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Genetic diversity analysis of aromatic rice (*Oryza sativa* L.) germplasm based on agro-morphological characterization

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ABSTRACT

Aromatic rice is a special class of rice known in the Indian subcontinent. A total of fifty-eight aromatic rice genotypes were evaluated on the basis of 12 agro-morphological traits at Agricultural Experimental Farm, University of Calcutta, Baruipur, West Bengal to characterize and estimate genetic diversity. Phenotypic coefficient of variation exhibited higher values but maintained close relation with genotypic coefficient of variation for all the traits. Additive gene action was prominent for traits like plant height, panicle length, number of filled grains per panicle and 1000 grain weight. A correlation study showed that grain yield per plant was positive and significantly correlated with tillers per plant, panicles per plant, number of filled grains per panicle, total number of filled grains per plant and 1000 grain weight. The principal component analysis revealed that total number of filled grains per plant had a strong relation with grain yield. Based on Manhattan clustering, fifty-eight genotypes were grouped into five distinct clusters. 24 genotypes in cluster III,17 in cluster I, 9 in cluster II,7 in Cluster IV and 1 genotype in Cluster V.

Key words: *Agro-morphological traits, aromatic rice, cluster, genetic diversity, genotypes*

INTRODUCTION

Rice plays a pivotal role in West Bengal and Indian agriculture. It is the staple food for more than 70% of Indians and more than half the world's population, 8 billion, approximately (Worldmeters, 2020). It is prevalent and grown in all states of India and across all ecologies. Due to enhanced rice production, India made a mark in international trade by becoming the fourth exporter of rice in the world. West Bengal is known as the rice bowl of India and is the largest producer of rice in the country (FAOSTAT, 2020).

India is very rich in rice genetic resources particularly, aromatic rice. Aromatic rice is a special class of rice with high market value due to its superior grain qualities and pleasant aroma (Singh et al., 2000). The foothills of Himalayas, covering Uttar Pradesh, Bihar and the Tarai region of Nepal, is considered as the centre of diversity of aromatic rice (Khush, 2000). It is widely grown in different states of North India like Himachal Pradesh, Jammu and Kashmir, Punjab, Haryana and parts of Uttar Pradesh (Nene, 1998). Due to the high demand for basmati rice (a type of aromatic rice) in the international market, about two-thirds of basmati produced in our country is exported to different countries and that increases every year (Siddiq, 1990). Also demand for aromatic rice has increased many fold in last two decades in national and international markets.

Trade-in aromatic rice has not received considerable attention in India (Marothia et al., 2007) even though scented rice varieties have competitive international prices and the country can earn huge foreign exchange. In Financial year 2018-19, India Exported 7.6 mt of non -basmati aromatic rice value of US $3048 million (APEDA 2020). Realizing the importance and demand of short grain aromatic rice in the world market, efforts have been initiated to collect, characterize and evaluate the aromatic short grain rice in India for documentation and to find suitable donors for different traits that are prerequisites for varietal development.

Genetic study exploring diversity in the landraces is essential for identifying new genes and further improving the germplasm (Thomson et al., 2007) for which it is required to collect and evaluate existing cultivars. Some small and medium-grained aromatic rice landraces can be excellent sources for improving quality in high-yielding varieties as they possess excellent aroma and other quality traits like elongation after cooking, taste, etc. Though several studies on genetic diversity of aromatic rice of different regions have been reported (Siddique et al., 2013; Islam et al., 2014; Ahmed et al., 2016 and Akter et al., 2018). In designing the mini-core collection, we considered phenotypic data (12 morphological traits) and representation from various regional gene pools of eastern India to preserve the maximum possible diversity (Kumar et al., 2020). The present study was done to assess the genetic variation in fifty-eight aromatic rice genotypes by evaluating the agro-morphological traits.

MATERIALS AND METHODS

The seeds of fifty-eight aromatic rice accessions collected from different parts of India including one check (Gobindobhog-a popular local landrace of West Bengal) (Table 1) were sown in the nursery bed. Out of 58 genotypes, 41 were collected from West Bengal, 11 were collected from central India, 3 were collected from Assam, 2 were collected from Bangladesh and 1 was collected from Odisha. The varieties included in the study are Basmati 370, Pusa Basmati I, Taraori Basmati, Kataribhog, Type-3, Dehradun Basmati, Dinesh, CR Sugandha, Pakistan Basmati, Sugandha, Kala Namak and the rest are land races. Twenty-five (25) days old seedlings were transplanted in the field during *kharif* season 2018. Seed material was sown in randomized block design (RBD) with row and plant spacing of 15 x 20 cm in three replications. In this study, the fertilizer dose of N: P: K used was 60:30:30 Kg ha^{-1}. Agro-morphological characters for randomly selected five plants in each replication were recorded at different crop growth stages. The quantitative characters like days to 50% flowering, days to maturity, plant height (in cm), tillers per plant, panicles per plant, panicle length (in cm), number of filled grains per panicle, number of unfilled grains per panicle, total number of grains per panicle, total number of grains per plant, 1000 grain weight (g) and total grain yield per plant (g) etc. were recorded. Genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (H) (broad sense) and genetic advance (GA) was measured by the methods described by Burton (1968) and Hanson et al. (1956). The correlation coefficients and PCA analysis was computed in SPSS 21.0. Genetic distance and cluster of the genotypes based on genetic similarity was computed by NTSYS Pc. 2.20.

RESULTS AND DISCUSSION

Estimation of genetic variation in quantitative traits

The analysis of variance (ANOVA) has revealed significant differences among the genotypes for the traits under the experiment (Table 2). The result showed that sufficient variability was present for the traits like days to 50% flowering, days to maturity, 1000 grain weight, number of filled grains per panicle, panicle length and total grains per plant.

In the present study, the phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV) for all the traits that implies the role of the environment. The same findings were reported earlier (Bhadru et al., 2012). The PCV and GCV were high for days to maturity (26.07, 23.60),1000 grain weight (30.26, 29.99) and total grain yield per plant (47.11, 35.42), indicating variability with respect to these attributes. Medium PCV and GCV were estimated for the traits days to 50% flowering (28.14, 25.98), plant height (15.27, 14.56), tillers per plant (25.18, 13.67) (Table 3). A narrow difference between PCV and GCV as in panicle length (11.17, 9.83) indicated less influence of environment in the expression of the traits and presence of sufficient genetic variability that may facilitate selection (Yadav, 2000). Sarawagi et al., 2000 observed less environmental influences for all traits except 50% flowering, days to maturity, and yield per plant. In the present investigation, high heritability (board sense) coupled with high to moderate genetic advances were observed for the traits plant height, panicle length,

Table 1. List of 58 Genotypes.

