAGE analysis Globulin protein bands

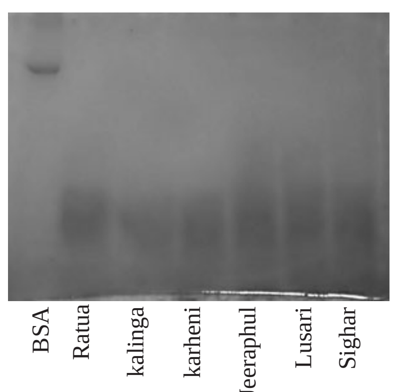

Figure 4: SDS-PAGE analysis of Glutelin proteins

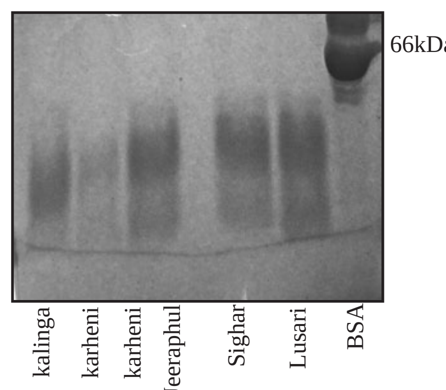

Figure 5: SDS-PAGE analysis of Prolamin proteins (Black arrow shows polymorphic fragments)

Conclusions

The present work provides information on seed storage protein profiling of seven local rice varieties. In conclusion, this study revealed that out of the seven local rice varieties collected, six varieties are glutelin rich. Seed storage protein profile analysis revealed polymorphic prolamin banding pattern in Kalinga and Karheni rice varieties. These polymorphic fragments may be exploited as markers for rice breeding.

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Evaluation of germplasm accessions for resistance to rice Brown planthopper, *Nilaparvata lugens* (Stål)

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Abstract

A total of 1003 germplasm accessions collected from different parts of India were mass screened for their reaction to brown planthopper, *Nilaparvata lugens* (Stål) by standard seed box technique using TN1 and PTB 33 as susceptible and resistant checks respectively during 2015-16 at Indian Institute of Rice Research, Hyderabad. Out of 1003 entries screened, 37 entries exhibited a damage score (DS) ranging from 0-5 and were designated as highly resistant, resistant and moderately resistant to BPH, and the remaining 966 entries were susceptible with a damage score of 5.1-9.0. Out of 37 accessions, two accessions *viz.*, IC 75975 (DS-0.77), IC 216750 (DS-(0.80) were highly resistant, 21 accessions were resistant (DS-1.0-3.0) and 14 accessions were moderately resistant (DS- 3.1-5.0). The selected resistant entries were assessed for their feeding preference by brown planthopper by measuring feeding marks. They exhibited more number of probing (feeding) marks by BPH ranging from 5.2–31.6/seedling indicating the non-suitability of the accessions for feeding by the insect. Resistant check PTB-33 recorded 18.4 probing marks and susceptible TN1 recorded 3.1 probing marks/ seedling. The identified resistant germplasm accessions can be used in the breeding programmes to develop BPH resistant varieties.

Key words: Brown planthopper, germplasm accessions, host plant resistance, mass screening, *Nilaparva lugens*, probing marks.

Introduction

Rice is one of the world's most important staple food crops. There are many constrains in the rice production among which insect pests remain a constant problem in all rice growing areas. One of the most economically important insects is the brown planthopper (BPH), *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae) which can cause huge damage where both nymphs and adults suck the plant sap directly and indirectly transmits viral diseases such as ragged stunt and grassy stunt (Jena *et al*., 2006). Due to the infestation, plants turn yellow and dry up rapidly. At early infestation, yellow patches appear, which soon turn brownish due to the drying up of the plants resulting in 'hopper burn', and could result in 30-100% yield loss (Park *et al*., 2008). The control of BPH with chemical insecticides not only results in insecticide resistance development, but also has detrimental impact on natural enemies (Jhansi Lakshmi *et al*., 2010a and c and b; BalaKrishna and Satyanarayana, 2013). Host plant resistance is the most important measure to keep the insect pests under control. It is considered, that a resistant plant variety that reduces the insect population by 50 per cent in each generation is sufficient to eliminate an insect of economic importance within few generations (Painter, 1951). The necessity to identify suitable new resistant donors for brown planthopper from different sources is important in order to combat the pest and develop varieties resistant to BPH. It is also necessary to understand the mechanisms responsible for manifesting resistance into the selected cultures with desirable characters, so that these can be utilized effectively in the breeding programme. Keeping this in view, present investigation was planned to evaluate the germplasm accessions for their resistance to brown planthopper and to study the antixenosis mechanism of resistance for feeding.

Materials and methods

Mass rearing of brown planthopper: BPH was mass reared on the susceptible rice variety TN1 as described by Jhansi Lakshmi *et al*., 2010c. BPH population was initially collected from rice fields and pure culture was maintained in the greenhouse at a temperature of 30±5°C with a relative humidity of 60±5% on 60 day old potted rice plants. Mass rearing was done in the cages of 70 cm x 62 cm x 75 cm dimension with glass panels on one side and wire mesh on all other sides. Twenty adult gravid female hoppers were collected with an aspirator and were released on pre-cleaned potted plants and were placed in oviposition cages. After four days of egg laying, the gravid females were collected and released on fresh batch of TN1 plants for further egg laying. Plants with eggs were taken out of cages and placed in separate cages for the nymphs to hatch. Fresh plants were placed in the cages with nymphs as and when required. The hatched nymphs were utilized for experiments as and when they attained the desired age. Necessary precautions were taken to keep the culture free from predators such as mirid bugs, spiders, other natural enemies and other hoppers like WBPH and GLH. Using this technique, a continuous pure culture of BPH was maintained during the period of study.

Mass screening of germplasm accessions: In order to identify the sources of resistance to BPH, 1003 germplasm accessions were mass screened under controlled greenhouse conditions as per the technique described by (Kalode *et al.*, 1975). The entries were pre-germinated in petridishes and sown individually with the help of forceps in screening trays (50cm x 40cm x 8cm) filled with fertilizer enriched puddled soil. Each screening tray contained 20 test lines with about 15 -20 seedlings per line, one row of resistant check (PTB 33) in the middle and two rows of susceptible check (TN1) in the border. Each row of susceptible and resistant check contained 30-40 seedlings. After planting, the screening trays were placed in fibre trays (60cm x 180cm x 8cm) filled with water. The screening trays were covered with mylar cages when the plants were 12-13 days old to prevent escape of the nymphs. First and second instar nymphs of BPH were released on the seedlings by tapping heavily infested plants from oviposition cages on the screening trays, ensuring that each test seedling was infested with at least 6-8 nymphs. The infested trays were monitored regularly for plant damage. When TN1 plants on one side showed damage, the tray was rotated by 180^{O} for even reaction on both the sides. When more than 90 per cent plants in the susceptible check were killed, the test entries were scored for the damage reaction, based on the 0-9 scale of International Standard Evaluation System (SES, 2013) (Table 1). All the 1003 germplasm entries were screened in two replications and the identified resistant accessions were screened in 5-7 replications.

Table 1: Criteria for BPH damage score in greenhouse screening

Resistance score	Plant state	Rating
0	No damage	Highly Resistant
1	Very Slight damage	
3	Lower leaf wilted with two green upper leaves	Resistant
5	Two lower leaves wilted with one green upper leaf	Moderately resistant
7	All three leaves wilted but stem still green	Moderately susceptible
9	All plants dead	Susceptible

Feeding behaviour of adult brown planthopper on 50 selected germplasm accessions based on probing marks: The highly resistant, resistant and moderately resistant entries along with some susceptible accessions, susceptible and resistant checks were selected to find out the feeding behaviour of one day old adult and third instar nymphs of brown planthopper expressed in terms of feeding marks or probing marks on the leaves and stems of the rice entries (Naito 1964). For this purpose, a single one day old adult female, third instar was caged for 24 hours on seven day old test entry in a test tube and this was replicated five times. After 24 hours, the insect was removed and the test plant was stained by dipping for one hour in one per cent aqueous erythrosine solution to distinguish the feeding marks from the test entries. The feeding marks were counted and the data were analysed statistically in completely randomized block design and the means were separated using DMRT.

Results and discussion

Germplasm accessions resistant to BPH

Results pertaining to screening of 1003 germplasm accessions are presented in Table 2.

Out of these 1003 germplasm accessions, 37 accessions exhibited a damage score (DS) ranging from 0-5 and were designated as highly resistant, resistant and moderately resistant to BPH, and the remaining 966 accessions were found susceptible with a damage score of 5-9. Out of 37 accessions, two accessions *viz.*, IC 75975 (DS-0.77) and IC 216750 (DS-0.80) were highly resistant, 21 accessions *viz.*, IC 76013, IC 76057, IC 216735, IC 216974, IC 540644, IC 216759, IC 216553, IC 75961, IC 76010, IC 216636, IC 75990, IC 216737, IC 216585, IC 216602, IC 216788,

IC 217492, IC 216618, IC 215054, IC 216680, IC 218166 were resistant (DS-1.0-3.0) and 14 accessions viz., IC 217610, IC 218053, IC 75797, IC 76000A, IC 217507, IC 76033, IC 216650, IC 216605, IC 216651, IC 216944, IC 217750, IC 217309, IC 216678 were moderately resistant (DS-3.1-5.0) (Figures 1 a, b and c).

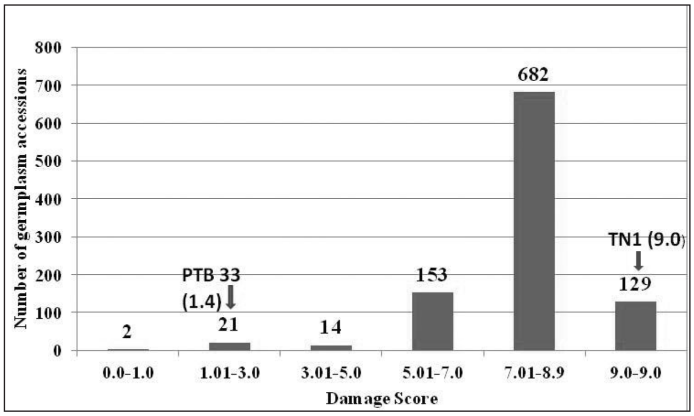
The frequency distribution graph (Figure 2) shows that in the remaining 964 germplasm accessions, 153 accessions were moderately susceptible with a damage score of 5.1 to 7.0, 682 accessions were susceptible with a damage score of 7.1 to 8.9 and the remaining 129 accessions were highly susceptible with a damage score of 9.0. The resistant check PTB 33 recorded a damage score of 1.4 and the susceptible check TN1 recorded a damage score of 9. Host plant resistance is the most economical and desirable method for the management of crop pests (Sharma, 2002). Screening for resistance to brown planthopper is a continuous process to identify new sources of resistance. In India, host plant resistance to BPH is being exploited in several research centres and very important sources of resistance have been identified.

Figure 2: Frequency distribution of damage score of germplasm accessions

Table 2: Damage Score and reaction of germplasm accessions to brown planthopper

Sr.No	Germplasm accessions	Damage score	Reaction	Sr. No	Germplasm accessions	Damage score	Reaction
1	IC75975	0.77	HR	21	IC215054	2.63	R
2	IC216750	0.8	HR	22	IC216680	2.64	R
3	IC76013	1.08	R	23	IC218166	2.99	R
4	IC76057	1.08	R	24	IC217610	3.07	MR
5	IC216735	1.27	R	25	IC218053	3.18	MR
6	IC216974	1.5	R	26	IC75797	3.2	MR
7	IC540644	1.53	R	27	IC76000A	3.24	MR
8	IC216759	1.61	R	28	IC217507	3.59	MR
9	IC216553	1.62	R	29	IC76033	3.84	MR
10	IC75961	1.64	R	30	IC216650	3.86	MR
11	IC76010	1.75	R	31	IC216566	3.87	MR
12	IC216600	1.93	R	32	IC216605	3.91	MR
13	IC216636	2.06	R	33	IC216651	3.99	MR
14	IC75990	2.1	R	34	IC216944	4.01	MR
15	IC216737	2.26	R	35	IC217750	4.21	MR
16	IC216585	2.32	R	36	IC217309	4.56	MR
17	IC216602	2.37	R	37	IC216678	5	MR
18	IC216788	2.38	R	38	TN1	9	HS
19	IC217492	2.39	R	39	PTB 33	1.4	R
20	IC216618	2.6	R	40	M0-1	4.86	MR

HR: Highly Resistant; R: resistant; MR: Moderately Resistant; MS: Moderately Susceptible; S: Susceptible; HS: Highly Susceptible



Figures 1a, 1b and 1c: Screening trays with germplasm accessions

Ramulamma *et al.* (2015) reported that out of 400 germplasm accessions tested, 2 were resistant and 13 were moderately resistant to BPH. Nagendra Reddy *et al*. (2016) screened 620 entries, out of which four entries viz., IET 23620, IET 23660, IET 23739 and IET 23771 were resistant and eleven entries were moderately resistant and remaining entries were susceptible. Akanksha *et al*. (2017) evaluated nine hundred and twenty rice germplasm accessions for their reaction to brown planthopper, out of which twelve accessions were resistant while 23 accessions were moderately resistant and others were susceptible. Reeta Lakra *et al*. (2016) screened 260 wild rice germplasm lines out of which 13 were highly resistant, 30 were resistant, 38 were moderately resistant, 5 were moderately susceptible and others susceptible. Ritu and Ravi Saxena (2009) screened 198 rice germplasm accessions for BPH resistance and of them 12 were resistant, 14 were moderately resistant and 178 were susceptible.

Feeding behaviour of brown planthopper on selected germplasm accessions based on probing marks:

BPH adults: The results on number of probing marks by BPH adults are presented in Table 3.

Table 3: Probing marks of adults of brown planthopper on germplasm accessions

S No	Germplasm accession Number	Probing Marks Adult		S No	Germplasm accession Number	Probing Marks Adult
1	IC75975	17.4±2.9 $^{d-o}$		27	IC76000A	14.4±2.6^{j-p}
2	IC216750	14±1.5 $^{j-p}$		28	IC217507	23.4±1.3^{b-d}
3	IC76013	22.8±1.0 $^{b-e}$		29	IC76033	17.2±2.8e-m
4	IC76057	13±2.4 $^{k-p}$		30	IC216650	26.2±0.8^{bc}
5	IC216735	14.4±0.9 $^{i-p}$		31	IC216566	19.6±2.2^{c-j}
6	IC216974	31.6±6.3^{b}		32	IC216605	19.8±1.1^{c-j}
7	IC540644	17.6±1.4^{d-m}		33	IC216651	19.8±2.2^{c-j}
8	IC216759	22.4±1.9^{c-f}		34	IC216944	21.2±2.5^{c-g}
9	IC216553	15.6±2.0^{g-o}		35	IC217750	21.6±1.6^{c-g}
10	IC75961	5.2±0.9^{s}		36	IC217309	18.6±1.8^{d-k}
11	IC76010	21±3.0^{c-i}		37	IC216678	13±1.2^{k-p}
12	IC216600	12.4±0.8^{l-p}		38	IC217107	18.6±1.7^{d-k}
13	IC216636	17.4±1.5^{d-m}		39	IC218002	13±1.6^{k-p}
14	IC75990	10.2±0.4^{p-r}		40	IC218085	8±2.5^{rs}
15	IC216737	16.2±0.9^{e-o}		41	IC216822	9.4±0.7^{p-r}
16	IC216585	12.2±1.1^{m-p}		42	IC75786	4.5±0.5^{s}
17	IC216602	20.8±1.2^{c-h}		43	IC218011	7.6±2.2^{q-s}
18	IC216788	14.8±2.0^{h-p}		44	IC216841	16.8±2.1^{e-m}
19	IC217492	19.4±2.4^{c-j}		45	IC218658	13±1.5^{k-p}
20	IC216618	18.4±2.5^{d-l}		46	IC217452	16.6±1.4^{e-m}
21	IC215054	19.6±2.5^{c-i}		47	IC75966	15.8±1.5^{f-m}
22	IC216680	19±1.3^{d-j}		48	IC218062	17.6±1.3^{d-l}
23	IC218166	16.2±3.1^{g-o}		49	TN1	3.1±0.7^{t}
24	IC217610	9.4±0.8^{p-r}		50	PTB 33	18.4±1.1^{e-k}
25	IC218053	20±2.5^{d-j}		51	M0-1	14.6±1.9^{i-p}
26	IC75797	12±2.4^{o-q}			SEd	0.3851
					CD(.05)	0.7592

Note: The means in a column followed by same letter are not significantly different from each other

The results indicated that there was a significant difference among the germplasm accessions with regard to probing marks. The resistant accession IC 216974 recorded maximum number of probing marks (31.6) while susceptible check TN1 has recorded lowest number of marks (3.1) by adult brown planthopper. The resistant entries recorded more number of probing marks compared to susceptible entries. Maximum number of probing marks were recorded in the resistant accession IC 216974 (31.6) followed by IC 216650 (26.2), IC 217507 (23.4), IC 76013 (22.8), IC 216759 (22.4), IC 217750 (21.6). The resistant check PTB 33 has more number of probing marks (18.4). The susceptible accessions recorded less number of probing marks (7.6-18.6) (Figure 3).

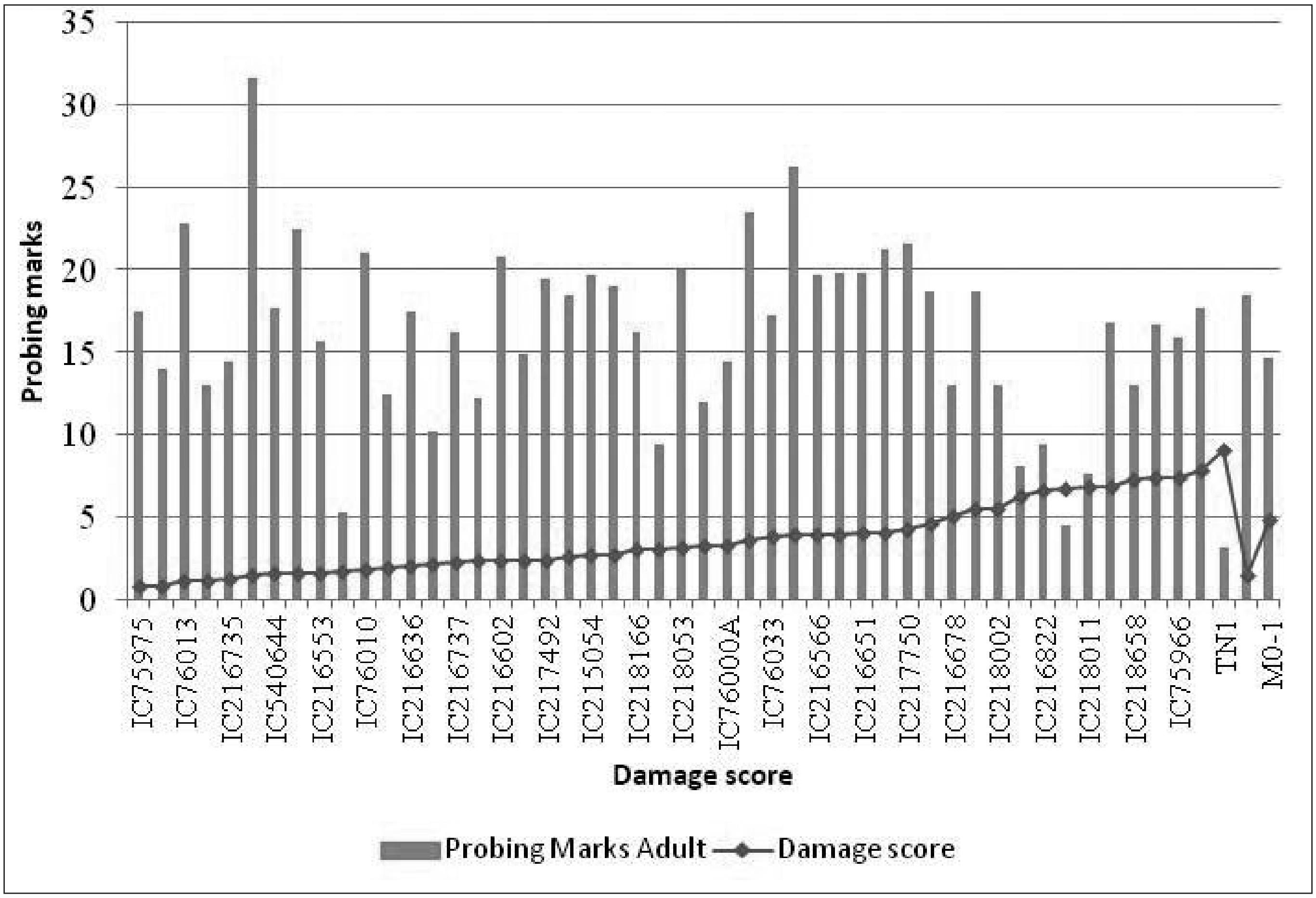


Figure 3: Relation between damage score and probing marks of BPH adults on germplasm accessions

BPH nymphs: BPH nymphs probed more number of times on the resistant germplasm accessions compared to susceptible accessions (Table 4). The resistant germplasm accession IC 216680 was probed maximum number (19.5) of times followed by IC 216974 (18), IC 76013 and IC 216650 (16.8), IC 217750 (16.4) and IC 216735 (16.2) and the resistant check PTB 33 received 12 feeding marks. The susceptible entries were probed less number of times (average 13.7 probing marks/seedling) and the susceptible check TN1 received the least number of probing marks (2.8) (Figure 4).