Serial no.	Entry name	Geographic origin/ Area of collection	Serial no.	Entry name	Geographic origin/ Area of collection
1	IET-18993	Uttar Pradesh	30	Kalo Nunia	West Bengal
2	Type-3	Uttar Pradesh	31	Kanakchur	West Bengal
3	Gobindobhog (selection)	West Bengal	32	Dadshal	West Bengal
4	Sirjot	Rice Research Station, Chinsurah,West Bengal	33	Kamal Dhan	Rice Research Station, Chinsurah,West Bengal
5	Radhunipagol	West Bengal	34	Binni Dhan	Bangladesh
6	Marisal	West Bengal	35	Laghu Dhan	West Bengal
7	Mugorai	Rice Research Station, Chinsurah,West Bengal	36	Kataribhog	West Bengal
8	Kalotua	Rice Research Station, Chinsurah,West Bengal	37	Kalfa Budh Sugandhi	Rice Research Station, Chinsurah,West Bengal
9	Dehradun Basmati	Uttar Pradesh	38	Pusa Basmati-I	IARI, New Delhi
10	Kaminibhog	West Bengal	39	Kash Dhan-II	West Bengal
11	Dinesh	Rice Research Station, Chinsurah,West Bengal	40	Tulsibhog	West Bengal
12	CR Dhan Sugandha	Odisha	41	Jamai Nadu	West Bengal
13	Paramanya	West Bengal	42	Taraori Basmati	Rice Research Station, Haryana
14	Gandeswari	West Bengal	43	Pakistan Basmati	Haryana
15	Baspata	West Bengal	44	Seetabhog	West Bengal
16	Gobindobhog	West Bengal	45	Kalijeera	Assam
17	Tulaipanji	West Bengal	46	NC-16432	Rice Research Station, Chinsurah,West Bengal
18	Motibas	West Bengal	47	Aus Khas	Rice Research Station, Chinsurah,West Bengal
19	Gontrabhog	West Bengal	48	NC-324	Rice Research Station, Chinsurah,West Bengal
20	Seetashal	West Bengal	49	Kamale Kamini	Bihar
21	Sugandha	West Bengal	50	Joha Black	Assam
22	Kala Namak	Bihar	51	Binni (Red)	Bangladesh
23	Danaguri	West Bengal	52	Kartick Khas	Rice Research Station, Chinsurah,West Bengal
24	Normal Joha	Assam	53	Basmati-370	Punjab
25	Laljeera	Madhya Pradesh	54	Local Basmati	Rice Research Station, Chinsurah,West Bengal
26	Badshabhog	West Bengal	55	NC-365	Rice Research Station, Chinsurah,West Bengal
27	Pokharna Sugandhi	Rice Research Station, Chinsurah,West Bengal	56	Chinishakkar	West Bengal
28	Sonamukhi Sugandhi	Rice Research Station, Chinsurah,West Bengal	57	Tulsimonjori	Bihar

number of filled grains per panicle, and 1000 grain weight. This study suggests that traits like 50% flowering, days to maturity, number of filled grains per panicle, number of unfilled grains per panicle and 1000 grain weight are primarily under additive genetic control and phenotypic selection for the traits can be useful. The range of days to maturity is 110-156, minimum time is taken by Mugorai whereas maximum by Laljeera to mature. Total number of filled grains per plant is highest in Gobindobhog (selection) (6879.3) and lowest in Gopalbhog(524.66), panicle length is maximum in Dehradun Basmati(32.3) and shows minimum range in Kash Dhan II (18.3). (Table 3).

Table 2. Analysis of variance (ANOVA) for the yield and yield attributing traits.

Source	Df	Days to 50% flowering	Days to maturity	Plant height	Tillers per plant	Panicles per plant	Panicle length	Number of filled grains per panicle	Number of unfilled grains per panicle	Total number of grains per panicle	Total number of filled grains per plant	1000 Grain weight	Grain yield per plant
Replications	2	48.84**	69.42**	61.44**	37.07**	43.72**	8.73**	54.15**	80.64**	596.51**	21.32**	0.44	135.8**
Treatments	57	102.01**	138.16**	866.45**	240.07**	107.03**	31.63**	827.5**	1554.79**	12614**	4625.39**	73.14**	1354.53**
Error	114	10.75	17.04	43.60	23.56	17.95	5.62	90.09	38.32	89.3	456.43	1.20	15.05

*Significant at 5% probability level, ** Significant at 1% probability level.
Df - Degrees of freedom.

Association among quantitative traits

Correlations measures the intensity of linear association between the traits. Further, the study helps the breeder to understand the mutual component characters on which selection can be based on for the genetic improvement. In the present investigation, the association analysis (Table 4) demonstrated that grain yield per plant was positive and significantly correlated with tillers per plant, panicles per plant, total number of filled grains per panicle, total grains per plant, 1000 grain weight and total number of filled grains per plant, indicating the importance of these characters for yield improvement in this population. Similar kind of associations were reported earlier by various researchers like Eradasappa et al. (2007), Krishna et al. (2008), Bhutta et al. (2019) for panicle number and Nayak et al. (2001) for plant height. The associations with other characters are to be considered simultaneously when characters have a direct bearing on yield.

The investigation conducted, reveals a negative correlation between grain yield per plant and the number of unfilled grains per panicle; a similar finding was reported by Vanisree et al. (2013) and Bhutta et al. (2019). Therefore, it is concluded that the greater the number of filled grains per panicle with less the number of unfilled grains per panicle results in more grains per plant. This negative association is pleitropy or linkage. A judicious selection of such a component helps in improvised development with desired characters under any situation. The results of correlation coefficients implied that plant height, panicle numbers per plant, number of filled grains per panicle and number of filled grains per plant might be considered for selection for yield improvement.

Correlation analysis thus revealed that panicles per plant and number of filled grains per panicle played a vital role in increasing grain yield per plant. Enhancing these traits may help to obtain a higher grain yield.

Principal component analysis

Principal Component Analysis (PCA) is a powerful tool in modern data analysis because it is helpful in extraction of most important information by compressing the data set and analyzes the structure of observations and the variables. It helps to find the proper combination of

Table 3. Estimates of genetic parameters of variation.

	Mean	Range	G.C.V(%)	P.C.V(%)	H(%)	GA
Days to 50% flowering	112.81	94-131	25.98	28.14	83.37	5.92
Days to maturity	137.81	110-156	23.60	26.07	89.32	6.64
Plant height (cm)	132.90	86-163.3	14.56	15.27	90.91	33.21
Tillers per plant	17.06	9-34.6	13.67	25.18	29.47	1.31
Panicles per plant	15.57	6.33-36	20.75	33.53	38.28	2.31
Panicle length (cm)	24.53	18.3-32.3	9.83	11.17	77.43	3.98
Number of filled grains per panicle	141.69	57.3-297.3	25.04	28.86	75.29	64.72
Number of unfilled grains per panicle	36.33	5-106.6	38.87	46.07	71.21	18.05
Total number of grains per panicle	178.40	74-404	22.14	25.71	74.20	67.13
Total number of filled grains per plant	2157.74	8.4-27.9	35.59	46.40	58.85	10.26
1000 grain weight (gm)	18.79	524.6-6879.3	29.99	30.26	98.20	9.78
Grain yield per plant (gm)	40.33	8.273-96.0953	35.42	47.11	56.53	15.31

G.C.V - Genetic coefficient of variability, P. C. V. - Phenotypic coefficient of variability, H - Heritability, GA - Genetic advance.

agronomic traits which would be helpful to attain high grain yield. Table 5 shows eigenvalues (latent roots), and the percentage of total variation accounted for them obtained from the PCA. The results depicted that the first four components of PCA with eigenvalues >1 contributed 82.58% of the total variations in the fifty-eight genotypes for the 12 morphological characters. Chakravorty et al. (2013) and Shoba et al. (2019) reported that four components contributed 75.9% and 70.14% of the total variation in rice, respectively.

PC1 accounted for 34.31% of the total variation in the population, having the contribution from total number of filled grains per plant followed by grain yield per plant. The second principal component (PC2) accounts for 21.72% (Table 5) of total variation having significant contribution of the traits, tillers per plant followed by days to 50% flowering. PC3 was accounted for 17.13% of the total variation and the trait that contributed most is days to maturity. Lastly, the fourth component showed 9.40% of variation with the contribution from plant height.

The first three principal components (PC1, PC2 and PC3) contributing about more than half of the total variance were plotted to observe relationships between the measured traits in the current investigation. In the

Table 4. Phenotypic correlation coefficients among yield and its component traits.

	DF	DM	PH	TP	PP	PL	FGP	UFGP	TGP	GW	TFGP	GYP
DF												
DM	0.677						.					
PH	0.399**	0.399**										
TP	0.267*	0.267*	0.205									
PP	0.229	0.229	0.167	0.642**								
PL	-0.093	-0.093	0.321*	-0.038	0.115		*					
FGP	0.260*	0.260*	0.337**	0.251	0.140	0.310*						
UFGP	-0.003	-0.003	0.127	0.000	-0.135	0.161	0.046					
TGP	0.245	0.245	0.354**	0.237	0.094	0.341**	0.959**	0.326*				
GW	0.062	0.062	0.016	-0.237	-0.140	-0.066	-0.268*	-0.431**	-0.378**			
TFGP	0.285*	0.285*	0.287*	0.541**	0.719**	0.267*	0.758**	-0.065	0.699**	-0.287*		
GYP	0.125	0.215	0.277*	0.384**	0.611**	0.198	0.533**	-0.352**	0.404**	0.364**	0.762**	

**. Correlation is significant at the 0.01 level. *. Correlation is significant at the 0.05 level.
DF - Days to 50% flowering, DM - Days to maturity, PH - Plant height, TP - Tillers per plant, PP - Panicles per plant, PL - Panicle length, FGP - Filled grains per panicle, UGFP - Unfilled grains per panicle, TGP - Total grains per panicle, GW - 1000 grain weight, TFGP- Total filled grains per plant, GYP - Grain yield per plant.

Table 5. Eigenvalue and percent of total variation and component matrix for the principal component axes.

Traits	PC1	PC2	PC3	PC4
Total Number of Filled Grains per Plant	0.917	0.040	0.221	-0.136
Grain Yield per Plant	0.811	-0.179	0.433	0.111
Total Number of Grains per Panicle	0.793	0.525	-0.244	-0.085
Number of Unfilled Grains per Panicle	0.701	0.084	-0.300	-0.254
Total Number of Filled Grains per Plant	0.706	0.633	-0.153	0.027
Panicle Length	0.662	-0.155	-0.358	0.310
Tillers per Plant	0.462	-0.689	0.215	-0.275
Panicles per Plant	0.459	-0.616	0.508	-0.177
Days to Maturity	-0.081	0.634	0.722	-0.100
Days to 50% Flowering	-0.145	0.646	0.696	-0.040
Plant Height	0.312	0.166	0.019	0.740
1000 Grain Weight	0.040	-0.408	0.458	0.514
Eigen Value	4.117	2.607	2.057	1.129
Variability(%)	34.312	21.728	17.138	9.409
Cumulative(%)	34.312	56.040	73.178	82.587

PC - Principal component.

rotated plot (Fig. 1) the variables are scattered across different components. The 3D rotation plot describes that the grain yield per plant, total number of grain per plant and panicle length are grouped together and have a cumulative effect on the yield.

Increased grain yield is an essential goal for the researchers. Accumulation of genes contributing to higher yield or eliminating the unfavourable genes through the breeding process might progress in potential yield results. The present investigation revealed that grain yield per plant had a strong relation with total number of filled grains per plant, panicle length, suggesting the need for more emphasis on these components for increasing the grain yield in aromatic

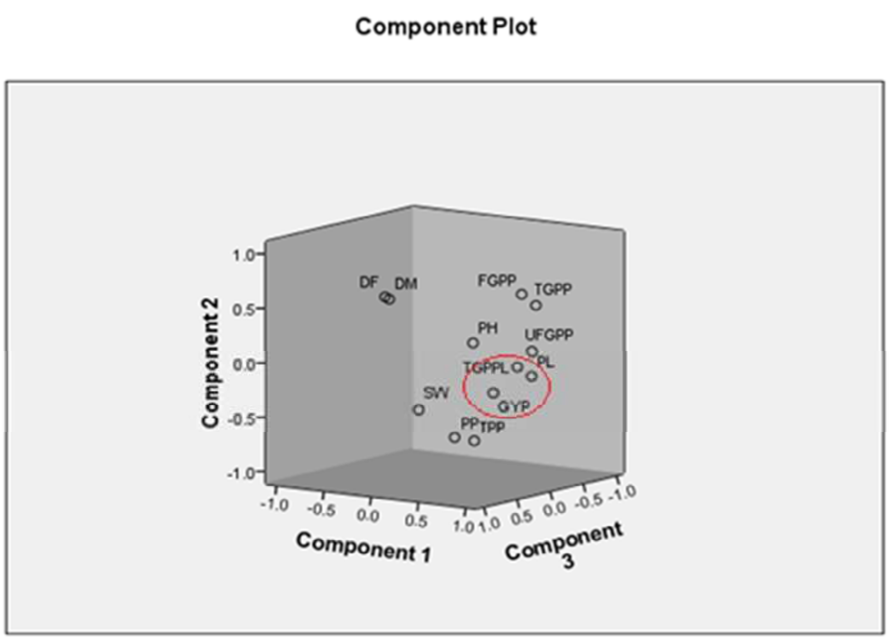

Fig. 1. Component plot in rotated space.
DF - Days to 50% Flowering, DM - Days to Maturity, PH - Plant Height, TPP - Tillers Per Plant, PP - Panicles per Plant, PL - Panicle Length, FGPP - Filled Grains Per Panicle, UGFPP - Unfilled Grains Per Panicle, TGPP - Total Grains Per Panicle, SW - 1000 Seed Weight, TGPPL - Total Filled Grains Per Plant, GYP - Grain Yield per Plant.