Table 4: Probing marks of brown planthopper nymphs on germplasm accessions

S No.	Germplasm accession Numbers	Probing Marks of Nymphs	S. No.	Germplasm accession Number	Probing Marks of Nymphs
1	IC75975	8.8±1.5l^{l-n}	27	IC76000A	13.4±1.4^{a-i}
2	IC216750	14.2±2.0^{a-i}	28	IC217507	7±0.7^{mn}
3	IC76013	16.8±1.4^{a-d}	29	IC76033	12.8±2.8^{b-l}
4	IC76057	9.1±2.2^{k-n}	30	IC216650	16.8±2.1^{a-c}
5	IC216735	16.2±1.4^{a-h}	31	IC216566	13.1±3.4^{a-j}
6	IC216974	18±1.3^{a}	32	IC216605	12.8±2.0^{a-k}
7	IC540644	12.5±2.2^{a-e}	33	IC216651	11.4±1.2^{d-m}
8	IC216759	10.8±1.1^{f-m}	34	IC216944	10.6±1.6^{f-m}
9	IC216553	15.2±2.6^{a-g}	35	IC217750	16.4±1.9^{a-e}
10	IC75961	14.8±0.9^{a-g}	36	IC217309	15±2.0^{a-g}
11	IC76010	4.8±0.2^{no}	37	IC216678	13.8±2.6^{a-i}
12	IC216600	14±1.3^{a-i}	38	IC217107	11.8±1.4^{d-l}
13	IC216636	10.8±1.7^{f-m}	39	IC218002	15.6±0.5^{a-f}
14	IC75990	11.4±1.1^{d-m}	40	IC218085	12.1±1.0^{a-k}
15	IC216737	10.2±1.3^{g-m}	41	IC216822	11±0.8^{e-m}
16	IC216585	9.6±1.4^{i-m}	42	IC75786	9±2.2^{j-n}
17	IC216602	12.4±1.8^{c-i}	43	IC218011	11±1.9^{j-i}
18	IC216788	14.6±2.4^{a-i}	44	IC216841	12.4±3.2^{d-l}
19	IC217492	12.8±1.6^{a-k}	45	IC218658	10.8±1.6^{f-m}
20	IC216618	10.2±1.2^{h-m}	46	IC217452	16.6±1.4^{a-d}
21	IC215054	14.2±2.1^{a-i}	47	IC75966	7.7±0.7^{mn}
22	IC216680	19.5±0.9^{ab}	48	IC218062	13.2±2.3^{a-j}
23	IC218166	13.8±1.5^{a-i}	49	TN1	2.8±0.4^{o}
24	IC217610	13.6±1.6^{a-i}	50	PTB 33	12.2±1.7^{c-l}
25	IC218053	12.4±1.1^{a-k}	51	M0-1	14.2±5.8^{a-k}
26	IC75797	5.6±1.0^{no}		SEd	0.372
				CD(.05)	0.7334

Note: The means in a column followed by same letter are not significantly different from each other

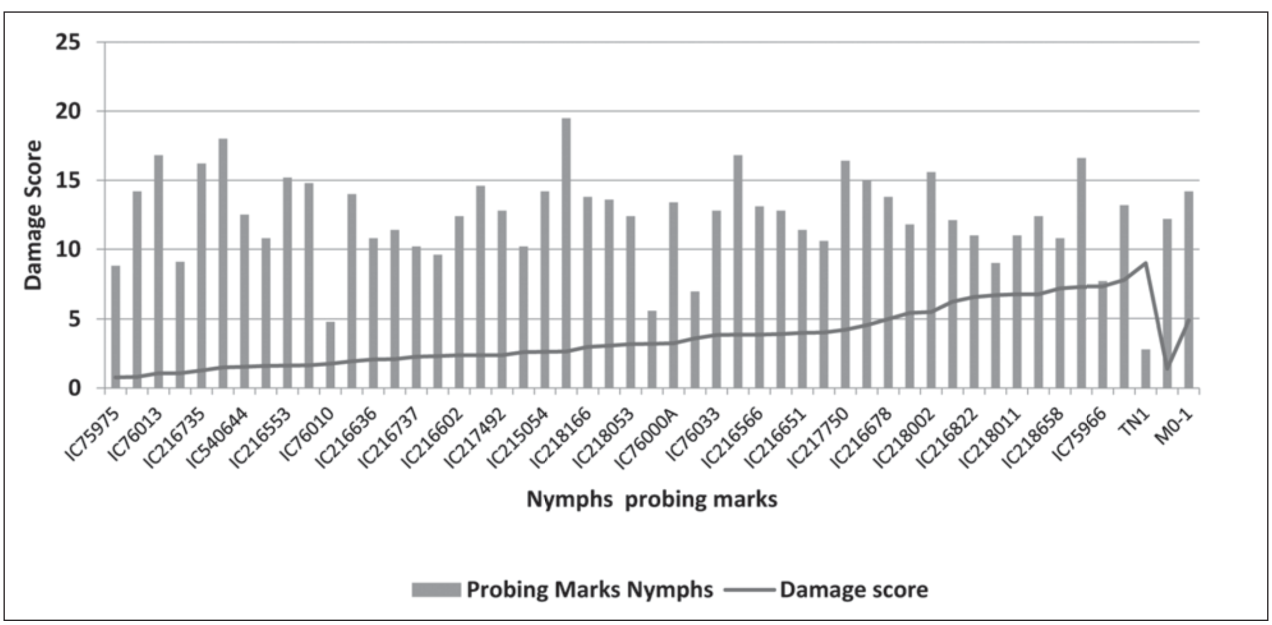


Figure 4: Relation between damage score and probing marks of BPH nymphs on germplasm accessions

In general nymphs probed less number of times than adults. More number of feeding punctures in the resistant and moderately resistant entries might be due to the reason that, these resistant and moderately resistant entries did not sustain prolonged feeding due to the presence of certain feeding deterrents or toxic chemicals or absence of feeding stimulants. Hence, the insect had to probe more on the resistant genotypes to locate feeding sites (Sogawa, 1982). Our results corroborate with the findings of several workers (Sogawa and Pathak, 1970; Karim 1975; Reddy and Kalode, 1985; Li *et al.* 1991; Pophaly *et al.* 2001; Alagar *et al.*, 2007; Kale *et al.* 2007; Anitha *et al.*, 2015) who reported that the number of probing marks were more on resistant varieties compared to susceptible ones. Udayababu *et al.* (2011) also reported that average probing marks on resistant plants ranged between 30.4 to 42.9 whereas resistant and susceptible checks have recorded 22.1 and 6.7 probing marks, respectively. Bhanu *et al.* (2014) observed that brown planthopper probed more number of times on the resistant cultures like MTU 1075 (128.1 probing marks), MTU IJ 206-7-4-1 (112.8 probing marks) and MTU PLA 99-1-3-1-2 (110.2 probing marks) compared to susceptible ones. Nagendra Reddy *et al.* (2016) reported that the resistant entries including IET No. 23620 (26.5) and IET No. 23660 (22.3) and moderately resistant entries including IET No. 23661 (25.0), IET No. 23705 (23.3) and IET No. 23702 (23.2) were probed more number of times which were on par with resistant check, Ptb 33 (26.5 feeding punctures). Nanda *et al.* (1999) recorded that PTB 33 had a maximum of 110 probing marks on the leaf sheaths on 10-day old plants compared to 22 probing marks on TN1. The rest of the test varieties had 35 to 85 probing marks. Our studies corroborate with the findings of above authors.

Correlation between damage score and probing marks

Correlation analysis between damage score and probing marks of adults (R^2=-0.3575) and nymphs (R^2=-0.20879) indicated negative correlation eventhough it is non-significant. More number of probing marks were observed on the germplasm accessions which are resistant and vice versa (Table 5).

Table 5: Correlation between Damage Score and Probing marks

	Damage score	Probing Marks Adult	Probing Marks Nymphs
Damage score	1		
Probing Marks-Adult	-0.3575	1	
Probing Marks-Nymphs	- 0.20879	0.3209	1

When the data were subjected to linear regression analysis (Table 6 and Figure 5), a negative relation was observed between damage score and number of probing marks of nymphs and adults. In the adults, probing marks (non-preference for feeding) is able to explain 12.7 percent of variation in damage score and for each unit increase in the probing marks, the damage score is decreased by 0.14 units. In the nymphs, probing marks is able to explain 4.3 percent of variation in damage score and for each unit increase in probing marks the damage score is decreased by 0.135 units. In addition to probing marks i.e non-preference for feeding, the varietal resistance is dependent on other parameters also. In the present study, the germplasm accessions resistant to BPH and with more number of probing marks which are not preferred for feeding can be used in the breeding programme to develop brown planthopper resistant varieties.

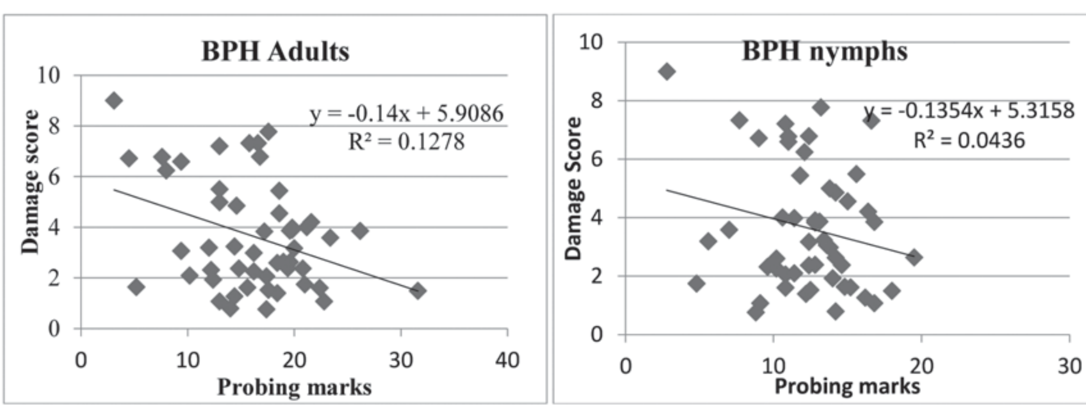


Figure 5: Regression between probing marks in BPH adults and nymphs and damage score

Table 6: Linear Regression analysis between damage score and probing marks

Variable	No of obser-vations	Regression equation	Standard Error	R2
Probing marks of nymphs	51	y = -0.135x + 5.315	1.157002764 0.090589566	0.0436
Probing marks of adults	51	y = -0.14x + 5.908	0.89088068 0.052254111	0.127

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Assessing the efficacy of new low dose herbicide molecule in puddled direct seeded rice

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Abstract

A field experiment was conducted to evaluate the effectiveness of new low dose post-emergence herbicide, florpyrauxifen-benzyl for broad-spectrum weed control in puddled direct seeded rice at five AICRIP locations i.e. Navsari, Vadgaon, Aduthurai, Karjat and Nellore. Experiment was laid out in randomized block design to test seven treatments, *viz.* T_1- florpyrauxifen-benzyl at 31.25 g a.i./ha, T_2- florpyrauxifen-benzyl at 37.5 g a.i./ha, T_3- bispyribac sodium at 30 g a.i./ha, T_4- pyrazosulfuron-ethyl at 25 g a.i./ha followed by metsulfuron-methyl + chlorimuron-ethyl at 4 g a.i./ha, T_5- Weed free condition, T_6- hand weeding twice and T_7- weedy check and were replicated thrice. Application of florpyrauxifen-benzyl reduced the density, dry biomass of weeds and increased the weed control efficiency to the tune of 78.3% and remained comparable to hand weeding twice. Florpyrauxifen-benzyl at 37.5 g a.i./ha recorded higher values of yield attributes thus leading to higher yield (4.92 t/ha) and was equally effective as standard check bispyribac sodium 30 g a.i./ha in suppressing the weeds and recording comparable yield (4.80 t/ha). Higher Energy productivity was noted under weed free situation (0.845) and was followed by application of pyrazosulfuron- ethyl 25 g a.i./ha *fb* metsulfuron-methyl + chlorimuron-ethyl at 4 g a.i./ha (0.746). Florpyrauxifen-benzyl at 37.5 g a.i./ha can be used as an alternative herbicide to standard recommended herbicide bispyribac sodium at 30 g a.i./ha under direct sown conditions.

Key words: florpyrauxifen-benzyl, direct seeded rice, yield, weed control efficiency, weed index

Introduction

Rice is consumed by more than half of the world's population and India is the second largest producer of rice in the world and is the major cereal crop of the country. Most of rice is grown by transplanting seedlings into puddled soils and is then kept flooded for most of the growing season. However, transplanting consumes large amount of labor, water and energy which are gradually becoming scarce and thus necessitates the need to shift to direct seeded rice (DSR) systems. But, one of the major constraints to the adoption of direct seeded rice are weeds. Weeds cause heavy damage to direct seeded rice (DSR) crop and yield losses due to weeds in India range from 20-85% (Rao *et al*. 2007) and in severe infestation it can cause crop losses to the tune of 100% (Prasad, 2011; Singh *et al*. 2014). Managing weeds in rice is one of the costliest methods in the rice production program and varies with rice ecosystem, soils and agro-climatic conditions (Sreedevi *et al*. 2012). Among all the methods, chemical control is effective, cheap and reliable option (Krishnamurthy *et al*. 2010). The main reason for the poor efficacy of weed control in direct seeded rice is that the herbicides used have narrow spectrum with a single mode of action which is unable to provide season long weed control (Mahajan and Chauhan, 2013) which leads to the development of herbicide resistance in weeds. Moreover, rice herbicides presently used are mainly pre-emergence and weeds coming at later stages of crop growth are not controlled effectively. Therefore, use of herbicides which provide broad-spectrum post-emergence weed control can prove to be desirable for effective weed management in direct seeded rice systems (IIRR Progress Report, 2016). Florpyrauxifen-benzyl is a novel 6-arylpicolinate molecule constituting of highly substituted 4 amino pyridine ring and a selective post-emergence weed killer with short persistence in soil. Few broad spectrum molecules are available to evaluate and identify new low dose post-emergence herbicides under direct seeded conditions in different agro-climatic locations for effective suppression of weeds. Therefore, present investigation was undertaken under All India Coordinated Rice Improvement Program (AICRIP).

Materials and methods

A field experiment was conducted during *Kharif* 2016 at five different AICRIP locations, *viz*. Navsari, Vadgaon, Aduthurai, Karjat and Nellore with an objective to find out the suitability of new herbicide along with standard recommended herbicides in direct seeded rice. The treatments comprised of T_1- florpyrauxifen-benzyl at 31.25 g a.i./ha, T_2- florpyrauxifen-benzyl at 37.5 g a.i./ha, T_3- bispyribac sodium at 30 g a.i./ha, T_4- pyrazosulfuron at 25 g a.i./ha *fb* by metsulfuron-methyl + chlorimuron-ethyl at 4 g a.i./ha, T_5- Weed free condition, T_6- Hand weeding twice and T_7- Weedy check. The treatments were tested in randomized block design with three replications. The herbicide florpyrauxifen-benzyl was applied at 4-7 leaf stage of weeds after sowing of rice crop, bispyribac sodium at 3-4 leaf stage of weeds and pyrazosulfuron ethyl within 3-5 days after sowing (DAS) and metsulfuron-methyl + chlorimuron-ethyl at 25-30 DAS. The treatment hand weeding twice was taken up at 25 and 45 DAS. High yielding variety of the specific location with recommended package of practices was adopted in the trial at test locations. The soil type varied from sandy loam to nearly black soils. Full dose of P and K and half dose of N was applied at the time of sowing and remaining half dose of N was applied in two equal splits at tillering and panicle initiation stage at all the locations. Weed population and biomass were recorded at flowering stage using iron quadrat of standard size.

Weed control efficiency and weed index were calculated using the formula:

$$\text{WCE (\%)} = \frac{\text{DMC} - \text{DMT}}{\text{DMC}} \times 100$$

Where, DMC is dry-matter of weeds in the control plots and DMT dry matter of weeds in treated plots.

$$\text{Weed Index} = \frac{X - Y}{X} \times 100$$

Where, X= Yield in weed free plot; Y= Yield in treated plot

Energy parameters were calculated as follows:

Input energy: The energy input was calculated as the summation of energy requirements for labour, farm machinery, seed, fertilizers and irrigation used in the system and is expressed in GJ/ha.

Output energy:

Output energy from the main product (grain) and by-product (straw) was calculated by multiplying the amount of production and its corresponding energy equivalent and conversion coefficients.

Energy productivity (EP):

$$\text{Energy productivity (kg/MJ)} = \frac{\text{Grain + straw yield (kg/ha)}}{\text{Total energy input (MJ/ha)}} \times 100$$

Statistical analysis: The data were subjected to analysis of variance using the procedure given by Gomez and Gomez (1976). Weed density data was subjected to square-root transformation [$\sqrt{(x + 0.5)}$] before analysis. The data for all the five locations were pooled.

Results and discussion

Weed flora of the experimental field

The major weed flora observed in the experimental field included grass weeds, sedges and broad leaved weeds. Among the grasses, *Echinochloa colonum*, *Echinochloa crusgalli*, *Eleusine indica*, *Digitaria sanguinalis* were the dominant weed species. Among the sedges, *Cyperus difformis*, *Cyperus iria*, *Cyperus rotundus* and *Fimbristylis miliacea* and among the broad leaved weeds, *Ammanica baccifera*, *Caesulia axillaris*, *Commelina benghalensis* and *Eclipta alba* were found. The composition of grasses, sedges and broad leaf weeds were 51%, 33% and 15% of the total weed population in weedy check. Relative proportion of grasses as noted in weedy check was more compared to sedges and broad leaf weeds. It is in conformity with the findings of Krishnamurthy *et al*. 2010 and Nikhil and Singh 2014, who reported dominance of grasses under direct seeded conditions.

Effect on weed population

The data on weed population at flowering stage indicated that all the weed control treatments significantly suppressed the population of grasses, sedges as well as broad leaf weeds (Table 1). Application of the herbicide florpyrauxifen-benzyl at both the doses was effective in checking the grassy weed population and comparable to the efficacy of other test herbicides in suppressing grassy weeds in direct seeded rice .Sedge population was lowest in weed free condition. And all test herbicides recorded onpar. The broadleaf weed population was lowest in weed free treatment and pyrazosulfuron fb metsulfuron methyl+chlorimuron ethyl application.

Effect on dry weed biomass

The data on total weed biomass indicated that significant reduction in weed biomass was recorded in all the herbicide treatments compared to weedy check (Table 1). Among the herbicide treated plots, florpyrauxifen-benzyl at 37.5 g a..i/ha was effective in recording lower biomass of grasses and sedges. All the weed control treatments recorded significantly lower biomass accumulation than the weedy check. Bispyribac sodium 30 g a.i/ha was equally effective as florpyrauxifen-benzyl at 37.5 g a.i./ha in reducing the grasses and broad leaf weeds.

Table 1: Weed population, weed dry biomass accumulation and weed indices at flowering stage in direct seeded rice in *Kharif* 2016 across pooled data of five locations

Treatments	Weed population(No/ m^2)			Weed dry biomass (g /m^2)			Total weed density (No./m^2)	Total weed biomass (g/m^2)	Weed control efficiency (%)	Weed Index
	Grasses	Sedges	BLWs	Grasses	Sedges	BLWs				
T1-Florpyrauxifen-benzyl (31.25g a.i./ha)	2.86 (10.80)	1.76 (3.34)	1.60 (2.28)	27.47	4.28	4.80	6.22 (16.5)	35.50	70.00	14.10
T2-Florpyrauxifen-benzyl (37.5g a.i./ha)	2.38 (6.87)	1.42 (2.04)	1.64 (2.37)	17.35	2.64	5.39	5.44 (11.28)	25.40	78.30	8.30
T3-Bispyribac sodium 30 g a.i./ha	2.59 (8.17)	2.22 (5.74)	1.71 (2.58)	20.01	8.37	6.53	6.52 (16.5)	35.00	70.10	10.60
T4-Pyrazosulfuron-ethyl 25 g a.i./ha *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g a.i./ha	3.00 (13.51)	1.63 (3.05)	1.49 (1.96)	30.57	3.49	3.98	6.12 (18.52)	38.00	68.00	8.50
T5-Weed free Condition	0.81 (0.20)	0.83 (0.26)	1.03 (0.86)	0.44	0.20	0.29	2.67 (9.32)	1.00	100.00	-
T6-Hand weeding twice at 20 and 45 DAS	1.93 (3.48)	1.77 (3.21)	2.07 (4.45)	6.79	5.04	10.34	5.77 (11.14)	22.20	81.00	0.90
T7-Weedy check	5.10 (31.02)	3.97 (20.06)	3.04 (9.22)	61.56	30.27	25.47	12.11 (60.3)	117.3	-	53.20
LSD(p=0.05)	0.61	0.56	0.51	10.08	3.17	3.00	1.68	16.25	NA	NA

Values given in parenthesis are the original values

NA-Not Statistically Analysed

Weed Indices

The efficiency of various treatments with respect to weed control efficiency fluctuated to a greater extent under the influence of various weed control treatments (Table 1). Among the herbicides, weed control efficiency was highest under the application of florpyrauxifen-benzyl at 37.5 g a.i./ha (78.3%) and was followed bispyribac sodium 30 g a.i./ha and florpyrauxifen-benzyl lower dose. Lower weed index was noted with florpyrauxifen-benzyl at 37.5 g a.i./ha (8.3) and was followed by pyrazosulfuron ethyl at 25 g a.i./ha *fb* metsulfuron-methyl + chlorimuron-ethyl at 4 g a.i./ha (8.5). Weedy check recorded the highest weed index (53.2) which indicated the losses caused due to weeds. In general, weed control efficiency increased and weed index declined with increase in the dose of florpyrauxifen-benzyl. Application of herbicides enhanced weed control efficiency and reduced weed index due to restricted weed growth, subsequently resulting in lower dry matter production by weeds and higher yield. Similar results have been reported by Suria *et al*. 2011.

Yield attributes and yield

Application of herbicides significantly influenced the yield attributes, *viz*. panicles/m^2, panicle weight and 1000 grain weight compared to weedy check (Table 2). The highest number of panicles was recorded in weed free condition. Among the herbicides, highest panicles/m^2 was noted with bispyribac sodium at 30 g a.i./ha and was similar to florpyrauxifen-benzyl at 37.5 g a.i./ha. Panicle weight and 1000 grain weight were not influenced by herbicide treatments.

Significant variation in grain yield was observed due to herbicide applications. The highest grain yield loss due to weeds to the tune of 57% was noted in weedy check. The florpyrauxifen benzyl at 37.5 g ai./ha recorded the highest yield (4.92 t/ha) and was at par to combination herbicide pyrazosulfuron-ethyl at 25 g a.i./ha *fb* metsulfuron-methyl + chlorimuron-ethyl at 4 g a.i./ha (4.91 t/ha) and bispyribac sodium at 30 g ai.i/ha (4.80 t/ha) Non-significant differences among the herbicides were recorded with respect to grain yield. Lesser yield in unweeded check might be due to higher weed competition and lesser availability of nutrients to the crop plants which resulted in lower grain and straw yield in control plots and is in conformity with the findings of Thakur *et al*. 2011.

It was observed from Figure 1 that grain yield was inversely related with weed biomass and increase in dry matter accumulation by weeds caused significant yield reduction. Negative relationship between weed biomass and grain yield has been reported by various researchers (Mahajan and Chauhan, 2013 and Chauhan *et al*. 2011). The unit increase in weed dry biomass caused a yield reduction by 17.29 kg in. Our results confirm the findings of Singh et *al*. (2008) and Mahajan and Chauhan, (2013).

Table 2: Efficacy of different herbicides on yield attributes, yield and Energy dynamics in direct seeded rice in *Kharif* 2016 across pooled data of five locations

Treatments	Panicle no /m^2	Panicle wt(g)	Test wt(g)	Grain yield (t/ha)	Straw yield (t/ha)	Energy Input (MJ/ha)	Energy Output (MJ/ha)	Energy Productivity (kg/MJ)
T1-Florpyrauxifen-benzyl (31.25g a.i./ ha)	265	2.39	20.29	4.61	6.35	15,995	14,717	0.69
T2-Florpyrauxifen-benzyl (37.5g a.i./ ha)	292	2.38	20.94	4.92	6.63	15,995	15,530	0.72
T3-Bispyribac sodium 30 g a.i./ha	297	2.46	21.06	4.80	6.89	15,995	15,674	0.73
T4-Pyrazosulfuron-ethyl 25 g a.i./ha *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g a.i./ha	276	2.38	20.75	4.91	7.01	15,995	15,988	0.75
T5-Weed free Condition	341	2.70	21.04	5.37	7.90	16,295	17,778	0.82
T6-Hand weeding twice at 20 and 45 DAS	301	2.41	20.68	4.84	7.16	16,145	16,077	0.74
T7-Weedy check	167	1.49	18.74	2.51	3.92	15,920	8,596	0.40
LSD(p=0.05)	31	0.25	1.23	0.43	0.57	NA	NA	NA

Values given in parenthesis are the original values
NA-Not Statistically Analysed

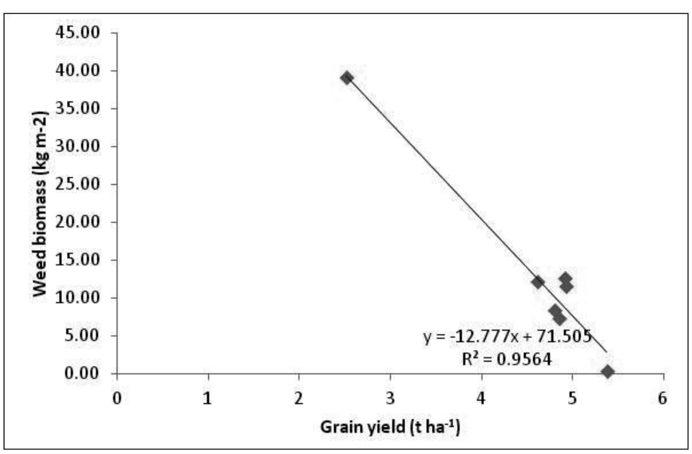

Figure 1: Relationship between grain yield and weed biomass

Energy attributes

The highest input and output energy (MJ/ha) was noted in weed free condition (16,295and 17,778) followed by hand weeding twice (16,145 and 16,077). All the herbicides, recorded same input energy but output energy varied. Among the herbicides, highest output energy (15,988) and productivity (0.746) was noted in application of pyrazosulfuron ethy at 25 g ai./ha *fb* metsulfuron methyl + chlorimuron ethyl at 4 g a.i./ha. Among the herbicide treatments, lowest energy productivity was observed in florpyrauxifen-benzyl at 31.25 g a.i./ha (0.685)

Conclusion

The results of the present study indicate that florpyrauxifen-benzyl at 37.5 g a.i./ha was effective and was similar to other combination herbicides and bispyribac sodium at 30 g a.i./ha based on the results of one season study at five locations, Thus, Post-emergence herbicide, florpyrauxifen-benzyl at 37.5 g a.i./ha at 4-7 leaf stage of weed can be applied in wet seeded puddle rice for efficient weed control to realize more productivity comparable to bispyribac sodium 30 g a.i./ha at 3-4 leaf stage of weeds.

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Productivity and profitability of rice-wheat system under organic and inorganic farming in mid hills of Himachal Pradesh

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Abstract

A field experiment was conducted AICRP-Rice during 2017-18 at CSK HPKV Rice and Wheat Research Centre, Malan to study the productivity and profitability domain of rice-wheat system under organic and inorganic farming in mid hills of Himachal Pradesh. Five treatments viz. $T_{1:}$ 100% RDF (recommended dose of fertilizers) through inorganic fertilizer , T_2: 100% RDF through organic fertilizers (equivalent of N), T_3: 75% through inorganic and 25% through FYM, T_4: Control (No fertilizer), T_5: Farmers' practice were tested in randomized block design with four replications. 'Kasturi' (basmati rice) was grown in *kharif* season followed by 'HS 542' wheat cultivar in *rabi* season. 210 Kg N (90 rice + 120 wheat), 100 kg phosphorus (40+60) and 70 kg potash (40+30)/ha were applied as recommended dose (T_1) in rice-wheat system. 42 t FYM on dry weight basis (18 t to rice + 24 t to wheat) was applied on N equivalent basis in T_2. Results revealed that Kasturi recorded productivity level of 4.08 t/ha under organic system (T_2) which was at par with 100% recommended dose of fertilizers (3.74 t/ha) applied through inorganic fertilizers (T_1). T_3 (integrated nutrient management) recorded more rice productivity of 4.10 t/ha, however, compared to 100%RDF. Wheat productivity in organic system was 4.34 t/ha which was at par with integrated nutrient supply system (3.78 t/ha, T_3) and the latter being at par with inorganic fertilizer nutrient (T_1; 3.60t/ha). Gross returns of rice –wheat system revealed that organic system (T_2) recorded higher value of Rs.2,28,412/ha followed by integrated nutrient management (T_3, Rs.2,14,212/ha) and 100% RDF (Rs.2,00,293). However, net return (Rs. 1,09,753/ha) and benefit cost ratio (1.21) was higher with inorganic nutrient supply system (T_1). Cost of FYM in organic system inflated the cost of cultivation; therefore, economic analysis was done by excluding the cost of FYM with the assumption that it is freely available with the hill farmers in integrated farming (but in reality FYM is not available for free). Hence, economic analyses done by excluding the cost of FYM revealed that maximum net returns of Rs. 1,49,474/ha & benefit cost ratio of 1.89 was recorded in organic production system (T_2) which is a sustained production system. The values of growth and yield attributes were low inabsolute control (T_4) and farmers' practice (T_5) and hence low productivity and profitability. Thus, farmers of mid hills should apply full dose of fertilizers to Kasturi basmati (90,40,40 kg NPK)- wheat (120,60,30 kg NPK) for higher productivity and profitability under inorganic production system. Under organic production system, an application of FYM (equivalent to fertilizer N) to both 'Kasturi' rice-wheat (18 t/ha to rice + 24 t/ha to wheat on dry weight basis) recorded more productivity (4.08 + 4.34 t/ha) and gross returns. The latter also records more net returns (Rs.1,49,474/ha) and benefit : cost (1.89) if farmers have FYM free of cost available with them as in integrated hill farming of Himachal Pradesh.

Key words: Rice –wheat system, organic, inorganic, integrated nutrient management, productivity, economics

Introduction

Rice (*Oryza sativa* L. –wheat (*Triticum aestivum* L. emend. Fiori&Paol) is the major cropping system in India, covering 10-12 million hectare areas. This system is equally important in Himachal Pradesh. There are indications of stagnation or even decline in productivity of this cropping system due to decline in soil organic matter, over-mining of nutrient reserves, loss of nutrients and non availability of cost effective fertilizers. Further, the application of inorganic fertilizers even in balanced fertilizers may not sustain soil productivity under continuous cropping. However, integrated use of organics and inorganics including crop residues may improve the soil productivity (Mankotia, 2007). In hills the fertilizer and pesticide inputs, by default, are being used less as compared to the plains-neighboring states. The whole of Himachal Pradesh has been has been included in GI (Geographical Indication) for basmati and there exists ample scope to contribute in the export pool of the country *vis a vis* to improve the economic condition of the hill farmers. Therefore, the present investigation was undertaken.

Materials and methods

A field experiment was conducted All India Coordinated Rice Improvement Project during 2017-18 at CSK HPKV Rice and Wheat Research Centre, Malan (76° 2′ E, 32° 1′ N and 950 m above mean sea level) to study the productivity and profitability domain of rice-wheat under organic and inorganic farming in mid hills of Himachal Pradesh. Five treatments *viz.* $T_{1:}$ 100% RDF (recommended dose of fertilizers) through inorganic fertilizers, T_2: 100% RDF through organic fertilizers (equivalent of N), T_3: 75% through inorganic and 25% through FYM, T_4: Control (No fertilizer), T_5: Farmers' practice were tested in randomized block design with four replications. These treatments were given to both the crops. The recommended dose of fertilizers to rice is 90-40-40 kg & to irrigated wheat is 120-60-30 kg $NP_2O_5K_2O$/ha. Thus, 210 Kg N (90 rice + 120 wheat), 100 kg phosphorus (40+60) and 70 kg potash (40+30)/ha were applied as recommended dose (T_1) in rice-wheat system. 42 t FYM on dry weight basis (18 to rice + 24 t to wheat) was applied at the time of field preparation, on N equivalent basis in T_2. 'Kasturi' (basmati rice) was grown in *kharif* season followed by 'HS 542' wheat cultivar in *rabi* season. The soil was medium in available nitrogen (428 kg), phosphorus (42 kg) & medium in potash (232 kg/ha) and acidic in reaction (pH 5.7). During rice cropping season 2108 mm rainfall was received in 67 days, however, the irrigations were provided to both the crops to avoid any moisture stress. The economics was computed by taking into account the prevailing market cost of inputs and price of inputs. The economic analyses included the cost of FYM. Cost of FYM in organic system inflated the cost of cultivation; therefore, economic analysis was also done by excluding the cost of FYM with the assumption that it is available with the hill farmers free of cost in integrated farming.

Results and Discussion

Effect on rice

Growth in terms of plant height & number of tillers per unit area and development (days taken to 50 % flowering) of rice crop were significantly varied by the treatments (Table 1). Application of nutrients either as organic ($T_{2:}$ 100% RDF through organic fertilizers (equivalent of N)) or inorganic ($T_{1:}$ 100% RDF (recommended dose of fertilizers) through inorganic fertilizers) or in integrated nutrient management (INM, $T_{3:}$ 75% through inorganic and 25% through FYM) resulted in statistically plants of the same height but significantly taller than in absolute control (T_4) and farmers' practice (T_5). In organic (T_2), plants were taller by 1, 6.6& 10.5 cm over inorganic (T_1), farmers practice (T_5) and absolute control (T_4), respectively. The variation in plant height is because of the varied availability of the nutrients under different treatments. Inorganic T_1&INM T_3 recorded more number of tillers per unit area being at par with organic T_2 compared to absolute control and farmers' practice. T_1 produced 53 more tillers compared to absolute control. The development of the crop i.e. days taken to 50 per cent flowering were varied significantly, recording significantly more days in organic (T_2) as well as in absolute control and farmers practice. Plants in organics took 3.8 more days to flowering compared to inorganic T_1. Absolute control took more days among the treatments.

INM (T_3) produced significantly more panicles compared to that of other treatments (Table 1). Application of 100 % RDF through inorganics (T_1) and organics (T_2) were statistically on par in producing the panicles per unit area. Number of filled spikelets per panicle were more in T_1being at par with organic and INM. However, unfilled spikelets per panicle were also more in INM being statistically at par with organic. Test weight was not varied significantly however lowest value was observed in absolute control. Panicle weight was statistically comparable in inorganic and INM but significantly more than absolute control and farmers' practice.

As the crop nutrition improved growth and yield attributes of rice crop, thereby the grain and straw yield was significantly affected by the treatments. Results revealed that Kasturi recorded productivity level of 4.08 t/ha under organic system (T_2) which was at par with 100% recommended dose of fertilizers (3.74 t/ha) applied through inorganic fertilizers (T_1). However, T_3 (integrated nutrient management) recorded more rice productivity of 4.10 t/ha compared to 100% RDF. Organic produced 9.2 per cent (0.34 t/ha) more grain yield over 100 % RDF and 32.5 per cent (1.0 t/ha) more over farmers' practice. Straw yield in INM was at par with 100% RDF & organic. Similar results have been reported by Anonymous (2017) & Mankotia and Shekhar, 2007.

Table 1: Effect of organic and inorganic nutrition on growth, development, yield attributes and yield of rice-wheat

Treatment / Parameter	T_1-100% RDF through inorganic fertilizers	T2-100% RDF through organic fertilizers (equivalent of N)	T3-INM (75% through inorganic and 25% through organic sources)	T4-Control (No fertilizer)	T5-Farmers' practice	CD (P=0.05)
Effect on rice						
Plant height (cm)	107.8	107.7	108.8	98.3	102.2	5.4
Number of tillers/m^2	173.5	164.5	173.5	120.7	151.0	28.5
Days taken to 50% flowering (d)	97.7	101.5	98.5	103.8	103.0	1.4
Number of panicles/m^2	151	155.5	171.2	111.2	124.2	13.8
Filled spikelets/panicle	127.8	126.5	124.2	100.5	108	13.41
Unfilled spikelets /panicle	21	23.7	29	17.5	17	6.37
Fertility %age	85.9	84.3	81.1	85.3	86.4	NS
Panicle weight(g)	2.78	2.73	2.7	2.15	2.25	0.25
Test weight(g)	22.97	22.21	22.89	22.2	21.8	NS
Straw yield (t/ha)	6.606	6.872	7.092	4.251	5.258	0.627
Grain yield(t/ha)	3.736	4.08	4.104	2.418	3.079	0.34
Effect on wheat						
Plant height (cm)	84.1	88.3	86.3	77.7	79.6	6.3
No. of ears/m^2	303.3	310.0	322.3	285.0	289.3	15.4
No. of grains/ear	30.2	33.8	32.4	27.1	27.9	3.45
Spike length (cm)	10.1	10.3	10.1	9.1	9.4	0.4
Test weight (g)	35.53	41.19	36.99	34.29	33.67	2.64
Straw yield (t/ha)	6.670	8.081	6.834	4.300	4.727	10.22
Grain yield (t/ha)	3.597	4.339	3.777	2.192	2.428	0.528

Effect on wheat crop

Growth and yield attributes of wheat crop were significantly varied by the treatments (Table 1). Wheat plants were taller in organic (T_2) being at par with 100 RDF (T_1) & INM (T_3) compared to absolute control and farmers practice. In organic, the plant attained 2.1, 8.7 & 10.6 cm more height over 100% RDF, farmers practice' and absolute control, respectively, due to the varied nutrient supply. Number of ears per unit area was more in INM, followed by organics and 100% RDF. Organics recorded 20.7 more ears/m^2 over farmers' practice. Length of spike was significantly less in absolute control and farmers' practice. The number of grains was more in organic (33.8/ear) being at par with INM and the latter was at par with 100 % RDF. However, test weight (41.2 g) was significantly more in organic (T_2) followed by INM (37.0 g) and 100% RDF (35.5 g) latter both being at par with each other.

As the growth and yield parameters of the wheat were improved with nutrition thereby the straw yield of the crop was significantly affected. Straw yield was significantly more in organic treatment. Wheat productivity in organic system (T_2) was 4.34 t/ha which was at par with integrated nutrient supply system (3.78 t/ha, T_3) and the latter being at par with inorganic fertilizer nutrient (T_1; 3.60 t/ha). Farmers' practice was significantly superior compared to absolute control. Results are in conformity with Bindia *et al*, 2005 and Mankotia *et al*, 2006 & 2008.

Economic returns of rice-wheat cropping sequence

Gross returns of rice –wheat system revealed that organic system (T_2) recorded higher value of Rs.2,28,412/ha followed by integrated nutrient management (T_3, Rs.2,14,212/ha) and 100% RDF (Rs.2,00,293) (Table 2). T_2 recorded Rs.21,412, 28,119 & 75938/ha more returns over INM, 100% RDF & farmers practice, respectively largely due to the variation in grain and straw yields of the crops. However, net return (Rs. 1,09,753/ha) and benefit cost ratio (1.21) was higher with inorganic nutrient supply system (T_1) as the cost of FYM inflated the cost of cultivation in organic and INM. Cost of FYM in organic system inflated the cost of cultivation; therefore, economic analysis was also done by excluding the cost of FYM with the assumption that it is freely available with the hill farmers in integrated farming. Hence, economic analyses done by excluding the cost of FYM revealed that maximum net returns of Rs. 1,49,474/ha & benefit cost ratio of 1.89 was recorded in organic production system (T_2) which is a sustained production system. As the values of productivity were low in absolute control (T_4) and farmers' practice (T_5) and hence these treatments recorded low profitability too.