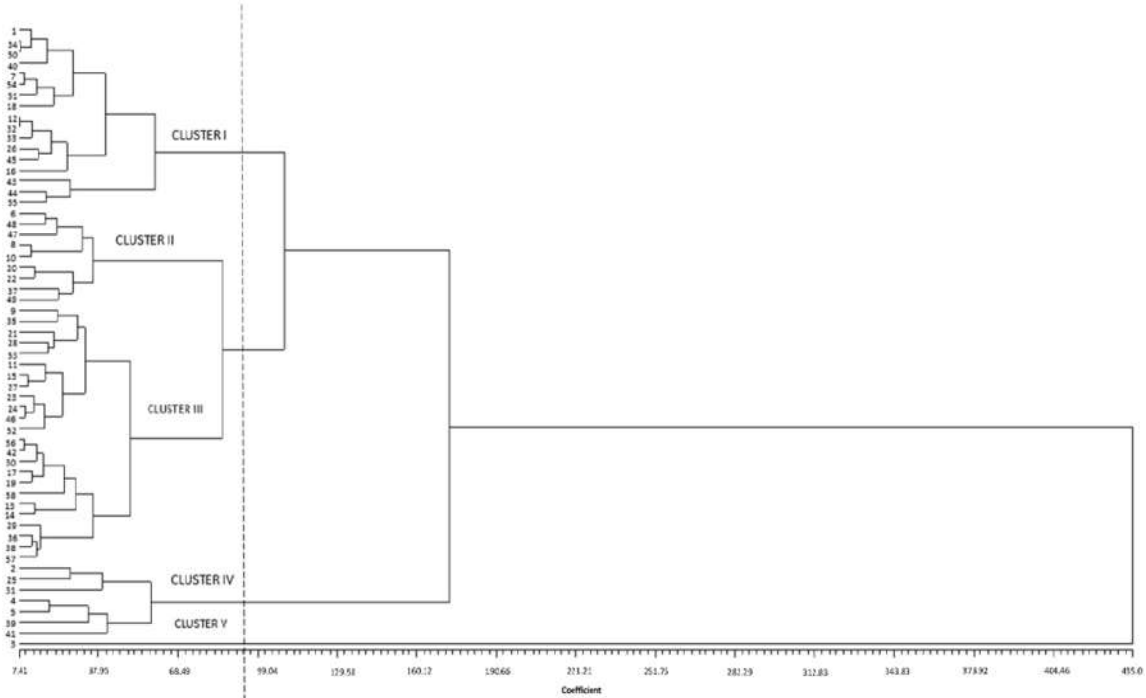

Fig. 2. Dendrogram of 58 aromatic rice genotypes based on quantitative traits. Refer to Table 1 for the name of rice genotypes.

rice. Breeders can use this technique for determining identification of the combination of traits that constitutes an ideal plant to increase the seed yield per plant. In this study, we have to give preference to the total number of filled grains per plant and panicle length. By plotting the PCs that are considered to be necessary and significant, would help select plants close to the ideal plant (Yan and Rajcan, 2002; Shoba et al., 2019). Thus, the results of PCA used in the present study have revealed the high level of genetic variation present in the population panel and explained the traits contributing to diversity.

Cluster analysis

Cluster analysis of fifty-eight aromatic rice genotypes based on agro-morphological traits were grouped into five distinct clusters based on Manhattan clustering. A maximum number *i.e.*, 24 genotypes were grouped into cluster III, followed by 17 in cluster I, 9 in cluster II and 7 in Cluster IV. Cluster V contains one genotype (Gobindobhog selection) (Fig. 2). Gobindobhog (selection) performed better among all genotypes and also showed high yield and high number of filled grains per plant. Genotypes belonging to different states and districts were grouped in a single cluster. The cluster composition showed that germplasm clustering was not associated with the geographical distribution, and accessions were mainly grouped due to their morphological differences. Hossain (2009) and Nascimento et al. (2011), Islam et al. (2018) and Iqbal et al. (2018) reported similar findings in case of rice and oilseeds respectively. The possible reason for grouping genotypes of different regions in one cluster could be the free exchange of germplasm among the breeders of different regions or unidirectional selection practiced by breeders in developing the promising cultivars. The highest genetic distance was observed between CR Dhan Sugandha and Kali jeera (9.820) followed by Badshabhog and Marisal (0.7050), Baspata and Laljeera, Sonamukhi Sughandhi and Jaminadu (0.562), Baspata and Laljeera (0.5180). Desirable segregants are expected to be produced by crossing genotypes with a high dissimilarity coefficients. The crosses consisting of these kinds of diverse parents are likely to express considerable amount of heterosis in the F_1 generation.

CONCLUSION

Aromatic rice genotypes selected for the study showed considerable genetic variability and divergence. Grain yield per plant was positive and significantly correlated with tillers per plant, number of panicles per plant, number of filled grains per panicle, total number of filled grains per plant and 1000 grain weight, suggesting the selection of these traits will lead to high yield. The PCA revealed that the total number of filled grains per plant had a strong relation with grain yield, suggesting the need for emphasizing on these components for increasing the seed yield in aromatic rice. The cluster analysis grouped the genotypes into different clusters with specific character traits, this will help to select parental lines for future breeding programmes. The highest genetic distance has been observed in between CR Dhan Sugandha and Kali jeera followed by Badshabhog and Marisal, Baspata and Laljeera, Sonamukhi Sughandhi and Jaminadu. Crossing between the above pairs of genotypes would most likely express a considerable amount of heterosis in the F_1 generation and provide a wide spectrum of recombinants in segregating generations.

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Genetics of grain yield and its component traits in drought tolerance rice

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ABSTRACT

The facts pertaining to the inheritance of basic and value addition traits are prerequisite in designing much suited breeding strategies to harness substantial genetic gain in crop plants. The present study was aimed at comprehensive scrutiny of the quantitative traits, responding drought tolerance in rice through generation mean analysis (GMA). We have evaluated six generations (P_1, P_2, F_1, F_2, B_1 and B_2) of cross, HUR-917 × DRR Dhan-42. The results revealed that all scales, A, B, C and D were significant for yield and attributing traits under irrigated and drought conditions, reflecting the presence of epistasis. Major yield contributing traits like days to 50% flowering (DFF), days to maturity (DM), plant height (PH), panicle length (PL), flag leaf length (FLL), number of grains per panicle (NGPP) and test weight (TW) showed the presence of duplicate epistasis under both conditions. Whereas, traits like the number of earbearing tillers (NEBT) and grain yield per plant (GYPP) shown duplicate epistasis under drought. The results suggest the prevalence of additive gene effect and non-allelic interactions/epistasis effect on the genetic control of majority of the yield traits. Additive (d) effect and dominant × dominant (l) gene interaction was the only significant portion of gene controlling grain yield per plant in the rice. The positive additive gene effect indicates that HUR-917 contributes more to the trait than DRR Dhan-42 and vice versa.