Table 2: Profitability of organic and inorganic rice–wheat system

Treatment	Gross returns (Rs./ha)	Cost of cultivation (Rs./ha)	Net returns (Rs./ha)	Benefit:cost (Rs./Rs. invested)	Cost of cultivation (Rs./ha)	Net returns (Rs/ha)	Benefit:cost (Rs/Rs invested)
		Including cost of FYM			Excluding cost of FYM		
T_1-100% RDF through inorganic fertilizers	2,00,293	90,540	1,09,753	1.21	90,540	1,09,753	1.21
T_2-100% RDF through organic fertilizers (equivalent of N)	2,28,412	1,57,938	70,474	0.45	78,938	1,49,474	1.89
T_3-INM (75% through inorganic and 25% through organic sources)	2,14,212	1,08,638	1,05,574	0.97	87,638	1,26,574	1.44
T_4-Control (No fertilizer)	1,27,565	78,938	48,627	0.62	73,938	53,627	0.72
T_5-Farmers' practice	1,52,474	81,438	71,036	0.87	81,438	71,036	0.87

Price ((Rs./t)): rice grain=25000, rice straw=2500, wheat grain= 14000, wheat straw=6000, FYM=500

Conclusions

Thus, farmers of mid hills should apply full dose of fertilizers to Kasturi basmati (90,40,40 kg NPK) - wheat (120,60,30 kg NPK/ha) for higher productivity and profitability under inorganic production system. Substitution of 25% N with FYM in integrated nutrient management is also encouraging. Under organic production system, an application of FYM (equivalent to fertilizer N) to both 'Kasturi' rice-wheat (18 t/ha to rice+ 24 t/ha to wheat on dry weight basis) records more productivity (4.08 + 4.34 t/ha) and gross returns. The latter also records more net returns (Rs.1,49,474/ha) and benefit : cost (1.89) if farmers have FYM free of cost available with them as in integrated hill farming of Himachal Pradesh.

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Genotypic variation in Rice (*Oryza sativa* L.) for Nitrogen Use Efficiency Under Optimal and Sub Optimal Nitrogen Levels

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Abstract

A field experiment was conducted for two years (2011-12 and 2012-13) at the ICAR-Indian Institute of Rice Research (ICAR-IIRR) Rajendrangar, Hyderabad, to assess the differences in grain yield and nitrogen (N) utilization efficiency of rice genotypes. Fifteen popular high yielding genotypes with varying acquisition and utilization of soil and fertilizer N were tested at N-0 (no external application of N) and N-100 (100 kg N/ha) levels in each year covering four seasons (two wet and two dry seasons) in total. Significant differences among the genotypes were observed in grain yield and nitrogen use efficiency parameters such as: agronomic efficiency (AE), physiological efficiency (PE), recovery efficiency (RE), partial factor productivity of applied N (PFP), per day productivity (PDP), harvest index (HI), N requirement (NR), N uptake rate (NUR) and N harvest index (NHI). Based on the grain yield data, the genotypes were grouped into efficient, responsive and efficient as well as responsive genotypes. The N-efficient genotypes that produced high grain yield utilizing soil available N alone were: Swarna, Jaya, Sampada, DRRH2, Tulasi; the responsive genotypes to the applied N were: Rasi, Annada, Tulasi, IR 64; the efficient as well as responsive genotypes those gave higher yield both at N0 and N100 levels were: Varadhan, PHB 71, DRRH2, RPBio 4918-248, RPBio4919-458, KRH2, DRRH3, Akshayadhan. Based on the N use efficiency indices, the genotypes were ranked. Rasi, Tulasi, Annada, MTU 1010 and Anjali from early duration group; Varadhan, PHB 71, RP bio 4918-248, RPBio4919-458, KRH2 from medium duration group and Swarna from late maturing group were found most promising. Thus, genotypic variation for N use efficiency in rice was evident and in the present study, the performance of genotypes over a range of soil and fertilizer N supply was consistent over two seasons in some genotypes and with seasonal variation in some genotypes.

Key words: Genotypes, Grouping, Nitrogen levels, Nitrogen use efficiency, Ranking, Rice

Introduction

Rice is the most important staple food crop in Asia. More than 90% of the world's rice is grown and consumed in Asia, where 60% of the world's population lives. In India, rice crop occupies about 44 million hectares area with annual production of 104.32 million tonnes and productivity of 2239 kg/ ha (India stat 2012-13). Rice is the foremost intensively grown crop in India having high yielding capacity but with decreasing fertilizer use efficiency as one of the major constraints in rice soils. For almost three decades after the Green Revolution, the rice yield growth rate was approximately 2.5% per year, however, during 1990s, this has decreased to ≈ 1.0% (Riveros and Figures 2000) across the world.

Among all essential nutrients, nitrogen (N) is the major element which is required in large quantities by rice. The larger amount (95 to 99%) of N occurs in the organic forms as a part of the soil organic matter complex which is not immediately available to crop plants. It is only the inorganic form of NH4 -N and NO_3 –N which is commonly taken up by plants. At present, consumption of N fertilizer is in the increasing trend, but fertilizer use efficiency is low in most of the production systems. The most limiting nutrient in irrigated rice is nitrogen and N recovery efficiency is only about 25-40% of applied N in most farmers' fields and N is mostly lost by leaching, denitrification, gaseous loss through volatilization and surface run off. Hence, there is a need to achieve increased nitrogen use efficiency.

Nitrogen use efficiency not only depends on the efficient fertilizer management, but also on the cultivar that is used. Genotypes differ in their ability to absorb and utilize nutrients and these genotypic differences in efficiency are related to the acquisition by the roots or utilization by the plant or both (Marschner 1995) and genetic variation in nitrogen use efficiency in rice was reported by several workers (Ladha *et al*. 1998, Singh *et al*. 1998, Hiroshi 2003). The existing N use efficiency pattern and the factors responsible for N use efficiency in existing popular rice varieties need to be well understood for further improvement in N use efficiency. Hence, the present study was undertaken to evaluate the nitrogen use efficiency of existing popular rice varieties and to identify efficient genotypes based on N use efficiency indices.

Materials and Methods

Experimental site characteristics: A field experiment was conducted for two years (2011-2012 and 2012-2013), covering four crop seasons [two wet season (WS, *kharif*) and two dry season (DS, *rabi*)] on a deep black clayey vertisol (Typic pellustert), at the Indian Institute of Rice Research farm, Hyderabad (17˚19″ N latitude, 78˚23″ E longitude, 542 m altitude with mean annual precipitation of 750 mm), to assess the genotypic differences in nitrogen (N) use efficiency and to identify the efficient rice genotypes for their responsiveness and use of soil and applied N.. The experimental soil characteristics were: slightly alkaline (pH 8.1); non-saline (EC 0.7l dS/m); calcareous (free $CaCO_3$ 5.01%); with CEC 44.1 C mol (p+)/kg soil and medium soil organic carbon (0.70%) content. Soil available N was low (215 kg/ha); with high available phosphorus (46 kg P/ha), potassium (442 kg K/ha), and zinc (12.5 ppm).

Treatment details: Detailed field studies were conducted for two years during *kharif* and *rabi* seasons at two nitrogen levels [without any external N application (N0) and with a recommended level (100 kg N/ha, N100) of N application] as main treatments. For this, the field was divided into two separate blocks by making a deep trench of 4 feet between them and placing thick polythene sheets in the trench deep into the soil to avoid leaching from plot to plot. Fifteen (15) popular and high yielding genotype (varieties and hybrids) were tested as sub treatments in a split plot design with 3 replications. The same set of genotypes were tested in both *kharif* and *rabi* seasons. A total of 30 genotypes were evaluated in two years. The recommended dose of fertilizers were given at the rate of 100-40-40-10 kg N, P_2O_5, K_2O and Zn/ha during both seasons through urea, single super phosphate, muriate of potash and zinc sulphate, respectively. Nitrogen was given in three equal splits at basal, maximum tillering and panicle initiation stages (to N100 plot only) while P, K and Zn were given as basal doses only. Chemical plant protection measures, irrigation and weeding operations were done according to normal practice and uniformly for all the treatments.

Observations and data recorded: Grain and straw yields were recorded at harvest and grain and straw samples were analysed for N content using standard procedure by micro kjeldahl method. Nitrogen uptake by grain, straw and total (grain + straw) was calculated and different parameters of NUE indices (agronomic, physiological, recovery and internal efficiencies, per day productivity, N uptake rate per day, harvest index, internal efficiency, partial factor productivity etc.) were computed using grain yield and nitrogen uptake data. Based on the grain yield data at N0 and N100, the genotypes were grouped into efficient (E), responsive (R) and efficient and responsive (ER) genotypes as per Fageria and Baliger (1993). Based on their NUE indices, the genotypes were ranked based on their mean rank value for all indices as per the procedure followed by Singh *et al.* (1998). All the data were subjected to standard statistical analysis, by applying analysis of variance for split plot design. Least significant differences (LSD) were conducted at a 5% level of probability, where significance was indicated by F-test.

Results and Discussion

Grain yield at two levels of N application

In the first year (2011-12), during *kharif*, the grain yield was significantly higher at N 100 compared to N 0 which was higher by 42% (Table 1). With regard to genotypes, all genotypes were superior at N100 over N0. Among the genotypes, in the early group, Rasi out yielded (4.59 t/ha) the other varieties and Prasanna recorded the lowest yield (3.32 t/ha). In the medium duration group, Varadhan recorded maximum yield (6.01 t/ha) and Vasumati recorded the lowest yield (3.73t/ha). This group recorded higher yields than early and late duration varieties. Whereas, in the long duration group, Swarna recorded comparatively higher yield (4.58 t/ha) and BPT 5204 recorded lowest yield (4.22 t/ha).

Though interaction effects were non-significant, medium duration group varieties, Varadhan, Sampada and PHB 71 were superior to other varieties at N0 and other two groups (early and late) were at par. At N 100 also, Varadhan, PHB 71 and Jaya were superior to other varieties.

During *rabi* 2011-12, grain yield was significantly higher at N100 compared to N0 by 58% and the per cent yield reduction in N0 over N100 was higher in *rabi* compared to *kharif* showing the significance of N requirement in dry season (Table 1). With regard to genotypes, all genotypes were superior at N100 over N0. Among the early group, Prasanna recorded significantly lower yield than the other four varieties which were on par at N0 as well as N100. In general, in *rabi*, early varieties performed better with similar yield levels as in *kharif* compared to medium and long duration varieties that recorded lower yields than in *kharif* which could be attributed to the exposure to higher temperatures and water stress in the later stages of crop growth due to longer duration.

In the medium duration group, at N0, the aromatic rice varieties (Pusa Basmati 1 and Vasumati) recorded significantly lower yields compared to all other genotypes which were at par, while, at N100, the varieties, Varadhan, PHB71 and DRRH2 were on par and significantly superior to other varieties. In the long duration group, at N0, all three varieties were at par but at N100, Swarna and BPT5204 were significantly superior to Mahsuri.

Table 1: Grain yield (t/ha) of genotypes as influenced by treatments

***Kharif* 2011**					***Rabi* 2011-12**				
Genotypes	**N0**	**N 100**	**Mean**	**Diff.**	**Genotypes**	**N0**	**N 100**	**Mean**	**Diff.**
Rasi	3.28	5.90	4.59	2.62	Rasi	2.96	5.61	4.29	2.65
Anjali	3.76	4.30	4.03	0.54	Anjali	3.09	5.53	4.31	2.44
Annada	3.21	5.62	4.42	2.41	Annada	3.52	5.11	4.32	1.59
Prasanna	2.90	3.73	3.32	0.83	Prasanna	1.90	2.98	2.44	1.08
MTU 1010	3.68	5.18	4.43	1.50	MTU 1010	3.39	5.38	4.39	1.99
Varadhan	4.76	7.25	6.01	2.49	Varadhan	3.35	5.49	4.42	2.14
Jaya	3.87	6.23	5.05	2.36	Jaya	3.71	4.34	4.03	0.63
Sampada	4.52	5.52	5.02	1.00	Sampada	3.09	4.17	3.63	1.08
PHB 71	4.71	7.02	5.87	2.31	PHB 71	3.72	5.22	4.47	1.50
Pusa Basmati 1	3.65	4.86	4.26	1.21	Pusa Basmati 1	2.80	4.12	3.46	1.32
Vasumati	3.14	4.32	3.73	1.18	Vasumati	2.83	4.16	3.50	1.33
DRRH2	3.91	5.31	4.61	1.40	DRRH2	3.36	5.04	4.20	1.68
Swarna	3.93	5.23	4.58	1.30	Swarna	2.35	4.80	3.57	2.45
BPT 5204	3.31	5.12	4.22	1.81	BPT 5204	2.31	4.65	3.48	2.34
Mahsuri	3.45	4.79	4.12	1.34	Mahsuri	2.24	3.88	3.06	1.64
Mean	3.74	5.36			Mean	2.97	4.70	3.84	
CD(p=0.05)	Main – 1.31; Sub – 1.08; MxS - NS				CD(p=0.05)	M- 0.58; S-0.54; S at M-0.76; M at S – 0.78			

In the second year (2012-13), during *kharif* 2012, all the genotypes recorded significantly higher grain yields at N100 over N0 similar to first year and the mean % yield reduction in N0 over N100 was 39% (Table 2). At N0, the genotypes RPbio4919-377/13, RPbio4919-458, KRH2, DRRH3, Akshayadhan and Swarna performed well recording 4.06-4.35 t/ha which were significantly superior to other varieties. At N100 level also, these genotypes were significantly superior with a grain yield range of 5.0-6.46 t/ha. Tulasi (3.75 t/ha) in early, KRH2 (4.25 t/ha) in medium and Swarna (4.06 t/ha) in the long duration group were superior to other varieties in their group at N0. Whereas, at N100, RPBio 4919-458 (6.46 t/ha) in medium and Swarna (5.07 t/ha) in the long duration group were high yielders. Best performance of high yielding rice cultivars even at reduced N fertilizer rate was reported by Hiroshi (2003).

Similar to the *kharif* 2012, during *rabi* 2012-13 also, grain yield was significantly higher at N 100 (5.26 t/ha) compared to N 0 (3.13 t/ha) which was higher by 68%. Compared to *kharif*, the per cent yield increase to N application was higher in *rabi* in both years showing the significance of N response in dry season. Much higher absolute grain yield and N response in dry season than in wet season in the tropics was also reported by De Datta and Malabuyoc (1976). With regard to genotypes, all genotypes were superior at N100 over N0 in their grain yield. This could be attributed to the fact that higher nitrogen application might have increased the chlorophyll formation and improved photosynthesis and thereby increased the plant height, number of leaves and number of tillers per unit area leading to the production of high dry matter resulting in higher yield (Tejeswara *et al.* 2014).

Table 2: Grain yield (t/ha) of genotypes as influenced by treatments

Kharif 2012					*Rabi 2012-13*				
Genotypes	**N0**	**N 100**	**Mean**	**Diff.**	**Genotypes**	**N0**	**N 100**	**Mean**	**Diff.**
Rasi	3.13	4.85	3.99	1.72	Rasi	2.94	5.11	4.03	2.17
Aditya	2.94	4.44	3.69	1.50	Aditya	2.88	5.04	3.96	2.16
Tulasi	3.75	4.8	4.28	1.05	Tulasi	2.87	5.82	4.35	2.95
Tellahamsa	3.3	3.94	3.62	0.64	Tellahamsa	2.83	5.06	3.95	2.23
Krishnahamsa	3.52	4.81	4.17	1.29	Krishnahamsa	2.54	4.75	3.65	2.21
IR 64	3.44	4.74	4.09	1.30	IR 64	2.62	5.42	4.02	2.80
KRH 2	4.25	5.74	5.00	1.49	KRH 2	3.17	5.96	4.57	2.79
DRRH3	4.12	5.45	4.79	1.33	DRRH3	3.27	5.48	4.38	2.21
RPBio 4918-248	3.97	6.12	5.05	2.15	RPBio 4918-248	3.48	6.03	4.76	2.55
RPBio 4919-458	4.13	6.46	5.30	2.33	RPBio 4919-458	3.49	5.74	4.62	2.25
RPBio 4919-377-13	4.35	5.65	5.00	1.30	RPBio 4919-377-13	3.85	5.3	4.58	1.45
Akshayadhan	4.17	5.56	4.87	1.39	Akshayadhan	3.49	5.88	4.69	2.39
Swarna	4.06	5.07	4.57	1.01	Swarna	4.1	5.14	4.62	1.04
RPBio 226	2.72	4.25	3.49	1.53	RPBio 226	2.75	3.84	3.30	1.09
Sugandhamati	3.18	4.64	3.91	1.46	Sugandhamati	2.73	4.67	3.70	1.94
Mean	3.67	5.1		28.2	Mean	3.13	5.26		
CD(p=0.05)	M-0.40; S-0.33MxS-0.47; SxM-0.49				CD(p=0.05)	M- 0.70; S-0.43; MxS-0.68; SxM-0.61			

In the early group, all four genotypes (Rasi, Aditya, Tulasi,Tellahamsa) were on par at N0 and at N 100, Tulasi was superior to other genotypes. All genotypes were responsive to applied N and the response was the highest in Tulasi. In the medium duration group, RPbio 4918-248, RPbio 4919-458, Akshayadhan and KRH2 were found to be more efficient in soil N utilization and also responsive to applied N. Most of the genotypes in this medium group recorded higher yields than early and late duration entries both at N0 and N100 levels. In the long duration group, Swarna was significantly superior to other two varieties with its consistent performance (by 20-35% higher yield) in both seasons. The variation in grain yield among different varieties was due to the differential efficiency of these varieties in converting dry matter into grain. Similar findings were also reported regarding varietal performance under different nitrogen levels in rice by Priydarshini and Prasad (2003) and Srilaxmi *et al*. (2005). Kanade and Kalra (1986) also reported highest paddy yield in highest nitrogen application.

Genotypic variation in nitrogen use efficiency (NUE) indices

NUE indices of the genotypes tested in two years are given in tables 3-6. In general, the agronomic efficiency (AE), physiological efficiency (PE), internal efficiency (IE), recovery efficiency (RE) and partial factor productivity (PFP) are higher in the genotypes that recorded higher grain yield either at N0 or at N100 levels and these values are close/similar to the optimum recommended values as suggested by Dobermann and Fairhurst (2000). According to them, optimum AE, PE, IE, RE and PFP values are 10 to 30, 40 to 60, 55 to 65, 30 to 50, and 40 to 80, respectively. The trend was similar in both the years and most of these NUE indices are higher in medium duration varieties followed by early duration varieties. Hiroshi (2003), from his experiments, also opined that medium maturity high yielding rice cultivars with higher NUE are appropriate for N reduced input systems.

If we see the seasonal variation, AE, PE, IE and HI values were higher in dry season which could be attributed to better sunshine in dry season that might have helped for efficient utilization of the absorbed nitrogen and comparatively higher grain yield than straw yield in dry season, while, RE, PFP and PDP were higher in wet season. The higher per day productivity could be due to early maturity in wet season compared to dry season where crop will be subjected to very low temperatures in the early crop stages and actual duration will be more in dry season. In both the years, N required for the production of one tonne grain was marginally lower in dry season compared to wet season there by indicating better utilization efficiency of N in dry season. Whereas, in case of NHI, that is, partitioning of N to grain, genotypic variation was evident though not much seasonal variation was observed. NHI also reflects the grain protein content and thus the grain nutritional quality (Sinclair 1998). Genetic variation in NUE of irrigated rice in Senegal was also reported by Gueye and Becker (2011).