Key words: *Drought tolerance, gene action, components of variance*

INTRODUCTION

Rice (*Oryza sativa* L.) is the premier food crop for more than half of world population. It is grown under diverse ecosystems across the globe and is directly linked to the livelihood and economy of most of the Asian countries (Rout et al., 2020). Being a water adoring crop, rice is constrained by several biotic (bacterial and fungal diseases) and abiotic (drought, heat, flooding etc.) stresses which caused substantial yield and quality loss (Khush, 2005). Current climatic changes and depleting soil resources threaten the sustainability of rice throughout the world. Water deficit is the most damaging factor that limits rice production in the rainfed ecosystem (Singh et al., 2021). Besides, shrinking arable land and depleting water resources along with resurging minor diseases and pests are other challenges for rice researchers, and necessitates exhaustive breeding attention/reorientation to meet the food demand (about 40% more rice) of our ever-growing population (8.5 billion till 2030) (Gurdev, 2006).

Rice is a semi-aquatic crop, that needs high water requirements for its cultivation, so, more prone to drought stress. Developing inbuilt drought resistant cultivars is found to be substantial to enhance rice sustainability under drought. Most of the improved cultivars grown in drought prone rainfed lowlands were originally bred for irrigated conditions and were never selected for drought tolerance (Kumar et al., 2007) or for submergence tolerance. The knowledge on the nature and magnitude of gene action involved is paramount important for the successful development of drought tolerant rice varieties. Generation mean analysis (GMA) is a much suited biometrical technique to study the genetics and gene action and to infer the underlying gene action governing quantitative traits in rice crop (Muthuvijayaragavan and Murugan, 2017; Kumar et al., 2019). Genetic analysis using GMA approach has been used to estimate the nature of gene actions governing the quantitative traits, and knowledge of additive, dominance and epistatic effects which are prerequisite in designing the most appropriate breeding strategies for substantial genetic gain enhancement in rice with great precision. It is a simple and very effective biometrical technique, able to partition/ estimate total epistatic/interaction gene effects into additive × additive (i), additive × dominance (j) and dominance × dominance (l) effects. This article is pertaining to assessing the nature of genes and action of drought tolerant traits in early duration rice.

MATERIALS AND METHODS

The experiments were conducted at two locations and seasons at Research Farm of Institute of Agricultural Sciences, BHU, Varanasi, Uttar Pradesh and research Farm of ICAR-National Rice Research Institute (NRRI), Cuttack during *kharif* 2018 to *rabi* 2019-2020. The field trials were grown in well fertile alluvial soil with a recommended dose of fertilizers (80 kg N, 40 kg P_2O_5 and 40 kg K_2O per hectare). The indica rice cultivars, HUR-917 and DRR Dhan-42 were sown on two staggered dates with 7 days intervals. The F_1s and BC generations of cross, HUR-917 (drought sensitive, used as a recurrent parent) and DRR Dhan-42 (drought tolerant carrying qDTY2.2 and qDTY4.1) were generated during *kharif*, 2018 to *kharif*, 2019. Then after, all six generations (P_1, P_2, F_1s, F_2, BC_1 and BC_2) were evaluated during *rabi* 2019-20 in three replications under RBD design. The plant population were maintained at 20 cm x15 cm spacing under recommended agro-practices.

Observations recorded

The phenotypic data were recorded for 11 quantitative traits *viz*., days to 50% flowering, days to maturity, plant height, panicle length, flag leaf length, flag leaf width, number of ear bearing tillers, number of grains per panicle, spikelet fertility percentage, test weight or 1000-seed weight, grain yield per plant. Five plants from parents (P_1, P_2), BC_1, BC_2 and F_1 and 15 plants from F_2 generation per replication were randomly selected and tagged for recording the observation of the traits under irrigated and reproductive stage drought stress (ROS- rain out shelter) condition.

Management of water stress

The trials were conducted under irrigated conditions (E1) as well as under rainout shelter conditions to impose reproductive stage drought stress (E2). Under irrigated conditions (E1), the experimental field was left uncovered to receive natural rainfall. In addition to this, experimental plots were irrigated as and when required to maintain appropriate moisture levels as recommended for irrigated rice. In case of E2, the experiment was conducted in rainout shelter to exclude any possibility of natural rainfall in the experimental plots. The seed of all generations P_1, P_2, F_1, F_2, BC_1 and BC_2 were sown and transplanted in the field and under rainout shelter. The reproductive stage drought was imposed by withholding the irrigation after 30 days of transplanting *i.e*., one week before panicle exertion. Plants were exposed to drought for two weeks (60-80 K Pa.) then after it was released by irrigation. Plant recovery was measured on the 10^{th} day after the release of drought. In the case of both trials, the crop was raised as per recommended package and practices.

Statistical analysis

Analysis of variance was performed by using the procedure of randomised block design analysis given by Panse and Sukhatme (1967) for all six generations. Gene action was analyzed by following the scaling test (Mather, 1949; Hayman and Mather, 1955). Hayman (1958) and Jinks and Jones (1958) devised the six parameter model for the estimation of various genetic components. Cavalli (1952) gave the 'Joint scaling test' method which includes any combination of families at a time. To estimate the parameters m, d and h 'weighted least square method' developed by Nelder (1960) and

Table 1. Scaling test and generation mean analysis for yield and its component traits in the parents P1, P2 and combinations F1, F2, B1 and B2 of HUR-917 x DRR dhan-42.

Traits/ Parameters	Environment	Scaling test				Generation mean analysis						□ H	Gene action/epistasis
		A	B	C	D	m (Hay man)	d (Hay man)	h (Hay man)	i (Add × Add)	j (Add × Dom)	l (Dom × Dom)		
Days to 50%	Irrigated	4.33**	-31.66**	4.66**	16.00**	107.66**	17.33**	-32.33**	-32**	18.00**	59.33**	4444.65**	D
flowering (days)	Drought	4.66**	-41.00**	-3	16.66**	110.00**	22.00**	-32.16**	-33.33**	22.83	69.66**	1713.67**	D
Days to	Irrigated	2.33**	-33.00**	0.66	15.66**	134.33**	17.00**	-32.33**	-31.33**	17.66	62.00**	5053.15**	D
maturity (days)	Drought	10.66**	-26.00**	14.00**	14.66**	139.66**	18.66**	-34.33**	-29.33**	18.33	44.66**	1754.13**	D
Plant height	Irrigated	5.00**	11.66**	-2	-9.33**	106.33**	-4.00**	17.00**	18.66**	-3.33	-35.33**	606.15**	D
(cm)	Drought	1.33	-6.33**	3.00*	4.00**	96.00**	3.33**	-6.50**	-8.00**	3.83	13.00**	111.53**	D
Panicle length	Irrigated	-1.96**	9.00**	1.03*	-3.00**	23.50**	-5.06**	6.11**	6.00**	-5.48	-13.03**	1462.03**	D
(cm)	Drought	2.93**	-4.33**	6.33**	3.86**	23.66**	3.46**	-7.90**	-7.73**	3.63	9.13**	313.63**	D
Flag leaf length	Irrigated	4..06**	-14.23**	3.66*	6.91**	37.86**	8.81**	-13.60**	-13.83**	9.15	24.00**	1260.84**	D
(cm)	Drought	2.46**	27.23**	3.56**	-13.06**	22.06**	-12.80**	26.65**	26.13**	-12.38	-55.83**	3455.37**	D
Flag leaf width	Irrigated	0.11	0.01	-0.06	-0.1	1.30**	0.10**	0.13	0.2	0.05	-0.33	9.94**	-
(cm)	Drought	0.20**	0.16	0.23	-0.07	1.35**	0.003	0.09	0.14	0.02	-0.51**	26.78**	-
No. of ear bea-	Irrigated	-0.66	-1.33**	-0.66	0.66	11.00**	-0.33	-3.00**	-1.33	0.33	3.33*	19.37**	-
ring tillers (no.)	Drought	5.66**	-3.00**	1.33	-0.66	11.66**	4.66**	0.66	1.33	4.33	-4.00*	311.86**	D
Number of gr-	Irrigated	7.00**	-43.00**	16.00**	26.00**	221.00**	23.33**	-50.66**	-52.00**	25	88.00**	3023.10**	D
ains per panicle	Drought	5.00**	13.33**	3.66**	-7.33**	183.66**	-4.00**	17.16**	14.66**	-4.16	-33.00**	301.61**	D
Spikelet fertility	Irrigated	1.27*	4.67**	0.5	-2.72**	86.18**	-0.84	4.78**	5.44**	-1.7	-11.38**	154.82**	D
(%)	Drought	3.54**	21.50**	5.26**	-9.89**	69.15**	-10.77**	19.15**	19.78**	-8.97	-44.83**	2338.92*	D
Test or 1000-	Irrigated	-0.07	24.96**	-0.71	-12.8	13.90**	-12.40**	26.04**	25.61**	-12.51	-50.51**	11238.26**	D
seed weight (g)	Drought	0.15	21.46**	0.79	-10.41**	12.99**	-10.74**	20.51**	20.82**	-10.65	-42.43**	13407.90**	D
Grain yield	Irrigated	-0.72	3.34**	1.80**	-0.41	16.37**	-2.08**	0.8	0.82*	-2.03	-3.44**	214.55**	-
per plant (g)	Drought	0.98*	8.56**	-0.15	-4.85**	7.26**	-3.77**	10.11**	9.70**	-3.79	-19.24**	922.00**	D

Note: *, ** is significant at 5% and 1% probability level

Hayman (1960) was used. Here, the weights are defined as the reciprocal of standard error. Accordingly, the expected generation means were calculated and compared with the observed generation mean values using χ^2 test. A significant χ^2 value indicates that the model is not adequate and the non-allelic interactions are added to the model.

RESULT AND DISCUSSION

Analysis of variance

The analysis of variance revealed that all six generations under irrigated and drought stress condition differed significantly for all the traits except flag leaf width and spikelet fertility in irrigated condition (Table 2). Similarly, the significant differences among lines for yield traits in drought tolerance rice were reported by Singh et al. 2019 and also by Rao et al., 2017, in submergence rice for most of the traits related to yield. Under normal condition, all studied traits shown positive and medium to high range of heritability (broad sense) whereas, under drought stress, it was recorded comparatively low, plant hight which is most critical trait under drought recorded negative heritability (Table 3). This is fully coroboroted with the findings of Nadarajan, 2010; Gnanamalar and Vivekanandan, 2013; Kumar et al., 2019; Gobu et al., 2021

Estimates from scaling tests

To determine the pattern of gene action of the target QTLs (qDTY2.2 and qDTY4.1) as well as product profile traits, the gene action of the traits studied was evaluated using a simple additive dominance model (Table 1). The scaling test analysis showed all scales, A, B, C and D were significant for the traits, panicle length, flag leaf length and number of grains per panicle under both conditions, drought and irrigated, indicates the presence of epistasis/non-allelic interaction in the expression of these traits in both environments i.e. irrigated as well as drought condition. All the traits related to yield in both irrigated and reproductive stage drought conditions in the present study were significant in either one of the scales or in combination representing the existence of epistatic/ non-allelic interactions between the genes involved. The scaling test in irrigated conditions showed significant for days to 50% flowering, days to maturity, plant height, panicle length, flag leaf length, number of grains per panicle, spikelet

Table 2. ANOVA for individual environment for all eleven traits in reproductive stage drought tolerance rice HUR-917/ DRR Dhan -42.

Source of variation	df	Days to 50% flowering (days)		Days to maturity (days)		Plant height (cm)		Panicle length (cm)		Flag leaf length (cm)		Flag leaf width (cm)		No. of ear bearing tillers (no.)		Number of grains per panicle		Spikelet fertility (%)		Test or 1000 -seed weight (g)		Grain yield per plant (g)	
		Mean sum of squares																					
		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S
Replicates	2	0.62	1.85	0.54	1.42	0.50	1.72	0.14	0.85	1.56	0.95	0.00	0.00	0.78	0.19	1.06	3.68	0.75	0.14	0.15	0.02	0.25	0.15
Generations	5	88.3-9***	116.5-5***	88.3-1***	84.2-0***	17.1***	35.3-6**	7.6-6***	4.7-0***	21.0-2***	65.8-1***	0.00	0.02***	1.6-1**	2.7-5*	809.99***	610.32**	2.52	79.38***	61.14***	50.93***	7.78***	17.28***
Errors	10	0.47	1.24	0.79	3.66	0.92	3.48	0.48	0.22	0.64	0.74	0.00	0.00	0.24	0.53	2.42	8.47	1.15	0.84	0.06	0.076	0.09	0.17

** and * Significant at 1 and 5 per cent level, respectively; ***: Significant at 0.01; N: Normal irrigated condition; S: Reproductive stage drought condition.

Table 3. Heritability (Broad Sense) values for all the traits under irrigated and drought conditions.