Table 3: Important nitrogen use efficiency (NUE) indices of genotypes (*kharif* 2011)

Genotypes	AE	PE	RE	PFP	NR		PDP		IE		HI		NHI	
					N0	N100	N0	N100	N0	N100	N0	N100	N0	N100
Rasi	26.2	37	70	59	15	20.3	33	59	66	49	0.52	0.51	0.65	0.67
Anjali	5.4	15	36	43	12.2	19.0	36	41	82	53	0.53	0.50	0.76	0.73
Annada	24.1	36	67	56	13.7	19.8	29	51	73	50	0.50	0.50	0.66	0.61
Prasanna	8.3	19	43	37	15	23.3	31	39	67	43	0.50	0.42	0.66	0.65
MTU 1010	15	25	61	52	13.8	21.6	32	45	72	46	0.53	0.45	0.70	0.59
Varadhan	24.9	44	57	72	13.5	16.7	37	56	74	60	0.53	0.53	0.66	0.72
Jaya	23.6	46	51	62	13.4	16.6	30	48	74	60	0.52	0.49	0.72	0.68
Sampada	10	31	32	55	13.5	16.8	33	41	74	59	0.51	0.47	0.70	0.66
PHB 71	23.1	28	83	70	12.5	20.3	35	52	80	49	0.54	0.46	0.69	068
PusaBasmati 1	12.1	24	50	49	14.3	20.9	28	37	70	48	0.52	0.44	0.72	065
Vasumati	11.8	22	54	43	18.9	26.3	24	33	53	38	0.42	0.38	0.61	0.51
DRRH 2	14	26	54	53	13.1	19.8	30	41	76	50	0.52	0.53	0.59	0.68
Swarna	13	18	71	52	16.7	26.1	28	37	60	38	0.50	0.39	0.47	0.50
BPT 5204	18.1	29	61	51	16.5	22.7	24	37	60	44	0.45	0.38	0.63	0.61
Mahsuri	7.5	18	42	48	18.8	24.6	29	34	53	41	0.39	0.35	0.61	0.54
CD (p=0.05)	1.25	0.43	0.43	2.24	1.98	0.64	1.73	1.50	3.96	0.75	0.071	0.071	0.071	0.071

AE- Agronomic efficiency (kg grain yield increase/kg N added); PE- Physiological efficiency (kg grain yield increase / kg N uptake; RE- Recovery efficiency (% of N recovered); PFP- Partial factor productivity (kg grain/ kg N added); IE - Internal efficiency (kg grain/ kg N taken up); NR- N requirement (kg grain/ton grain produced); PDP – per day productivity (kg grain yield per day) HI-Harvest index; NHI-Nitrogen harvest index

Table 4: Important nitrogen use efficiency (NUE) indices of genotypes (*Rabi* 2011-12)

Genotypes	AE	PE	RE	PFP	NR		PDP		IE		HI		NHI	
					N0	N100	N0	N100	N0	N100	N0	N100	N0	N100
Rasi	29.2	69	42	59	10.9	12.7	22	41	91	79	0.59	0.60	0.74	0.74
Anjali	24.4	52	47	55	12.6	15.5	23	41	79	65	0.54	0.53	0.65	0.65
Annada	15.9	52	30	51	11.3	13.7	26	38	88	73	0.58	0.55	0.72	0.70
Prasanna	9.8	52	19	27	14.0	15.9	15	23	71	63	0.53	0.45	0.69	0.66
MTU 1010	19.9	65	30	54	13.0	13.9	25	40	77	72	0.57	0.56	0.69	0.71
Varadhan	21.4	46	46	55	12.0	15.7	25	40	83	64	0.58	0.52	0.74	0.74
Jaya	6.3	31	20	43	11.9	14.8	27	31	84	67	0.59	0.54	0.66	0.65
Sampada	10.8	56	19	42	13.5	14.6	21	28	74	68	0.51	0.51	0.62	0.64
PHB71	15.0	62	24	52	11.3	12.7	27	38	88	79	0.60	0.58	0.75	0.72
PusaBasmati 1	13.2	44	30	41	13.4	16.4	20	30	75	61	0.50	0.49	0.63	0.64
Vasumati	13.3	64	21	42	15.8	15.7	21	30	63	64	0.49	0.51	0.63	0.66
DRRH2	16.8	56	30	48	11.8	14.0	24	36	88	74	0.59	0.54	0.73	0.70
Swarna	22.9	65	35	46	14.8	15.1	14	28	67	66	0.42	0.47	0.58	0.59
BPT 5204	24.9	65	29	48	18.0	15.0	14	29	55	67	0.43	0.46	0.55	0.60
Mahsuri	16.4	62	26	39	17.0	16.6	14	24	59	60	0.36	0.42	0.48	0.57
CD(p=0.05)	4.3	2.8	2.4	5.8	1.50	1.82	1.98	0.75	1.9	5.1	0.064	0.035	0.069	0.069

AE- Agronomic efficiency (kg grain yield increase/kg N added); PE- Physiological efficiency (kg grain yield increase / kg N uptake; RE- Recovery efficiency (% of N recovered); PFP- Partial factor productivity (kg grain/ kg N added); IE - Internal efficiency (kg grain/ kg N taken up); NR- N requirement (kg grain/ton grain produced); PDP – per day productivity (kg grain yield per day) HI-Harvest index; NHI-Nitrogen harvest index

Table 5: Important nitrogen use efficiency (NUE) indices of genotypes (*Kharif* 2012)

Genotypes	AE	PE	RE	PFP	NR		PDP		IE		HI		NHI	
					N0	N100	N0	N100	N0	N100	N0	N100	N0	N100
Rasi	17	39	45	49	18.1	21.1	26.3	40.8	55	48	0.47	0.53	0.60	0.65
Aditya	15	42	38	44	18.0	20.4	24.6	37.3	56	49	0.53	0.53	0.61	0.63
Tulasi	11	26	38	48	14.9	19.6	31.4	40.3	67	51	0.59	0.53	0.64	0.61
Tellahamsa	7	31	24	40	17.3	20.3	27.5	33.4	58	50	0.46	0.44	0.56	0.65
Krishnahamsa	13	31	41	48	15.4	19.8	28.2	38.5	65	51	0.49	0.44	0.60	0.59
IR 64	13	59	26	47	16.9	17.0	27.5	37.9	59	57	0.48	0.48	0.62	0.62
KRH 2	15	35	44	57	12.8	17.2	32.4	43.8	79	59	0.52	0.46	0.65	0.57
DRRH3	13	21	75	55	12.5	23.2	31.5	41.6	80	45	0.52	0.43	0.70	0.54
RPBio 4918-248	21	47	47	61	13.6	16.5	29.4	45.3	74	61	0.48	0.43	0.66	0.61
RPBio 4919-458	23	55	43	65	12.7	14.7	30.6	47.9	79	68	0.46	0.44	0.61	0.72
RPBio 4919-377-13	13	36	37	56	12.2	15.9	32.2	41.9	83	63	0.46	0.46	0.71	0.64
Akshayadhan	13	33	40	56	14.6	18.4	30.9	41.2	69	55	0.44	0.46	0.61	0.67
Swarna	10	41	34	51	14.7	18.5	27.1	33.8	69	55	0.44	0.43	0.62	0.57
RPBio 226	15	47	40	43	17.3	20.5	20.1	31.5	58	51	0.38	0.43	0.58	0.63
Sugandhamati	15	47	32	46	17.1	18.6	22.7	33.1	59	54	0.41	0.40	0.63	0.61
CD(p=0.05)	1.5	3.1	2.7	2.8	2.04	0.87	1.31	3.22	3.8	2.8	0.08	0.063	0.043	0.076

AE- Agronomic efficiency (kg grain yield increase/kg N added); PE- Physiological efficiency (kg grain yield increase / kg N uptake; RE- Recovery efficiency (% of N recovered); PFP- Partial factor productivity (kg grain/ kg N added); IE - Internal efficiency (kg grain/ kg N taken up); NR- N requirement (kg grain/ton grain produced); PDP – per day productivity (kg grain yield per day) HI-Harvest index; NHI-Nitrogen harvest index

Table 6: Important nitrogen use efficiency (NUE) indices of genotypes (*Rabi* 2012-13)

Genotypes	AE	PE	RE	PFP	NR		PDP		IE		HI		NHI	
					N0	N100	N0	N100	N0	N100	N0	N100	N0	N100
Rasi	21.7	75.9	28.6	51.1	16.5	15.1	24.7	42.9	60.7	66.3	0.55	0.54	0.72	0.67
Aditya	21.7	80.7	26.9	50.4	16.8	14.9	24.2	42.4	59.4	67.0	0.56	0.53	0.75	0.70
Tulasi	29.4	49.8	59.2	58.2	13.3	16.7	24.1	48.9	75.4	59.8	0.57	0.56	0.70	0.69
Tellahamsa	22.6	44.8	50.6	51.0	14.2	17.8	23.6	42.5	70.5	56.2	0.55	0.51	0.69	0.74
Krishnahamsa	22.1	49.3	44.9	47.5	12.7	16.3	20.3	38.0	78.2	61.5	0.53	0.49	0.66	0.64
IR 64	28.0	65.9	42.5	54.2	16.3	15.7	20.9	43.3	61.2	63.6	0.44	0.54	0.58	0.62
KRH 2	28.9	59.2	48.8	59.6	15.7	21.1	20.2	28.2	80.4	68.5	0.56	0.55	0.69	0.65
DRRH3	22.2	57.0	38.9	54.8	12.4	14.6	23.4	45.5	69.3	63.7	0.52	0.48	0.60	0.57
RPBio 4918-248	25.5	61.0	41.8	60.3	14.4	15.7	24.9	41.9	78.3	69.9	0.53	0.46	0.63	0.63
RPBio 4919-458	22.6	42.1	53.6	57.4	13.6	18.7	19.5	33.4	81.9	59.7	0.52	0.49	0.68	0.55
RPBio 4919-377-13	14.5	38.3	37.8	53.0	12.8	14.3	25.8	44.7	76.8	60.3	0.54	0.51	0.68	0.60
Akshayadhan	23.9	59.6	40.1	58.8	12.2	16.7	25.8	42.5	72.0	66.4	0.52	0.50	0.61	0.61
Swarna	10.4	40.8	25.6	51.4	13.0	16.6	28.5	32.0	74.2	63.6	0.55	0.51	0.72	0.63
RPBio 226	10.9	28.6	38.0	38.4	13.9	15.1	25.8	43.5	63.8	47.3	0.46	0.40	0.66	0.55
Sugandhamati	19.4	38.6	50.3	46.7	13.5	15.7	27.3	34.3	73.6	53.5	0.52	0.47	0.72	0.52
CD(p=0.05)	1.5	6.0	3.0	2.3	0.99	1.36	1.52	1.46	3.2	4.1	0.069	0.095	0.064	0.059

AE- Agronomic efficiency (kg grain yield increase/kg N added); PE- Physiological efficiency (kg grain yield increase / kg N uptake; RE- Recovery efficiency (% of N recovered); PFP- Partial factor productivity (kg grain/ kg N added); IE - Internal efficiency (kg grain/ kg N taken up); NR- N requirement (kg grain/ton grain produced); PDP – per day productivity (kg grain yield per day) HI-Harvest index; NHI-Nitrogen harvest index

Grouping of genotypes based on grain yield

Based on the grain yield recorded at N0 and N100, the genotypes were grouped in to efficient (E), responsive (R), efficient and responsive (ER) and Non efficient and non-responsive (NE,NR) as per Fageria and Baliger (1993). The first group was efficient (E), Where these genotypes produced more than average yield of 15 genotypes at N0 (low N) level, but response to N application at (N 100) was lower than the average yield. The genotypes Swarna and DRRH2 in *kharif* 2011; Jaya and Sampada in *rabi* 2011-12; Tulasi and Swarna in *kharif* 2012 and Swarna in *rabi* 2012-13 are falling in this group (Table 7). The second group was responsive (R) group and here the genotypes which produced less than average grain yield of 15 genotypes at N0 level, but responded to N application (N100) that is, recorded more than the average yield are classified in this group. The genotypes falling into this group were: Rasi and Annada in *kharif* 2011; Rasi and Swarna in *rabi* 2011-12 and Tulasi, Rasi, IR64 and Aditya in *rabi* 2012-13. The third group of genotypes can be considered as efficient and responsive (ER). The genotypes which produced above the average yield of 15 genotypes both at N0 and N100 levels were classified into this group. Genotypes Varadhan, Jaya, Sampada and PHB 71 in *kharif* 2011; Anjali, Annada, MTU1010, Varadhan, PHB71 and DRRH2 in *rabi* 2011-12; KRH2, DRRH3, Akahayadhan, RP bio4919/377-13, RP bio 4918-248 and RPbio 4919-458 in both seasons of *kharif* 2012 and *rabi* 2012-13 fall into this group.

The genotypes which fall into ER group are most desirable because these genotypes can produce more at a low N level and also respond well to the applied N and they can perform better under wide range of N environments. The next desirable group is efficient (E) because genotypes of this group perform well under low N level producing more than average yield and these can directly go to the resource poor farmers. The responsive (R) genotypes can be used in breeding programs. The rest of the genotypes fall into fourth group, non efficient and non responsive (NE, NR) and these are less desirable from NUE point of view. Similar results were reported by Fageria and Filho (2001) in low land rice genotypes.

Table 7: Grouping of genotypes based on grain yield

Group	*kharif* 2011	*rabi* 2011-12	*kharif* 2012	*rabi* 2012-13
Efficient (E)	Swarna, DRRH2	Jaya, Sampada	Tulasi, Swarna	Swarna
Responsive (R)	Rasi, Annada	Rasi, Swarna	-	Rasi, Tulasi, IR64, Aditya
Efficient and responsive (E,R)	Varadhan, Jaya, Sampada, PHB 71	Anjali, Annada, MTU1010, Varadhan, PHB 71, DRRH2	RPBio4918-248, RPBio4919-458, KRH2, DRRH3, Akshayadhan, RPbio4919/377-13	RPBio4918-248, RPBio4919-458 Akshayadhan, RPBio 4919-377-13, KRH2, DRRH3

Ranking of genotypes based on nitrogen use efficiency (NUE) indices

Based on the NUE indices, the genotypes were ranked. Since none of the genotypes possessed same rank for all NUE indices and no single genotype recorded all maximum values, the ranking was done based on the mean value of their ranks (Table 8) as was also reported by Singh *et al.* (1998) and Rao *et al.* (2006). Thus, Varadhan and MTU 1010 in *kharif* and *rabi* of 2011- 12 and KRH2 in both seasons of 2012-13 topped the list with lowest mean rank values. Similarly, in the duration wise ranking (Table 9), Rasi, Annada, MTU1010, Anjali and Tulasi in the early; Varadhan, PHB71, KRH2, RP bio 4918-248 in the medium and Swarna in the late maturity group were found most promising genotypes with almost similar response in both seasons. The genotypes, Rasi and Swarna showed their consistent superiority in two consecutive years. The consistent performance of efficient genotypes over a range of soil and fertilizer N supply was also reported by Singh *et al.* (1998). A close observation of grouping and ranking of genotypes based on grain yield and NUE indices indicated the emergence of same set of genotypes from both categories as the most N use efficient genotypes. Similar ranking system and genotype performance for NUE in rice was also given by Broadbent *et al.* (1987).

Table 8: Ranking of genotypes based on NUE indices

kharif 2011			*rabi* 2011-12			*kharif* 2012			*rabi* 2012-13		
Genotypes	Mean of Ranks	Final Rank	Genotypes	Mean of Ranks	Final Rank	Genotypes	Mean of Ranks	Final Rank	Genotypes	Mean of Ranks	Final Rank
Varadhan	4.4	1	MTU 1010	4.5	1	KRH2	5.6	1	KRH2	4.5	1
PHB 71	4.9	2	Varadhan	4.9	2	RPBio4918-248	5.7	2	RPBio4918-248	5.6	2
Rasi	5.1	3	Anjali	5.7	3	RPBio4919-458	5.7	3	Tulasi	6.1	3
Jaya	5.9	4	Rasi	6.2	4	Rasi	5.8	4	Akshayadhan	7.5	4
Annada	6.6	5	PHB71	6.2	5	Akshayadhan	5.9	5	Rasi	7.6	5
MTU 1010	7.3	6	Annada	6.4	6	DRRH3	6.8	6	RPBio4919-458	7.6	6
DRRH2	7.4	7	DRRH 2	7.3	7	RPBio4919-377-13	6.9	7	Aditya	7.8	7
Sampada	7.6	8	Vasumati	8.1	8	Tulasi	7.4	8	Krishnahamsa	7.9	8
Anjali	7.7	9	Swarna	8.5	9	Krishnahamsa	8.0	9	Swarna	7.9	9
PusaBasmati 1	8.5	10	Jaya	8.8	10	Aditya	8.1	10	Tellahmamsa	8.8	10
Swarna	9.5	11	Sampada	9.4	11	IR64	8.2	11	IR64	8.9	11
Prasanna	9.8	12	BPT 5204	9.9	12	Swarna	8.6	12	RPBio4919-377-13	9.0	12
BPT 5204	10.0	13	PusaBasmati 1	9.9	13	Tellahmamsa	9.3	13	DRRH3	9.1	13
Vasumati	11.1	14	Mahsuri	11.4	14	Sugandhamati	9.6	14	Sugandhamati	10.2	14
Mahsuri	11.6	15	Prasanna	12.8	15	RPBio226	9.7	15	RPBio226	12.0	15

Table 9: Ranking of genotypes duration wise (days)

Early (110-120)	Medium (125-135)	Late (>140)	Early	Medium	Late
***kharif* 2011**			***kharif* 2012**		
Rasi	Varadhan	Swarna	Rasi	KRH2	Swarna
Annada	PHB71		Tulasi	RPbio 4918-248	
MTU 1010	Jaya		Aditya	RPbio 4919-458	
rabi 2011-12			*rabi* 2012-13		
MTU 1010	Varadhan	Swarna	Tulasi	KRH2	Swarna
Anjali	PHB71		Rasi	RPbio 4918-248	
Rasi	DRRH 2		Aditya	Akshayadhan	

From the present study, it can be concluded that significant genotypic variation was observed with regard to grain yield and various nitrogen use efficiency (NUE) indices under sub-optimal as well as optimal N conditions. Significant seasonal variation from the data indicated higher response to N application in dry season compared to wet season with regard to grain yield and most of the NUE indices. Among the different duration groups, medium duration genotypes were superior to early and late maturing groups in terms of their efficiency in utilizing soil available N as well as applied N. The seasonal variation in response to N and N use efficiency of the genotypes was evident in case of some genotypes. Based on the grain yield and N use efficiency indices, Rasi, MTU 1010, Tulasi and Aditya from early; Varadhan, PHB 71, RPBio 4918-248 and KRH2 from medium; Swarna from late maturing groups were found most promising and are the most desirable genotypes for a wide range of soil N availability.

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Dynamics of Rice Production in India-Emerging sustainability issues - Options Available

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Abstract

Rice is an important cereal food crop in India and is cultivated in diverse agro-ecological regions in India. An attempt is made in this paper to trace the dynamics of rice cultivation in the last two decades in India at state level by using data at two points of time, and identify emerging sustainability related issues and available options for handling the issues. It is observed that dynamics of paddy production in some states is not explained exclusively by economics of paddy cultivation. Further there is growing concern regarding mismatch between hydrological suitability and paddy area expansion in some areas. Several policy and technological options are being suggested to correct this mismatch and also address sustainability issues associated with rice cultivation. But many of these options are focussing on any one single sustainability issue only. Hence, for addressing several sustainability issues simultaneously, basing on SRP framework, India has to develop its own standards. Policies, technological options and future research on rice need to be aligned towards the so developed standards. Along with this there is need for delineating areas suitable for rice cultivations, based on hydrological suitability..

Key words: Sustainability, dynamics, water productivity, rice, paddy.

Introduction

Rice is an important cereal food crop in India, constituted 22 percent of Gross Sown Area (GSA) of the country in 2014-15. In 2015-16, value of output of rice crop constituted 14 percent of total value of output from crops in India. In 2016-17 rice was cultivated in 43.19 million hectares in India, resulting in rice production of 110.15 million tonnes. As per recent estimates, rice production in India stands at 111.01 and 115.60 million tonnes in 2017-18 and 2018-19 respectively. A plethora of policies *viz*., Minimum Support Price (MSP) policy, paddy procurement policy, Buffer stock maintenance policy, Public distribution policy, and National food security Act (2013), rice export-import policy, input subsidy policy and policy on rice research are influencing incentives to different stakeholders in rice sector in India, thereby leading to observed outcomes of area, production and productivity. India is the largest exporter of rice in triennium ending 2016-17, with a share of 25.6 percent (CACP, 2018). Rice is cultivated in diverse agro-ecological regions in India. In this backdrop an attempt is made in this paper to trace the dynamics of rice cultivation in the last two decades in India at state level, and identify emerging sustainability related issues (based on review) and available options for handling the issues.