Traits	Heritability under irrigated condition	Heritability under drought
Days to 50% flowering (days)	0.92	0.33
Days to maturity (days)	0.56	0.19
Plant height (cm)	0.66	-0.24
Panicle length (cm)	0.38	0.63
Flag leaf length (cm)	0.81	0.68
Flag leaf width (cm)	0.27	3.04
No. of ear bearing tillers (no.)	0.65	0.35
Number of grains per panicle	0.55	0.44
Spikelet fertility (%)	0.70	0.45
Test or 1000-seed weight (g)	0.88	0.82
Grain yield per plant (g)	0.35	0.04

fertility except for flag leaf width, effective bearing tillers, test weight and grain yield per plant for scale A, for scale B, all the traits except flag leaf width showed the significant result, for scale C, traits days to 50% flowering, panicle length, flag leaf length, number of grains per panicle and grain yield per plant were showed significant result and for scale D, all the traits except flag leaf width, effective bearing tillers and test weight showed the significant result. While under drought stress (reproductive stage) condition, the scaling test showed significant for days to 50% flowering, days to maturity, plant height, panicle length, flag leaf length, number of grains per panicle, spikelet fertility for all scales A, B, C, and D. However for scale A, all traits except plant height, test weight showed significant. For scale B, except flag leaf width remaining all traits showed significance. For C scale, except for days to 50% flowering, flag leaf width, effective bearing tillers, test weight and grain yield per plant showed significance and for scale D all the traits except flag leaf width and effective bearing tillers showed the significant result.

The joint scaling test revealed significant Chi-square value for all the traits revealed non-adequacy of the simple additive dominance model implies that there is existence of non-allelic interaction effect (epistasis). Mean value of all studied traits were highly significant, indicates substantial genetic variations among the parents to be utilized in breeding programs. All traits except flag leaf width under both condition recorded higher dominance 'h' value than additive 'd' indicates abundancy of dominance effect and additive x dominance and dominance x dominance non-alleliec interaction. Results suggest that utilizing HUR 917 and DRR Dhan 42 in biparental crosses and later stage selection might be useful for substantial yield improvement under drought.

This result has a full agreement with the findings of Mahalingam and Nadarajan, 2010; Gnanamalar and Vivekanandan, 2013; and Kiani, 2013, who reported the presence of epitasis for all the characters studied in the combination of TS29 / Basmati-370. The results revealed that the data did not fit into a simple additive dominance model; the role of epistatic is prominent, which does not fit into a three-parameter model, so the data were submitted to a six-parameter analysis (Hayman, 1958).

Estimation of gene effects based on six generation means

The epistatic interaction model was found adequate to explain gene action in the traits, days to 50% flowering, days to maturity, plant height, panicle length, flag leaf length, flag leaf width, number of grains per panicle, spikelet fertility, ear bearing tillers, test weight, and grain yield per plant using a digenic non-allelic /epistatic interaction model with six parameters m, d, h, i, j, and l. The estimates of gene effect indicate that the observed traits had a high level of variation. In both irrigated and (reproductive stage) drought conditions, mean and additive components for days to 50% flowering, days to maturity, plant height, panicle length, flag leaf length, flag leaf width, ear bearing tillers, number of grains per panicle, spikelet fertility, test weight and grain yield per plant were highly significant (Murugan and Ganesan 2006) except flag leaf width under drought condition and spikelet fertility under irrigated condition. The dominance (h) and dominance × dominance (l) gene interaction or effects with opposite signs were observed by six parameters analysis of the cross HUR-917/DRR Dhan-42 for the traits days to 50% flowering, days to maturity, plant height, panicle length, flag leaf length, flag leaf width, number of ear bearing tillers, number of grains per panicle, spikelet fertility, test weight and grain yield per plant depicts duplicate epistasis in both irrigated and drought conditions. These results are in full agreement with the earlier reports of Kiani et al., 2013; Kumar et al., 2019; Gobu et al., 2021. Among the interactions, dominance × dominance gene interactions showed significance for the majority of the traits followed by additive × additive and additive × dominance gene interactions. Similar results were reported by Verma et al., 2006. Additive x dominance interaction showed negative values in higher frequency when compared to additive x additive interaction and dominance x dominance interaction. However, the magnitude of additive × additive interaction and dominance × dominance was much higher than additive dominance interaction for the majority of traits in both irrigated and drought conditions. The positive sign in the additive gene effect indicates that HUR-917 contributes more to the trait than DRR Dhan-42 and vice versa.

CONCLUSION

This study revealed the existence of additive gene effect and along with non-allelic interactions have a profound effect on the genetic control of the majority of the yield traits. Therefore, it is suggested that bi-parental mating followed by recurrent selection or diallel-selective mating might be the most preferable strategy for the further breeding invigoration of drought tolerant breeding pool. Intermating superior segregants in advance generations will be useful to recover superior transgressive segregants in later generations. Additive (d) effect and dominant × dominant (l) gene interaction were the only significant portion of a gene controlling grain yield per plant of the rice. The positive sign in the additive gene effect indicates that HUR-917 contributes more to the trait than DRR Dhan-42 and vice versa have high breeding value for drought breeding programs.

Compliance with Ethical Standards: The authors declare the research work is in Compliance with Ethical Standards.

Conflict of Interest: The authors declare they have no conflicts of interest.

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

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DUS characterization of traditional varieties and advanced cultivars of rice using 29 essential characters

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ABSTRACT

For the establishment of the distinctness, forty-four genotypes of rice were characterized at different stages of crop growth using 29 agro-morphological traits following Distinctiveness, Uniformity and Stability test (DUS) during rabi, 2020-21 at Regional Agricultural Research Station, Warangal. The rice genotypes under study recorded a wide range of variability for most of the essential traits studied. Out of 29 descriptors studied, two characteristics leaf auricles and leaf ligule shapewere found monomorphic, six were dimorphic, ten traitswere trimorphic, seven other characters resulted tetramorphic. The descriptors that registered maximum variation were decorticated grain: colour, decorticated grain: shape (in lateral view), panicle: attitude of branching, spikelet: colour of tip of lemma were found to be polymorphic in nature. This comprehensive characterization of rice genotypes is very important for rice breeding and will be beneficial for breeders, researchers and farmers from the stand point of selection and conservation of different landraces for further utilization in crop improvement programmes and also to seek protection under Protection of Plant Varieties and Farmers Rights Act.