Methodology

The study is based on secondary data collected from various Government Publications available in public domain. Data on rice area, production, yield, MSP, procurement of paddy were collected from Agricultural Statistics at Glance-2017 published by Directorate of Economics and Statistics (DES), Government of India (GOI-2017), New Delhi, and Hand book of statistics on Indian States 2017-18 published by Reserve Bank of India. Data on cost of cultivation of paddy was collected from publications of Directorate of Economics and Statistics, GOI, New Delhi. Standard cost concepts were used in analysis which are as given below.

Cost A1 = Value of hired human labour + value of hired bullock labour + value of owned bullock labour + value of owned machinery labour + hired machinery charges + value of seed (both farm produced and purchased) + value of insecticides and pesticides + value of manure both owned and purchased + value of fertilizer + depreciation on implements and farm building + irrigation charges + land revenue, cesses and other taxes + interest on working capital + miscellaneous expenses

Cost A2 = Cost A1 + Rent paid for leased in land

Cost B1= Cost A1 + interest on value of owned fixed capital assets (excluding land)

Cost B2 = Cost B1 + rental value of owned land (net of land revenue) and rent paid for leased in land

Cost C2 = Cost B2 + imputed value of family labour

Cost A2+FL= Cost A2+ imputed value of family labour

Tabular analysis was used in analysing the data. Major portion of the analysis in the current study is based on data pertaining to two selected years of recent two decades i.e., 1996-97 (starting year) and 2016-17 (ending year). In 2016-17, more number of states were there compared to 1996-97, as some new states were carved out from other states. Hence for comparison in analysis, wherever necessary, data of new states were combined with data of their respective parent states.

Results and discussion

Area under rice in India has increased from 41.24 million ha in 1983-84 to 43.19 million ha in 2016-17, indicating an increase of 1.95 million ha (Fig.1). During the same period rice production has increased from 60.10 million tonnes to 110.15 million tonnes. Maximum area under rice (45.54 million ha) was reported in 2008-09. Between the years 1983-84 and 2016-17, rice yield per hectare increased from 14.57 quintals to 25.50 quintals, still lower than global average yield. However within India, wide regional variation is observed in rice yield. In 2016-17 maximum rice yield of 39.96 quintal was observed in the case of Punjab and lowest rice yield of 18.47 quintals was observed in the case of Madhya Pradesh.

Table 1: State wise rice area, production and yield in selected years

States/Union Territories	Rice area (million ha)		Rice production (million tonnes)		Rice yield (Kg/ha)		Area under irrigation (%)
	1996-97	2016-17	1996-97	2016-17	1996-97	2016-17	2014-15
Andhra Pradesh	4.11	2.11	10.69	7.45	2601	3531	97.1
Assam	2.49	2.45	3.33	5.23	1336	2135	11.0
Bihar	5.07	3.29	7.28	7.48	1437	2274	65.0
Chhattisgarh	na	3.83	na	8.05	na	2102	35.7
Gujarat	na	0.84	0.95	1.93	na	2298	61.5
Haryana	0.83	1.39	2.46	4.45	2964	3201	99.9
Jharkhand	na	1.59	na	3.56	na	2239	5.0
Karnataka	1.36	1.01	3.21	2.54	2364	2515	76.0
Madhya Pradesh	5.40	2.29	5.94	4.23	1101	1847	34.2
Maharashtra	1.48	1.63	2.61	3.35	1769	2055	26.1
Odisha	4.47	3.88	4.44	8.38	993	2160	33.3
Punjab	2.16	2.76	7.33	11.03	3397	3996	99.7
Tamil Nadu	2.17	1.44	5.81	4.04	2671	2806	94.4
Telangana	na	1.68	na	5.17	na	3077	98.1
Uttar Pradesh	5.55	5.65	11.77	12.95	2121	2292	86.7
Uttarakhand	na	0.26	na	0.63	na	2423	70.0
West Bengal	5.80	5.15	12.64	15.09	2179	2930	46.9
All India	**43.43**	**43.19**	**81.74**	**110.15**	**1882**	**2550**	**60.1**
Andhra Pradesh (Undivided)	4.11	3.79	10.69	12.62	2601	3330	
Bihar (Undivided)	5.07	4.88	7.28	11.04	1437	2262	
Madhya Pradesh (Undivided)	5.40	6.12	5.94	12.28	1101	2007	
Uttar Pradesh (Undivided)	5.55	5.91	11.77	13.58	2121	2298	

Source: Agricultural Statistics at a glance, different years

na: Not available

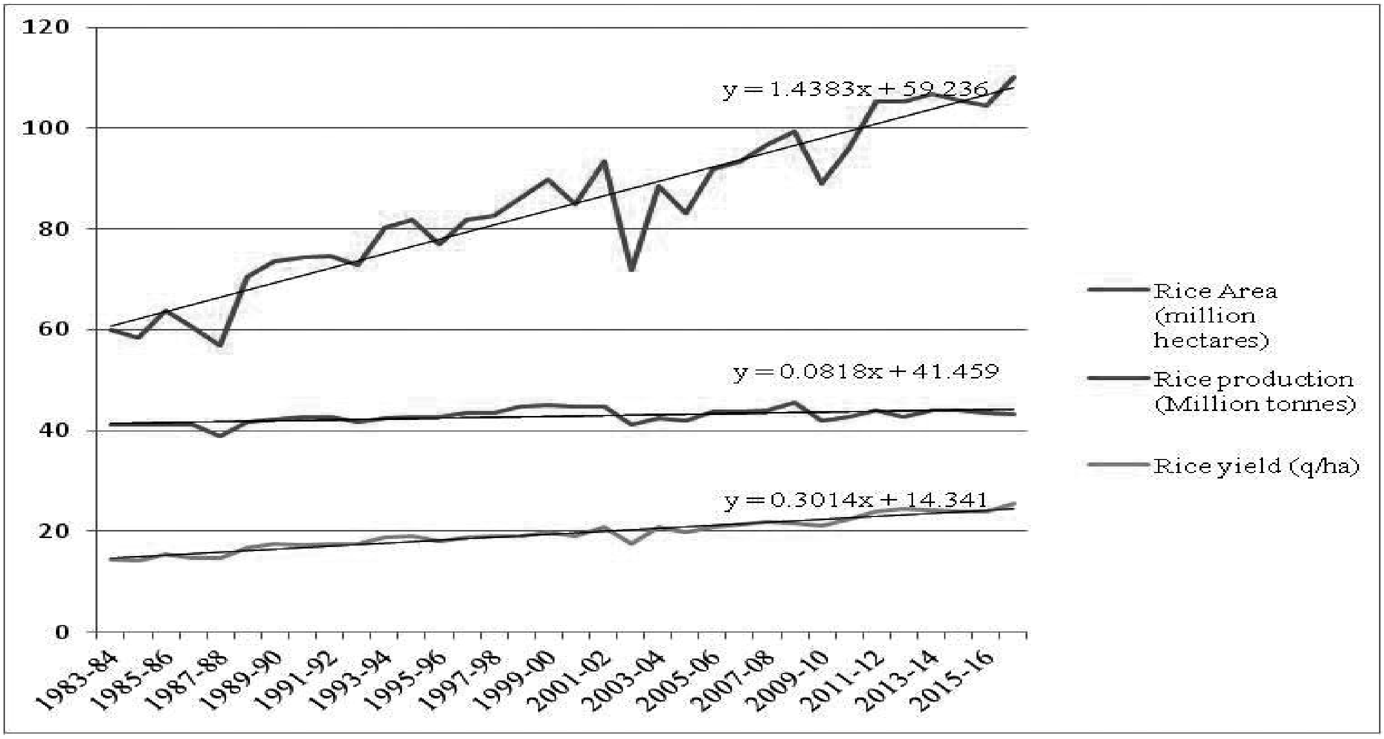

Figure 1: All India rice area, production and yield trends

Results of State level analysis of data on rice area, production and yield are presented in Table.1. In 2016-17 all India rice area decreased by 0.24 million ha compared to rice area in 1996-97. The decrease in rice area was due to decrease in rice area in Andhra Pradesh (undivided), Assam, Bihar (undivided), Karnataka, Odisha, Tamil Nadu and West Bengal. These states together contributed 58.64 percent rice area and 57.98 percent of rice production in the country in 1996-97. But in 2016-17, their contribution decreased to 52.33 and 53.51percent in all India rice area and production respectively. Out of these states, Andhra Pradesh (undivided), Karnataka, Tamil Nadu and West Bengal were the states with average rice yields higher than national average yields both in 1996-97 and 2016-17. Further in case of Karnataka and Tamil Nadu, decline in rice area was associated with decrease in total rice production in 2016-17 compared to 1996-97.

In 2016-17 rice area increased compared to 1996-97 in Haryana, Madhya Pradesh (undivided), Maharashtra, Punjab, and Uttar Pradesh (undivided). These states together contributed 35.49 and 36.85 percent of country's rice area and production respectively in 1996-97. Their share in India's rice area and production increased to 41.24 and 40.57 percent respectively in 2016-17. Out of these states, Punjab and Haryana are high yielding states.

Is this rice dynamics is associated with change in profitability of rice crops in these states?

This issue is analysed, utilizing state wise cost of cultivation data for paddy for the years 1996-97 and 2015-16 (latest year for which data is available) in the present study. Himanshu (2018) reported that in case of rice, at all India level, MSP margin over C2 cost varied between 1 percent to 47 percent in the period 2004-05 to 2017-18. In the current study it is observed that C2 cost per Quintal of output was more than Minimum Support Price (MSP) in the case of Andhra Pradesh (undivided), Assam, Haryana and Madhya Pradesh (undivided) in 1996-97 (Table.2). In 2015-16, similar situation (of C2 cost more than MSP) was observed in the case of Haryana, Madhya Pradesh (divided), Maharashtra, Odisha, Tamil Nadu, Uttar Pradesh (divided) and West Bengal. Thus, in case of Andhra Pradesh and Assam, in 1996-97 C2 cost was more than MSP, but in 2015-16 C2 cost was lower than MSP indicating profitability of rice production in that year. In 2015-16, newly formed states Chhattisgarh and Uttarakhand were facing the situation of lower C2 cost compared to MSP, and were diverging from their parent states which faced C2 cost greater than MSP. Only Jharkhand was in convergence with its parent state i.e., Bihar in 2015-16, with C2 cost lower than MSP. On the whole it is observed that in 2015-16, rice cultivation was profitable with C2 cost lower than MSP in Andhra

Pradesh (undivided), Assam, Bihar (divided), Chattisgarh, Gujarat, Jharkhand, Karnataka, Punjab, and Uttarakhand. Then, why the area under Rice declined in Andhra Pradesh (undivided), Assam, and Karnataka? This might be due to the fact that MSP in India is not statutory and not effective in all states. Hence, another way of looking at economics of rice production is to compare realized price per quintal of output with C2 cost.

Table 2: Economics of Rice production in India in selected years in major rice growing states

States/Union Territories	C2 cost (Rs/q)		Yield (q/ha)		Realized price (Rs/ q)		Net-returns as percentage of total cost	
	1996-97	2015-16	1996-97	2015-16	1996-97	2015-16	1996-97	2015-16
Andhra Pradesh	405.82	1321.55	47.04	58.63	428.70	1429.75	5.56	8.20
Assam	401.22	1399.64	21.01	32.82	412.15	1048.80	5.03	-25.08
Bihar	377.16	1271.13	21.43	27.49	414.20	1140.74	9.78	-10.27
Chhatisgarh	na	1374.79	na	31.88	na	1242.33	na	-9.71
Gujarat	na	1097.31	na	43.17	na	1444.51	na	30.57
Haryana	424.68	1543.66	43.44	52.27	457.48	1708.73	7.72	10.76
Jharkhand	na	1349.11	na	21.77	na	1163.27	na	-13.74
Karnataka	na	1339.42	na	51.88	na	1728.39	na	27.47
Madhya Pradesh	389.44	1709.98	22.61	22.02	439.44	1355.45	12.77	-21.08
Maharashtra	na	2468.55	na	24.00	na	1922.05	na	-24.42
Odisha	365.02	1450.32	24.18	35.28	402.73	1106.84	10.42	-23.71
Punjab	344.81	1061.66	51.64	69.89	405.91	1494.20	17.76	40.74
Tamil Nadu	na	1435.17	na	49.13	na	1451.33	na	0.92
Uttar Pradesh	309.20	1541.04	34.02	35.85	398.51	1222.98	28.84	-20.42
Uttarakhand	na	935.36	na	47.24	na	1241.35	na	32.21
West Bengal	379.16	1423.29	37.20	44.91	427.35	1215.72	12.76	-14.80
Minimum Support Price	380	1410						

Source: DES, Cost of cultivation
na: not available

Based on analysis of cost of cultivation data, it is observed that in 1996-97, in all the states, realized price per quintal of output (which was computed by dividing total value of main product with derived yield) was more than MSP. In 2015-16, realized price per quintal of output was lesser than MSP in Assam, Bihar (divided), Chhattisgarh, Jharkhand, Madhya Pradesh (divided), Odisha, Uttar Pradesh (divided), Uttarakhand and West Bengal.

Highest difference between realised price and C2 cost per quintal paddy (i.e., profitability) was observed in case of Uttar Pradesh (undivided) in 1996-97 and Punjab in 2015-16. In Assam, Bihar (undivided), Odisha, and West Bengal (where rice area declined in 2016-17 compared to 1996-97), difference between realized price per quintal and C2 cost per quintal was negative. But in Andhra Pradesh (undivided), Karnataka, and Tamil Nadu the difference between realized price per quintal and C2 cost per quintal was positive. Hence, despite realised price per quintal was more than C2 cost, rice area decreased in these states.

Among the states whose rice area increased in 2016-17 compared to 1996-97, it was observed that difference between realized price per quintal and C2 cost per quintal in 2015-16 was negative in case of Chhattisgarh, Madhya Pradesh and Maharashtra. Thus, despite realised price per quintal was less than C2 cost, rice area increased in these state. On the other hand realized price was more than C2 cost per quintal in the case of Uttarakhand, but was less than C2 cost in the case of Uttar Pradesh (divided). However, in case of Haryana, and Punjab increase in rice area was associated with positive difference between realized price and C2 cost per quintal. Hence, only in some states, economics of rice production was associated with rice area expansion/decrease when analysis was based on per unit output basis.

In order to get further insights, analysis was carried out on area basis i.e., per hectare basis. In 1996-97, net returns were positive in all the states. But in 2015-16, in case of Assam, Bihar (divided), Jharkhand, Chhattisgarh, Madhya Pradesh, Maharashtra, Odisha, Uttar Pradesh (divided) and West Bengal net returns were negative (i.e., total returns were less than total costs). This could be the cause behind decreasing rice area between the selected years in Bihar (undivided), Odisha and West Bengal. In the case of Andhra Pradesh (Undivided) and Tamil Nadu, though total returns were more than total costs, net return share in total cost was very low. This might have led to decline in rice area in 2016-17 in these states. The way out for this is increasing realized price or reducing cost of production or increasing yield. From 2018 *kharif* onwards, GOI has started fixing MSP at 1.5 times (A2+FL) cost which is lower than C2 cost. Murali and Vijay (2017) reported higher share of land under pure tenancy in Andhra Pradesh (undivided), and Tamil Nadu. This by way of higher land rent (because of competition for land) might also contribute to higher cost of paddy cultivation in these states.

Table 3: State wise rice production and procurement details for selected years

States/Union Territories	State rice area share in all India rice area (%)		State Rice production share in all India rice Production (%)		State rice procurement share in all India rice procurement (%)		Share of rice procurement in state rice production (%)		Rice procurement in 2016-17/ procurement in 1996-97
	1996-97	2016-17	1996-97	2016-17	1996-97	2016-17	1996-97	2016-17	
Andhra Pradesh	9.46	4.89	13.07	6.76	34.92	9.77	42.35	49.99	0.82
Chhattisgarh	na	8.87	na	7.31	na	10.56	na	49.96	
Haryana	1.91	3.22	3.01	4.04	9.29	9.40	48.88	80.52	2.98
Madhya Pradesh	12.42	5.30	7.27	3.84	4.48	3.45	9.77	31.06	2.27
Odisha	10.29	8.98	5.43	7.61	3.67	9.53	10.72	43.32	7.63
Punjab	4.97	6.39	8.97	10.01	32.65	29.00	57.69	100.20	2.61
Tamil Nadu	5.00	3.33	7.10	3.67	5.69	0.38	12.71	3.56	0.20
Telangana	na	3.89	na	4.69	na	9.43	na	69.54	
Uttar Pradesh	12.78	13.08	14.40	11.76	7.02	6.18	7.73	18.18	2.59
Uttaranchal	na	0.60	na	0.57	na	1.85	na	112.06	
West Bengal	13.36	11.92	15.46	13.70	1.23	5.05	1.26	12.74	12.09
All India	100.00	100.00	100.00	100.00	100.00	100.00	15.86	34.59	2.94
Andhra Pradesh (Undivided)	9.46	8.78	13.07	11.46	34.92	19.21	42.35	58.00	1.62
Madhya Pradesh (Undivided)	12.42	14.17	7.27	11.15	4.48	14.00	9.77	43.45	9.2
Uttar Pradesh (Undivided)	12.78	13.68	14.40	12.33	7.02	8.03	7.73	22.53	3.36

Source: Computed using data from Agricultural Statistics at a glance
na: not available

In a recent study Bora *et al.* (2018) found that in states where public procurement of paddy is lower (Odisha, West Bengal and Uttar Pradesh), realised sale price of paddy was lower. Results of analysis of present study on dynamics of public procurement of paddy in 1996-97 and 2016-17 are presented Table 3. 1996-97, 11 major rice growing states in India, contributed 70 percent of rice area, 75 percent of rice production and 98.94 percent of public paddy procurement at national level. In 2016-17, the same states contributed 70 percent of rice area, 74 percent of rice production and 94.6 percent of public paddy procurement. In 1996-97, Andhra Pradesh was the major contributor (34.92%) in public procurement of paddy, followed by Punjab (32.65%) and Haryana (9.29%). But in 2016-17, Punjab was the major contributor (29%), followed by Chhattisgarh (10.56%) and Andhra Pradesh (divided). In all the 11 selected states quantity of paddy procured in 2016-17 was higher compared to 1996-97, except in Tamil Nadu. Share of paddy procured in state paddy production also increased in 2016-17 compared to 1996-97 in all paddy procurement states, except for Tamil Nadu. But, there were wide disparities in quantum of rice procurement. In Punjab and Haryana, share of paddy procured in total state paddy production was above 80% in 2016-17. This share was lowest in Tamil Nadu (3.56%) followed by West Bengal (12.74%). West Bengal, contributed 13.70 percent of country's paddy production, but its share in paddy procured in the country was only 5.05 percent in 2016-17. Similar situation was observed in case of Tamil Nadu also. No paddy procurement was reported from Assam, Bihar, Jharkhand, Karnataka, and Maharashtra states separately, which together contributed 24 percent of paddy production in the country. This lower and lack of procurement could have led to lower price realization by farmers in Assam, Bihar, Odisha, and West Bengal (due to lack of competition from public sector), there by leading to decrease in paddy area. Karnataka and Maharashtra are the exception where in, despite no procurement is reported separately, price realized for paddy was higher than MSP. But in Maharashtra, though realized price was lower than C2 cost, still paddy area in the state was increased in 2016-17 compared to 1996-97.In contrast, in Karnataka though realized price was higher than both MSP and C2 cost, but area under rice decreased in 2016-17 compared to that in 1996-97.

As stated earlier India is the largest exporter of rice. In India, there was a ban on export of non-basmati rice from 15th October 2007, and was replaced with Minimum Export price on 31st October 2007. In between there were several policy changes like ban on export of non-basmati rice from central pool, total ban, etc. The ban on export of non-basmati rice from India was lifted in September 2011 allowing private parties to export from their privately held stocks under Open General Licence (OGL). Basmati rice in India is protected under Geographic Indication (a kind of Intellectual Property rights) and the certification is limited to Punjab, Haryana, Himachal Pradesh, Delhi, Western Uttar Pradesh, Uttarakhand and two districts of Jammu and Kashmir. It was observed that export price of rice from India was higher than domestic wholesale price of rice during 2013-2017 (CACP, 2018). This might have also influenced rice area expansion in Punjab, Haryana and Uttarakhand. Murali and Vijay (2017) reported that "land hunger" of agricultural labour through the tenancy market is constraining crop diversification in some states. Hence, tenancy market might also be a factor determining extent of rice area in some states.

Emerging sustainability Issues and options available:

a) Stress on water resources

Till now in India, increasing rice production per unit area was the focus of research and input subsidy polices. This has led to a situation of depleting water resources. Kampman (2007) estimated that during 1997-2001, share of water foot print of paddy production in total crop water print in India as 39.3 percent. Sharma *et al.* (2018), estimated the total consumptive water use of rice production in India per year as 221 BCM. Chapagain and Hoekstra (2011) estimated water foot print for producing rice in India as 2020 m^3 per tonne of rice and a percolation loss of 1403 m^3 per tonne of rice. Depleting water resource has now led to shift in focus to increasing rice production per unit of water. Decline in paddy area observed (in 2016-17 compared to 1996-97) in the current study with respect to Andhra Pradesh (undivided), Karnataka, and Tamil Nadu is in line with water saving objective (as these states are experiencing) water stress. But the expansion in paddy area observed (in 2016-17 compared to 1996-97) in Maharashtra, Haryana, Punjab, and Gujarat is not desirable from the perspective of water saving (as these states are also experiencing water stress). Hence for addressing mismatch between the hydrological suitability and rice cropping pattern in India, several policy measures are being suggested.

Najmuddin *et al.* (2018) in the case of Bihar reported that water productivity for rice varied with season and increased with proportion of irrigated area in total rice area. Mohanty *et al*. (2017) suggested that eastern India which has the majority of rainfed rice ecosystems, could be prioritized to intensify rice production. Based on analysis of state level water productivity of rice in physical terms Sharma *et al.*(2018), observed highest irrigation water productivity (0.75 kg/ m^3 irrigation water applied) in Jharkhand and lowest productivity in Maharashtra (0.17kg /m^3 irrigation water applied). They also analysed irrigation water productivity of rice in economic terms, reported highest water productivity of rice in Chhattisgarh (11 Rs/m^3 irrigation water applied) and lowest water productivity in Maharashtra (2.75 Rs/m^3 irrigation water applied). Hence, they suggested that paddy cultivation in Maharashtra need to be discouraged except in small Konkan belt. They also observed that in states of Punjab and Haryana, though land productivity was high, water productivity of rice was lower despite having 100 percent irrigation. Further they observed that Punjab, where area under rice was less than many states, emerged as the third highest water consuming state. Hence, Sharma *et al.* (2018), suggested crop diversification in Punjab and Haryana states. These two states together with Western Uttar Pradesh have been identified as the water stress hot spots globally also (OECD, 2017).

Sharma *et al.* (2018), reported that states with higher irrigation water productivity have yet achieved only lower irrigation levels due to regionally skewed policies for agriculture in India. They inferred that imperfect water pricing policies, skewed procurement policies, inadequate electricity supply and input subsidies have led to mismatch between the hydrological suitability and rice cropping pattern in India. Joshi *et al.* (2018) reported that in Punjab, "varietal stickiness" i.e., inertia to change from long duration Pusa-44 variety rice was due to combination of 3 factors *viz*., higher yield of the variety, assured procurement and tariff free electricity. Srivatsava *et al.* (2017) estimated that withdrawal of energy subsidy, will lead to 29 % groundwater saving in Punjab. For improving water productivity Sharma *et al*. (2018) suggested a move from price policy approach of heavily subsidizing inputs to directly depositing money in the bank account of farmers on per hectare basis, leaving input prices to be determined by market forces. They suggested future water productivity studies, incorporating the state-wise cost of irrigation water applied.

Gill *et al*. (2018) in the context of Haryana, reported that in the case of paddy cultivation, the actual number of irrigations has been between 2 and 2.5 times of the optimum number of irrigations by electricity-operated tube wells and diesel-operated pumpsets. They suggested that in certain agro-climatic zones where rainfall is less and land is sandy, the electricity subsidy can be completely withdrawn for the irrigation of paddy crop, as a measure to save water and energy. They also suggest that subsidy can be redesigned, and can be divided according to average cultivated area, so as to make it equitable and save water.

Sreevidhya and Elango (2019) estimated that by means of rice exports, India has Virtual Water (VW) export of 195.61 Gm^3 during 2006-07 to 2015-16. They have considered virtual water content of rice (i.e., water required in the production of rice) as 2850 m^3 per tonne of rice and observed that the highest VW export from India was through rice (among crop and livestock products). They have estimated virtual water import by India in the form of rice import as 0.024 Gm^3 during 2006-07 to 2015-16. In India on rice import an import duty of 70-80 percent is there. It is being opined that rationalization of import duty on rice import can support crop-diversification. Chapagain and Hoekstra (2011) opined that in international context as irrigation systems are generally heavily subsidized and water scarcity is never translated into a price, the economic or environmental costs are not contained in the price of rice. Sreevidhya and Elango (2019) suggested that agricultural products that are produced by stringent water efficient methods only need to be encouraged for exports.

In rice several water saving technologies like System of Rice Intensification (SRI), Direct Seeded Rice are being advocated. Though these are water saving technologies, several adoption constraints like scarcity of skilled labour (in the context of SRI), yield reduction (in the case of DSR) are reported by some studies (Dharmendra *et al.*, 2017 and Devi *et al.*, 2017). Further, instead of promoting DSR as water saving technology in water safe area (as a water conservative measure), is being promoted in water stressed areas, i.e., parts of Andhra Pradesh and Karnataka as a stress coping mechanism. In states like Punjab use of DSR is rather a response to labour scarcity than response to water stress.

b) Green House Gas (GHG) emission

Vetter *et al*. (2017) reported that in India highest GHG emission was associated with rice production when compared to other crops. Methane is the main GHG associated with rice production and methane is a short lived GHG. Some studies indicated that Methane emission in rice production can be reduced by water management i.e., by practicing intermittent irrigation in place of continuously flooded system. However, some studies (Kritee *et al*., 2018) reported that nitrous oxide (a long lived GHG) emission may increase under intermittent irrigation. This is indicating trade-off between emission of methane and nitrous oxide. Kritee *et al*. (2018) based on evidences from their study results across three agro-ecological regions in India, suggested that co-management of water with inorganic nitrogen and/or organic matter inputs can decrease climate impacts caused by GHG emission. Shift to rice varieties with lower GHG emission such as short duration varieties, hybrid rice varieties is also being viewed as an option (McFadden *et al*., 2013). Harnessing consumer willingness to pay premium price for rice that has lower GHG emission is also being viewed as option to promote adoption of rice cultivation practices with low GHG emission (Akaichi, 2017).

From the discussion in the preceding paragraphs, it is evident that multiple sustainability issues are associated with paddy cultivation. As a response to address these sustainability issues, first Standards for sustainably produced rice was released in 2015 by the Sustainable Rice Platform (SRP). The SRP is a multi-stakeholder platform convened by the UN Environment and the International Rice Research Institute (IRRI) in order to promote resource use efficiency and sustainability in the global rice sector. As of January 2019, 97 members (agricultural research institutions, agri-food business, public sector and civil society organizations) are there in SRP including some from India.

SRP Standards are indicators (Table 4) for economic, environmental and social sustainability, based on which a country can evaluate sustainability of its rice cultivation (practices) and value chain, and target improvement over years. However exact desirable/optimal values for some indicators need to be decided at country level or sub national level based on agro-ecological conditions, taking into consideration the possible trade-off between different indicators. These values have to be decided with multi-stake holder participation.

Table 4: Performance indicators for sustainable rice cultivation

Indicator Number	Indicator	Unit	Desirable movement direction over years
1	Profitability: net income from rice	Income/ha/year	Increase
2	Labor Productivity	Net income from rice/ number of human labour days	Increase
3	Productivity	Kg/ha	Increase
4	Food safety	Percentage of milled rice that falls within safety requirements for heavy metals, pesticide residues and mycotoxins	Increase
5	Water use efficiency	Yield per unit of water	Increase
6	Nutrient use efficiency-N	Yield per Kg element of N	Increase (provided farmers do not mine their soil)
7	Nutrient use efficiency - P	Yield per Kg element of P	
8.	Pesticide use efficiency	0-100 score based on answers to a set of questions related to pesticide usage practices and outcomes	Increase
9	Green House Gas emission	Amount of methane emitted per unit of land	Decrease
10	Health and safety	0-100 score based on answers to a set of questions related to practices and outcomes	Increase
11	Child Labour	0-100 score based on answers to a set of questions related to practices and outcomes	Increase
12	Women's empowerment	0-100 score based on answers to a set of questions related to practices and outcomes	Increase

Source: SRP(2015)

Smith *et al*. (2019) demonstrated the potential of a VSS (Voluntary Sustainability Standards) in sugarcane to reduce eutrophication, water use, greenhouse gas emission and natural ecosystem conservation. VSS are stakeholder derived principles with measurable and enforceable criteria to promote sustainable production outcomes, may be an effective way to reduce the negative impacts of agriculture. Since sugarcane happens to be a commercial crop, with strong linkages in the value chain, VSS will be relatively easy for implementation. But in rice, the situation is different. However, increasing consumer concern for food safety, preference for eco-friendly agriculture is being viewed as opportunity for promoting sustainable cultivation practices in rice also. Nguyen *et al*. (2018) tested the feasibility of a market based incentive mechanism by eliciting consumers' willingness to pay for rice produced and labelled under national sustainable production standards in Vietnam. They reported that, domestic consumers were willing to pay 9 percent premium for certified sustainably produced rice. This premium price will incentivize adoption of sustainable rice production standards by farmers. Demont and Rutsaert (2017) suggested three strategies to make rice value chain more sustainable *viz*., (i) embodying sustainability in the product through certified sustainable production labels, (ii) internalizing sustainable production through vertical co-ordination (like contract farming) and (iii) disembodying sustainability through book and claim certificate trading(which is adopted presently in the case of palm oil). Recently Indigo agriculture and Anheuser-Busch (in U.S) announced partnership for sustainable rice production(Seed World). Besides market based approach, State intervention for promotion of integrated technology packages through a policy can also be one option for sustainable rice production as was observed in Vietnam (Stuart *et al*. 2018).

Conclusions

The present study is based on observations at state level, at two points of time. It is observed that rice dynamics in India is not in line with observed economics of rice production in some states. Micro-level studies extending the analysis to district level, covering entire rice value chain may yield insights regarding deviations observed with respect to some states. However, multiple sustainability issues are emerging in rice cultivation as there is mismatch between the hydrological suitability and rice cropping pattern in India. In order to address these issues several policy options (like rationalization/removal of power subsidy, crop-diversification, rationalization of rice export-import policy) and technological options (like SRI, alternate wetting and drying, DSR, switching to short duration varieties, co-management of irrigation and nutrients) are being suggested. However, all these options are focussing on any one individual sustainability issue only but not all. For addressing several sustainability issues simultaneously, Standard for sustainably produced rice developed by SRP can be a framework. Following this framework, there is need for India also to develop standards for its rice production. Policies, technological options and future research on rice need to be aligned towards the so developed standards. Besides that there is urgent need for delineating areas for paddy cultivation based on hydrological suitability.

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ORIGINAL RESEARCH ARTICLE OPEN ACCESS

Promising Technologies to Bridge the Rice Yield gaps across the Country: Experiences from Frontline Demonstrations program

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Abstract

Frontline demonstrations are considered to be the most effective and useful extension activity to demonstrate the latest technologies developed at research stations to the ultimate clientele, that is, farmers, in their own fields. The principle of "seeing is believing" is operational in these demonstrations, as the farmers become easily convinced when they see the performance of new technologies in the fields of their neighboring farmers. During 2017-18, through this programme, a cafeteria of rice technologies were demonstrated in 723 hectare area covering 20 states and five major rice ecosystems of the country. Out of 723 FLDs reported, about 78.7 % were conducted in irrigated rice ecosystem; whereas about 6.87% of FLDs were conducted in rainfed uplands. More than 11.51 % of FLDs were organized in shallow lowlands and 2.07% in hill ecologies. FLD technologies demonstrated in irrigated ecosystems have recorded mean yield of 5.16 t/ha whereas in Shallow lowlands FLD technologies have recorded an average yield of 5.34 t/ha. Average demonstration yields in rainfed uplands was 3.94 t/ha. A critical analysis revealed that the mean yield advantage was the highest in hill ecologies (29%). There is a tremendous scope to bridge the yield gaps (particularly Yield gap-II) in case of Rainfed uplands (24.66 % mean yield advantage), irrigated ecologies (20.66%) and Shallow lowlands (20.97%). For this, proper extension strategies need to be deployed for large scale adoption of these technologies. In total 50 technologies have been identified from 20 states based on their performance in farmers field conditions. This shows the attainable yield potential in the farmers' fields, which needs to be considered for planning the extension programs in these regions. The range of yield advantages explains that there are few promising technologies, if properly adopted by the farmers may result in enhancing the farm level productivity.

Key words: Rice, Frontline Demonstrations, Adoption behaviour, Promising rice technologies

Introduction

The yield gaps in rice between potential and farmers' yields are still substantially high due to the combination of factors like, bio physical, poor management and low socio-economic conditions of farmers and lack of resources, especially credit and knowledge. Majority of the constraints can be overcome by targeting the most suitable varieties / hybrids to specific agro-climatic and other conditions. Technology targeting and encouraging large scale adoption of recently released varieties will lead help not only in bridging the yield gaps but also in improving the income levels of the farmers.

The main reason for low productivity of rice in India is that rice is grown under various production ecologies mainly grouped as irrigated and rainfed systems. While former is considered most favourable, rainfed system has again a wide range of subsystems like shallow, mid and deep water rainfed lowlands and rainfed uplands. Productivity in these systems varies widely. This warrants regular identification of the promising technologies suitable for these ecosystems that could be promoted on large scale.

To address the problems of stagnating food grain production and need to bridge the yield gaps, Government of India has launched the Centrally Sponsored Scheme, 'National Food Security Mission' (NFSM) in August 2007. The major objective of this scheme is to increase production and productivity of rice, wheat and pulses on a sustainable basis so as to ensure food security of the country. The approach is to bridge the yield gap through dissemination of improved technologies and farm management practices.

The Frontline Demonstrations (FLDs) for Rice are an approved component of the National Food Security

Mission to augment production of food grains in the country and are conducted by the ICAR/SAUs system. The ICAR-Indian Institute of Rice Research, Hyderabad, is the nodal Institution for organizing the FLDs on rice.

Frontline Demonstration is a form of applied research through ICAR/SAUs system on latest notified/released varieties along with full package of practices on selected farmers' fields with a view to demonstrate the potentiality of the technologies to (a) participating farmers (b) neighbouring farmers and other agencies; (c) to analyze the production (d) performance of the technologies for scientific feedback.

Frontline Demonstrations (FLDs) helps to identify the suitable and promising technological solutions for different ecosystems based on their performance in the farmers conditions in comparision with the technologies conventionally used.

Methodology of conducting FLDs

A comprehensive package consisting of new seed (variety/hybrid) and recommended cultivation and plant protection practices, etc., is demonstrated to farmers. Financial assistance is provided for critical inputs such as seed, fertilizer, weedicide, pesticide, etc.

Figure 1: Identifying promising technologies under FLD programme

The unique feature of these demonstrations is the active involvement of concerned scientists for providing technical guidance from time to time and the active participation of farmers in implementing the recommended technologies. The organization of field days at an appropriate stage of the crop at strategic locations for a cluster of 20−30 demonstrations is an integral part of these demonstrations, which adds significantly to their effectiveness. These field days provide an on-the-spot opportunity for a large number of interested farmers to acquaint themselves with the advantages of the new potential promising technologies, to have their doubts clarified with subject matter specialists during question-and-answer sessions, and to meet the scientists and extension officials who are aware of the latest developments in agriculture. Technologies demonstrated have addressed various issues of productivity, profitability and sustainability in rice production (Table 1.)

Table 1: Issues addressed through Rice Frontline demonstrations

S No.	Ecosystem	States Covered	Issues addressed
1.	Irrigated	Andhra Pradesh, Bihar, Gujarat, Haryana , Jammu & Kashmir, Karnataka, Kerala, Madhya Pradesh, Odisha, Telangana, Tripura, Uttar Pradesh, Uttarakhand	Higher yields, Water saving, Reduced cost of cultivation; Nutritional Security, Better Market, Biotic stress management, Submergence Tolerance Disease resistance, Labour saving, Retain rice farming,Farm mechanization,Seed production, Drudgery reduction, Drought tolerance, Resource Conservation
2.	Hill	Himachal Pradesh Uttarakhand	Early duration; Introduction of Hybrids; Higher yield drudgery reduction; Cold tolerance
3.	Rainfed Shallow Lowlands	Jharkhand, Tripura , West Bengal	Higher Yields, Introduction of Biofortified product Better Market stress tolerance
4.	Rainfed Upland	Jharkhand, Maharashtra, West Bengal	Abiotic stress management; Higher yields; Early maturing varieties
5.	Coastal Saline/ Problem soils	West Bengal	Higher yield; Submergence tolerance

Results and Discussion

During the year 2017-18, demonstrations were conducted in different ecosystems viz., irrigated, rainfed uplands, shallow lowlands, hills and coastal saline. The technologies demonstrated have recorded differential performance and yield advantages in different ecosystems.

Technology performance under FLDs

Andhra Pradesh Rice Research Institute & Regional Agricultural Research Station, Maruteru, West Godavari district demonstrated the flood tolerant variety Bheema (MTU 1140) that tolerates three types of floods viz. flash floods for 10 days at vegetative stage, stagnant flooding and submergence during germination for 2 weeks with non lodging trait. The demonstration undertaken in Ramanapalem, Mogulthur Mandal, West Godavari had yield advantage of 33% wheras it was 30% in the Luthukur, Mamidikudur Mandal, East Godavari. This varietal technology is reported to be suitable for direct seeded conditions as it possesses 2 weeks anaerobic germination (80% plant survival) and is being suggested for wider cultivation during *kharif* season in place of PLA1100 (Badava mahsuri), MTU 1064 (Amara) and Swrna sub1. In the changing climatic conditions, such varieties would best address the problems like submergence or drought etc.

The variety CR Dhan 909 was demonstrated by ICAR-Research Complex for Eastern Region, Patna at 68 beneficiary farmers' field in 30.25 hectares of land in Madhubani and East Champaran districts of Bihar. An average yield of 5.15 t/ha was obtained in FLD plots. The demonstration of the same variety conducted in 6.4 ha with the help of KVK Buxar, Bihar recorded an average grain yield of 5.35 t/ha. Both the demonstrating and neighbouring farmers were very happy and excited over the performance of aromatic rive variety CR Dhan 909 for its aroma and high tillering ability in the variety. The demonstrated variety displayed its resilience when affected by flood for about 10-12 days and was able to quickly recover from the effect of flood in comparison to other rice varieties.

Department of Genetics and Plant Breeding, IGKV Raipur conducted 6 FLDs in two districts namely, Raipur and Durg to showcase the relative advantage of Chhattisgarh sugandhitbhog and Indira Aerobic 1. In the demonstrated locations, both the varieties recorded 16.59 and 20.91 % of yield advantage (with 4.92 t/ha and 3.99 t/ha productivity respectively).

Demonstrations of GNR-2, GNR-3, Purna and GNRH-1 were conducted in an area of 5.0 ha, 7.70 ha, 2.5 ha and 4.80 ha, respectively performed very well in South Gujarat where they exhibited overall 21.2%, 10.4%, 35.8 % and 10.5 % grain yield superiority over respective checks. They were happy about the substantial market price of GNR-3 and Purna. Incidentally, both varieties were non-lodging.

Rice and Wheat Research Centre, Malan of CSK Himachal Pradesh Krishi Vishvavidyalaya conducted 10 FLDs on four rice varieties HPR 2612, HPR 2720 (Red rice), HPR 2880 and HPR 2143 with complete package of practice, in four clusters of Rait, Dharamshala, Bhawarna and Nagrota Bhagwan blocks of Kangra district. HPR 2720 is a high yielding blast resistant red rice variety recommended for irrigated ecology in area with 650 to 1500 m altitude. The variety has more of iron and zinc content and has medicinal properties. It fetches more prices in the market. HPR 2656 has been recommended for rainfed upland conditions of low and mid hill conditions of the state. The red rice variety HPR 2720 recorded yield advantage of 0.8 t/ha over the local checks and farmers were happy to accept and increase area under this variety as it is more nutritive and fetches higher price. Compared to commonly grown variety RP 2421, new variety HPR 2880 recorded yield advantage of 19.3 per cent and was found suitable for increasing the rice production and productivity in the district. Farmers were happy to put more and more area under this variety under irrigated conditions. For upland area which forms a significant share in rice production of the state, HPR 2656 attracted the attention of the farmers as its productivity is more as well as it gives more of straw yield which is fed as dry fodder to the animals in the hill farming.

In Kashmir, 20 FLDs were organized by Sher-e-Kashmir University of Agricultural Science and Technology of Kashmir. Totally 50 farmers benefitted demonstrating the Shalimar Rice 4 (SKAU 408) for lower altitudes of Valley upto 1600 metres above mean sea level and Shalimar Rice 5 (SKAU 402) for high altitudes of Valley beyond 1800 metres above mean sea level that had better yield advantages.

Central Rainfed Upland Rice Research Station (CRURRS - NRRI), Hazaribagh conducted 20 FLDs on Sahbhagi Dhan and IR 64 *Drt* 1 involving 44 farmers from Masipirhi, Chichikala, Dasokhap, Bongadag, Babhanbhai and Digwar. Sahabhagidhan recorded an average yield of 3.73 t/ha with yield advantage of 24.33% over local variety. In case of IR 64 *Drt* 1, 22% more yield was recorded

Krishi Vigyan Kendra (KVK), Koderma under the aegis of CRURRS, Hazaribagh (NRRI) carried out 5 FLDs on DSR with Sahbhagi Dhan. While DSR condition yielded 30% more yield compared to normal transplanting, the former method also had other advantages such as reduced cost of cultivation.

Zonal Agricultural Research Station, Mandya (UAS, Bengaluru) organized demonstrations on KMP – 175 under Aerobic method (high water use efficient, released for aerobic cultivation in Zone 6 of Karnataka) and KMP 149. Across the locations, KMP – 149 recorded higher yield of 6.2 t/ha with 30% yield advantage.

Kerala, like many other rice growing states of the country, has been facing acute shortage of labour. Hence mechanized farming was taken up under demonstrations. RARS, Pattambi organized 20 hectares of Farm mechanization in six different panchayats Viz., Thachampara, Mannur, Nellepilly, Pudunagaram, Kodumbu and Kottayi. Machine transplanting successfully addressed the problem of labour shortage and delayed transplanting.

Mechanization in rice farming with active involvement of women's' SHGs in Kerala is bringing about remarkable changes in rice production. Yield advantages are observed in all the panchayats when compared to the normal practice of manual planting. Farm mechanization in rice farming recorded the yield advantage of minimum of 625 to the maximum of 1550 kg extra yield in mechanical transplanting over manual planting. Farm mechanization in rice is also resulting in cost reduction of minimum of Rs.2250 to the maximum of Rs. 7500 per hectare. Besides this timely planting and attracting the farmer's to continue rice farming is an additional advantage from the program.

JNKVV College of Agriculture Balaghat, organized FLD's on rice on recently released Hybrid JRH-19, under irrigated ecosystem at village- Nevergaon, Block-Lalburra (Balaghat). AICRIP COA Balaghat conducted 25 demonstrations in Balaghat district. The demonstrations on partial SRI with Hybrid JRH-19 as well as local improved varieties were taken up using plant protection measures. The average yield reported by adopting the improved practice was 5.45 t/ha as against 4.22 t/ha and increased in yield over farmer's practice. Partial SRI demonstrations not only increased grain yield but also saved water by 30%. There is a need to demonstrate the early maturing highly yielding hybrids (110-115 days) due to the erratic poor rainfall and limited irrigation for successful succeeding *rabi* crops. Farmers expressed satisfaction for improved early maturing high yielding hybrid.

Agricultural Research Station, Shirgaon conducted FLDs on the improved high yielding variety Ratnagiri 5 in the districts of Palghar, Ratnagiri, Sindhudurg, Raigad. In the demonstrated fields the variety Ratnagiri 5 which is short slender type, Short slender grain, moderately resistant to leaf blast, neck blast and bacterial leaf blight, early maturing (115-120 days) variety performed well and yielded 43% more than that of the Ratnagiri 24. Also in Maharashtra, Regional Agricultural Research Station, Karjat conducted 4 demonstrations on Karjat 9 with 24% yield advantage over the check varieties.

ICAR Research Complex for North East Hill region, Regional Centre Lamphalphet organized 25 FLDs on recently released rice varieties (RC Maniphou 9, 10, 13) in Bishnupur District, Imphal West, Thoubal districts. The RC Maniphou 13 recorded an average yield of 5.52 t/ ha with yield advantage of 50 % over local checks. Similarly, all the demonstrated varieties yielded better than the local check varieties.

National Rice Research Institute, Cuttack organized 60 FLDs on several varieties like CR Dhan 200, CR Dhan 204, CR Dhan 205, CR Dhan 206, CR Dhan 304, CR Dhan 310, CR Dhan 311, CR Dhan 505, Satyabhama, Sahabhagidhan, Swarna Sub-1 and CR Dhan 500.

A promising variety CR Dhan 204 that was demonstrated in Danpur, Kendrapada Cluster recorded an average yield of 5.2 t/ha with yield advantage of 35% over local popular checks. All the varieties demonstrated in different clusters have recorded impressive yield advantages and farmers were willing to adopt these varieties in subsequent seasons.

Rice variety CO 52 is suited to *samba* season of Tamil Nadu state wherein sowing was taken up in the month of September-October. Apart from delta regions, Western and Northern and Eastern parts of Tamil Nadu are being cultivated with medium duration fine grain rice varieties like BPT 5204 and Improved white. Ponni which occupy an area of about 10 lakh hectares representing 50% of rice total area in Tamil Nadu . In order to replace these varieties, FLDs were conducted with CO 52 to popularize by Department of Rice, TNAU.

In Telangana, IIRR conducted demonstrations to popularize the high zinc variety DRR Dhan 45 under Integrated Weed Management, IPM. Special attention towards soil problems like acidity, alkalinity, micro-nutrients deficiency effectively managed through soil test based fertilizer applications and soil borne pests and diseases were tackled through spraying of *Pseudomonas fluorescence* and pheromone trap installations, Cartap hydrochloride, neem oil spray for stem borer management. The farmers were satisfied with the interventions followed during the demonstrations to get 17.25% yield advantage. RARS Warangal conducted demonstrations on WGL 44 and proved its higher yield advantage of 58.5% in Rayaparthi mandal of Warangal district.

ICAR Research Complex for NEH Region Tripura Centre, Lembucherra conducted demonstrations on recently released variety- Tripura Nirog plus SRI or ICM showed about 15-50% per cent yield advantage over the farmers practice across the locations.

Department of Genetics and Plant Breeding, BHU conducted 15 FLDs on various varieties like HUR 917, HUR 105 Sub-1, HUR 917 + INM, HUR 1309, HUR 105, HUR 105 + INM, HUR 4-3 and HUBR 10-9 in Varanasi, Mirzapur, Ghazipur, Ganj, Jaunpur, Azamgarh, Gorakhpur, Kushi Nagar and Chandauli districts. HUR 105 recorded better yields compared to the normal package of practices. Department of Agronomy, BHU organized FLDs in 10 ha area among 20 farmers of three districts viz. Varanasi, Chandauli and Mirzapur in different villages of U.P on three agronomic technologies i.e. INM, IWM and double transplanting in the demonstrations. These technologies were tested on 5 rice varieties, viz. HUBR 2-1, HUR-105, HUR 4-3, HUR-917 developed by BHU along with DRR Dhan-44 developed by IIRR. DRR Dhan -44, a new variety introduced among farmers has performed well and has given 20-40% increase in yield over local varieties like Sonam, Rupali etc. Most of the farmers are convinced about INM and IWM technology in rice crop through FLDs. The demonstrated varieties have replaced the local varieties like Sonam, Rupali and Moti.

ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora conducted demonstration on VL Dhan 68 involving 101 farmers from Almora district. VL Dhan 68 was released for commercial cultivation in 2014 for the irrigated transplanted medium duration condition of the mid-hills of Uttarakhand and Meghalaya. It matures within 125-130 days and can give yield up to 45 quintals per hectare under standard agronomic practices. It is also resistant to blast, the most important disease of rice in the hills. In the demonstrated fields, the variety recorded better yields with yield advantage of 34% compared to local checks.

Rice Research Station (Govt. of West Bengal), Chinsurah (Hooghly) in collaboration with various local organisations demonstrated fourteen improved varieties under different rice ecosystems viz. coastal saline (Gosaba 5 and Gosaba 6), rainfed shallow lowland (Swarna-Sub1, BINA Dhan 11, Dhiren, Sampriti, Dhruba, Sujala and Kaushalya), and rainfed upland (Sahbhagi Dhan, Ajit, MTU 1010, Puspa and IR 64 Drt1) at farmers' fields in 20 villages under 10 different Community Development (CD) Blocks of the four districts. They exhibited yield advantages to the extent of 3.41-3.98% under coastal saline ecosystem, 4.61-19.87% under rainfed shallow ecosystem, and 4.83-40.56% under rainfed upland ecosystem when demonstrated with whole package of practices. In drought-prone rainfed upland areas, tolerant rice varieties like IR 64 Drt1 and Sahbhagi Dhan did withstand better than local varieties.

Out of 723 FLDs conducted, about 78.7 % were conducted in irrigated rice ecosystem; whereas about 6.87% of FLDs were conducted in rainfed uplands. More than 11.51 % of FLDs were organized in shallow lowlands and 2.07% in hill ecologies. The summary table reveals that the mean yield advantage was the highest in Hill ecologies (29%). There is a tremendous scope to bridge the yield gaps (particularly Yield gap-II) in case of Rainfed uplands (24.66 % mean yield advantage), irrigated ecologies (20.66%) and Shallow lowlands (20.97%).

FLD technologies demonstrated in irrigated ecosystems have recorded mean yield of 5.16 t/ha where as in Shallow lowlands FLD technologies have recorded an average yield of 5.34 t/ha. Average demonstration yields in rainfed uplands was 3.94 t/ha. This shows the attainable yield potential in the farmers' fields, which needs to be considered for planning the extension programs in these regions. The range of yield advantages explains that there are few promising technologies, if properly adopted by the farmers may result in enhancing the farm level productivity.

Table 2: FLDs in various ecosystems (2017-18)

Ecosystem	Total FLDs (ha)	Mean FLD Yield (t/ha)	Mean Check Yield (t/ha)	Mean % Yield Advantage
Irrigated	569.55	5.16	4.35	20.66
Shallow Lowlands	83.26	5.34	4.46	20.97
Hills	15	3.62	2.82	29.55
Rainfed Upland	49.74	3.94	3.14	24.66
Coastal Saline	6	3.80	3.32	14.89
Total or Mean	723.55	4.37	3.61	22.14

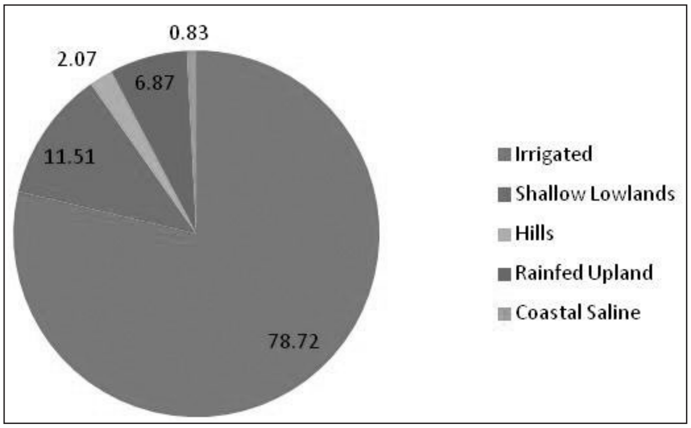

Figure 2: Ecosystem wise breakup of Rice FLDs conducted

Promising Technologies Identified through FLD Program

In total 50 technologies have been identified from 20 states. The criteria adopted to identify these technologies are relative yield advantage over the existing technologies and the kind of local problem the technology tried to address. This is not an exhaustive list, but only indicative list giving those technologies that could be tried in these states. These technologies will help either in withstanding abiotic stresses (such as submergence –Samba Sub-1, IR 64 Drt-1), improving the field productivity (JRH 19, HUBR 2-1), solving the local problems (Problem soil management, Indira Aerobic -1), labour scarcity (Demonstrations of Paddy Thresher, mechanical transplanting), early harvest for facilitating *rabi* crops (Sahbhagi dhan), better basmati options for farmers (Pusa 1509 and Basmati 564), consumer preferences (RC Maniphou-13), replacing the popular varieties (CO 52, CR Dhan 909) etc., But a viable strategy should be in place before these promising technologies making a difference in the livelihoods of farmers.

It may be noted that, a technology with highest percentage yield advantage may not necessarily be a technology that has wider adaptability. In such cases, the percentage yield advantage may help in enhancing the farm level productivity. A technology with average percentage of yield advantage may have wider adaptability, which may result in enhancing the production in larger area. Hence, the development departments may consider these technologies to take up for popularization programmes in much larger areas.

Table 3: Performance of promising technologies identified from FLDs 2017-18

S. No.	State	Ecosystem	Promising technology identified	FLD Yield (t/ha)	Check Yield (t/ha)	% Yield Advantage
1.	Andhra Pradesh	Irrigated	MTU 1140(Bheema)	5.76	4.31	33.64
2.	Bihar	Irrigated	CR Dhan 909	5.15	2.77	85.92
3.	Chhattisgarh	Irrigated	Chhattisgarh sugandhitbhog 1	5.2	3.2	62.5
4.	Chhattisgarh	Irrigated	Dubraj selection 1	5.02	3.1	61.93
5.	Chhattisgarh	Irrigated	Tarunbhog Selection 1	4.87	3.2	52.18
6.	Chhattisgarh	Irrigated	Indira Barani dhan	4.08	3.2	27.5
7.	Gujarat	Irrigated	PURNA	2.20	1.62	35.80
8.	Himachal Pradesh	Hill	‘HPR 2720’ red rice variety	3.39	2.58	31.2
9.	Himachal Pradesh	Hill upland	“HPR 2656’	3.28	2.23	46.9
10.	Jammu & Kashmir	Irrigated	Shalimar Rice 4 (SKAU 408)	7.47	5.90	26.61
11.	Jammu & Kashmir	Irrigated	Shalimar Rice 5 (SKAU 402)]	5.50	4.20	30.95
12.	Jharkhand	Rainfed Upland & Shallow lowland	Sahabhagidhan	3.73	3.00	24.33
13.	Jharkhand	Rainfed Upland & Shallow lowland	DRR Dhan 42	4.38	3.59	22.01
14.	Jharkhand	Rainfed Upland & Shallow lowland	Sahabagi Dhan with DSR	3.45	2.65	30.1
15.	Karnataka	Irrigated	KMP – 149	6.20	4.75	30.53
16.	Karnataka	Irrigated	KMP – 175(Aerobic Method)	5.15	4.00	28.75
17.	Kerala	Irrigated	Rice farm mechanisation	5.13	4.15	23.61
18.	Kerala	Irrigated	Management of weedy rice	7.35	5.86	25.43
19.	Madhya Pradesh	Irrigated	MTU1010	4.27	3.25	31.38
20.	Madhya Pradesh	Irrigated	JR767	4.05	3.13	29.39

S. No.	State	Ecosystem	Promising technology identified	FLD Yield (t/ha)	Check Yield (t/ha)	% Yield Advantage
21.	Madhya Pradesh	Semi irrigated	JRH 19	5.45	4.22	29.15
22.	Maharashtra	Rainfed	Ratnagiri 5	4.51	3.15	43.17
23.	Maharashtra	Rainfed	Karjat 9	4.39	3.52	24.72
24.	Manipur	Hill and NE Plain	RC Maniphou- 9	5.04	3.50	44.00
25.	Manipur	Hill and NE Plain	RC Maniphou- 10	5.07	3.63	39.67
26.	Manipur	Hill and NE Plain	RC Maniphou- 13	5.52	3.66	50.82
27.	Odisha	Irrigated	CR Dhan 204	5.20	3.850	35.06
28.	Odisha	Irrigated	CR Dhan 206	5.00	3.98	25.63
29.	Odisha	Irrigated	CR Dhan 310	5.00	3.94	26.90
30.	Odisha	Irrigated	CR Dhan 311	5.10	4.00	27.50
31.	Tamil Nadu	Irrigated	CO 52	6.88	5.92	16.0
32.	Tamil Nadu	Irrigated	DRR Dhan 42	2.52	2.09	20.65
33.	Tamil Nadu	Irrigated Ecology	Direct Seeded Rice, Alternate Wetting Drying, Mechanized TP	5.93	4.87	21.77
34.	Telangana	Irrigated	Integrated Weed Management in DRRDhan 45	7.00	5.97	17.25
35.	Telangana	Irrigated	Siddhi (WGL-44)	5.69	3.59	58.5
36.	Telangana	Irrigated	DRR Dhan 45	5.26	4.61	14.10
37.	Tripura	Shallow Lowland	SRI + Tripura Nirog	7.80	5.10	52.94
38.	Tripura	Shallow Lowland	SRI + Tripura Nirog	7.40	4.90	51.02
39.	Tripura	Shallow Lowland	SRI + Tripura Nirog	7.10	4.70	51.06
40.	Uttar Pradesh	Irrigated	HUR 105	6.77	5.02	34.86
41.	Uttar Pradesh	Irrigated	IWM + DRR Dhan 44	4.95	4.0	23.75
42.	Uttar Pradesh	Irrigated	NDR 2065	5.33	4.21	26.60
43.	Uttar Pradesh	Irrigated	Sambha Sub- 1+ INM	4.97	4.14	20.05
44.	Uttar Pradesh	Irrigated	NDR 2065 + INM	5.47	4.25	28.71
45.	Uttarakhand	Irrigated Hills	VL Dhan 68	4.13	3.06	34.95
46.	West Bengal	Rainfed upland	Sahbhagi Dhan	4.54	3.23	40.56
47.	West Bengal	Rainfed upland	Ajit	4.17	3.33	25.23
48.	West Bengal	Rainfed upland	MTU 1010	4.24	3.38	25.44
49.	West Bengal	Rainfed upland	Puspa	4.36	3.19	36.68
50.	West Bengal	Rainfed upland	IR 64 Drt1	4.15	3.24	28.09

Conclusion

During the year 2017-18, through this programme, a cafeteria of rice technologies were demonstrated in 723 hectare area covering 20 states and five major rice ecosystems of the country. FLDs organized during this year have been effective in creating the awareness about the potential of new rice varieties, hybrids and other management technologies. In majority of the cases the yield advantages recorded by the FLD technologies were significant.

Out of 723 FLDs reported, majority (78.7 %) were conducted in irrigated rice ecosystem and there is a scope to increase the number of FLDs in rainfed ecologies. It is also revealed that the mean yield advantage was the highest in Hill ecologies (29%). There is a tremendous scope to bridge the yield gaps (particularly Yield gap-II) in case of Rainfed uplands (24.66 % mean yield advantage), irrigated ecologies (20.66%) and Shallow lowlands (20.97%). For this, suitable extension strategies need to be identified and deployed for large scale adoption of these technologies.

In total 50 technologies have been identified from 20 states based on their performance in farmers field conditions. These technologies will help either in withstanding abiotic stresses, improving the field productivity, solving the local problems, labour scarcity, early harvest for facilitating *rabi* crops, better basmati options for farmers, consumer preferences, replacing the popular varieties etc. Identification of promising varieties coupled with a viable strategy should be in place for making significant difference in the livelihoods of farmers. The new varieties and technologies demonstrated need to be popularized in an extensive way, so as to enhance the productivity and production on a location specific basis. The fruits of FLDs can be harnessed on large scale, if proper follow up activities are taken up by the state departments of agriculture.

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Manuscripts should be sent online to the Journal office to rms_28@rediffmail.com; rmsundaram34@gmail.com as an attachment. All the enclosed figures (as ppt files), graphs (as MS Excel worksheet with original data) and photographs (as jpg or ppt files with high resolution) may be submitted as separate files. Avoid using more than one font. The manuscript should be typed in double spaced with margins of at least 2.5 cm. On the first page give the title, a byline with the names of authors, their affiliation and corresponding author's e-mail ID. Abstract should be followed by a list of key words, and abbreviations used in the paper. The usual order of sections to be included after title and abstract pages are: Introduction which includes literature review; materials and methods; results and discussion; conclusion (optional), acknowledgements and references followed by figures and tables.

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Tables: Tables are used for reporting extensive numerical data in an organized manner and statistically analyzed. They should be self explanatory. Prepare tables with the word-processing tables feature and tabs or graphics boxes should not be used. Table head should be brief but complete and self contained. Define all variables and spellout all the abbreviations. An exponenetial expression (eg. x 103) in the units line is often needed to keep length of the data reasonably short, and referenced with an explanatory note. Unless otherwise required, two decimal place values are suggested. Follow the articles published in recent journal for table format.

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