Key words: *DUS, distinctness, characterization,forty-four genotypes, 29 descriptors*

INTRODUCTION

Rice is regarded as "Grain of life" as it is the primary source of food for more than onethird of world's population. Further, to acknowledge the importance of rice in human life, the year 2004 was declared as "International Year of Rice" by the United Nations. Rice crop is grown under diverse agro-ecological conditions ranging from hills to coasts and is endowed with rich genetic wealth. Owing to its preferential climatic conditions, large production area, soil and irrigation, India stands second after China with the production of 118.87 million metric tonnes in an area of 43.66 million hectares holding a productivity of 2.7 metric tonnes per hectare (Indiastat, 2019-20).India, as one of the origins of rice, serves as a repository for elite germplasm. To make the cultivation of rice more remunerative, it is imperative and entirely necessary to breed cultivars having high yield potential and inbuilt resistance to biotic and abiotic stresses. Further, the development of a new variety relies mainly on the selection of superior genotypes to generatethe genetic variation, which is a pre-requisite for crop improvement programmes. Farmers' varieties, unlike high yielding varieties (HYVs) are endowed with prodigious genetic variability as they are traditionally cultivated. Plant genetic resources serve as store house of genes of resistance to abiotic and biotic stresses, that can further be utilized or incorporated into modern cultivars. With the introduction of HYVs and incipient technologies, the age-old practice of growing traditional varieties and landraces having immense potential for different important traits has become a major concern. Therefore, detailed investigation and comprehensive characterization of such genotypes would be a significant measure for identifying and utilizing the pertinent donors in genetic improvement programs and also protecting the unique rice in modern era (Parikh et al., 2012). In line of this, being signatory to the General Agreement on Trade and Tariffs (GAAT), Government of Indiahas enacted its Sui generis system, Protection of Plant Varieties and Farmers' Right Act (PPV&FRA), 2001 for providing protection to plant varieties based on Distinctiveness, Uniformity and Stability (DUS) test, apart from novelty (Anonymous, 2007). A major purpose of characterization is to establish the distinctiveness between the germplasm and also to establish their unique detection profiles on the basis of grouping individuality prescribed by Distinctness, Uniformity and Stability (DUS) guidelines. In this context, an attempt was made to characterize a set of forty-four genotypes of rice germplasm for different essential traits to identify the variability available in the collection.

MATERIALS AND METHODS

The present investigation was carried out during *rabi*, 2020 at Regional Agricultural Research Station, Warangal. In the present study forty-four genotypes were characterized for 29 essential traits. List of genotypes used in the present study is presented in Table 1. Each genotype was sown in three rows of 4 m length following a spacing of 20 cm between the rows and 15 cm between the plants in randomised block design (RBD) with three replications. Standard agronomic practices were performed uniformly for all the experimental units. Crop was raised following recommended package of practices. Observations were recorded on ten randomly chosen plants of each genotype per replication for twenty-nine essential traits following appropriate procedures as per the "Guidelines for the Conduct of Test for DUS on Rice" (PPV & FRA, 2007).

RESULTS AND DISCUSSION

The 29 essential traits were studiedand the character basal leaf: sheath colour showed distinct variation among the 44 genotypes studied. On observation for the presence of anthocyanin pigment on leaf sheath, 36 varieties were found green and eight displayed the anthocyanin colouration. Three genotypes exhibited purple, four showed purple lines while remaining one genotype expressed light purple. Pubescence on leaf blade surface was found in all 44 varieties, 17 showed weak and 20 expressed medium pubescence while seven genotypes showed strong pubescence. The high diversity for the leaf pubescence can be of great help in developing the varieties possessing tolerance to sucking pests (Rao et al., 2015). All the 44 genotypes had auricles of which 33 were colourless, eight exhibited light purple and 3 showed purple colouration, while

Table 1. List of genotypes used in this study.

S. no.	Entry name	Place of collection
1	Njavara	Kerala
2	Kasyamsannalu	Local collection at Khammam district
3	Ramsree	West Bengal
4	Manipuri black	Manipur
5	Kalabunt	West Bengal
6	Bahurupi	Odisha
7	Sammelabogulu	Local collection at Khammam district
8	Laicha	Chattisgarh
9	Kudel	Local collection at Khammam district
10	Kistappasannalu	Local collection at Khammam district
11	Ranikanda	West Bengal
12	Chattisgarh local	Chattisgarh
13	Ramyagali	Local collection at Khammam district
14	Asthothal	Local collection at Khammam district
15	Burma black	Andaman & Nicobar
16	Narayana kamini	Local collection at Khammam district
17	Ambe mohar	Maharashtra
18	Yellava samba	Local collection at Khammam district
19	Kakirekkalu	Andhra Pradesh
20	Ratnachodi	Odisha
21	Nico	West Bengal
22	Kasmikanda	Local collection at Khammam district
23	Jeeraga samba	Tamil Nadu
24	Kamarsambra	Local collection at Khammam district
25	Kandasagar	Local collection at Khammam district
26	Gani	Local collection at Khammam district
27	Chitthloorisannalu	Local collection at Khammam district
28	Didianga	Local collection at Khammam district
29	Karejajawal	Local collection at Khammam district
30	WGL 1245	RARS, Warangal
31	WGL 1246	RARS, Warangal
32	WGL 1252	RARS, Warangal
33	WGL 1261	RARS, Warangal
34	JGL 27356	RARS, Jagtial
35	JGL 28545	RARS, Jagtial
36	KNM 1638	ARS, Kunaram
37	WGL 962	RARS, Warangal
38	KPS 2874	ARS, Kampasagar
39	KNM 6871	ARS, Kunaram
40	KNM 6869	ARS, Kunaram
41	WGL 1413	RARS, Warangal
42	KNM 7715	ARS, Kunaram
43	RNR 21278	ARI, Rajendranagar
44	WGL 1262	RARS, Warangal

coming to the shape of the ligule, in all the 44 genotypes it was split shape (Rawte et al., 2017) of which 35 genotypes had white ligule, three possessed purple ligule while the rest six exhibited light purple colouration. The time of heading (50% of plants with panicles) for 44 genotypes was observed and noticed that 4 genotypes were of early duration, 30 genotypes were of medium duration and 10 lines were late in heading. Erect type of flag leaf blade was observed in 20 genotypes and semi-erect in 24 lines.

Character spikelet and trait is spikelet : density of pubescence of lemma was trimorphic with 15 showing weak, 16 lines showing medium pubescence, while 13 lines displayed strong pubescence. It is important to note that no genotype exhibited male sterility. Six genotypes showed strong coloration while four genotypes werewith medium colouration and the remaining genotypes showed no anthocyanin coloration below the apex on lemma. For colour of stigma 33 genotypes exhibited white, three were yellow and eightwere purple coloured. For the stem length (excluding panicle) 36 genotypes were very short, five were short and three showed medium length (Fig. 1).

38 genotypes have shown no coloration at nodes and the remaining six were found to have anthocyanin colouration at node. Panicle length for two genotypes was short, 18 had medium length panicles, 23 were long while kakirekkalu was very long. For the trait flag leaf:attitude of blade (late observation) 20 showed erect, 16 expressed semi erect and eight displayed horizontal attitude.

For the character panicle (curvature of main axis) 23 were deflexed while other 21 were having drooping curvature. For the character spikelet: colour of tip of lemma,14 genotypes exhibited white coloured stigma, seven showed yellow colour, 11 were brown, seven genotypes were purple and five genotypes were black coloured. For the character sterile lemma colour, the genotypes were classified into straw (21), gold (three), white (16) and purple (four) colour. 37 genotypes showed no awns and seven possessed awns, appearing mostly at the tips and along the length of panicle with mostly yellowish-brown colour. Branching attitude of panicle was erect for two genotypes, 10 recorded erect to semi erect, 21 displayed semi-erect type, eight had semi-erect to spreading type and three showed spreading

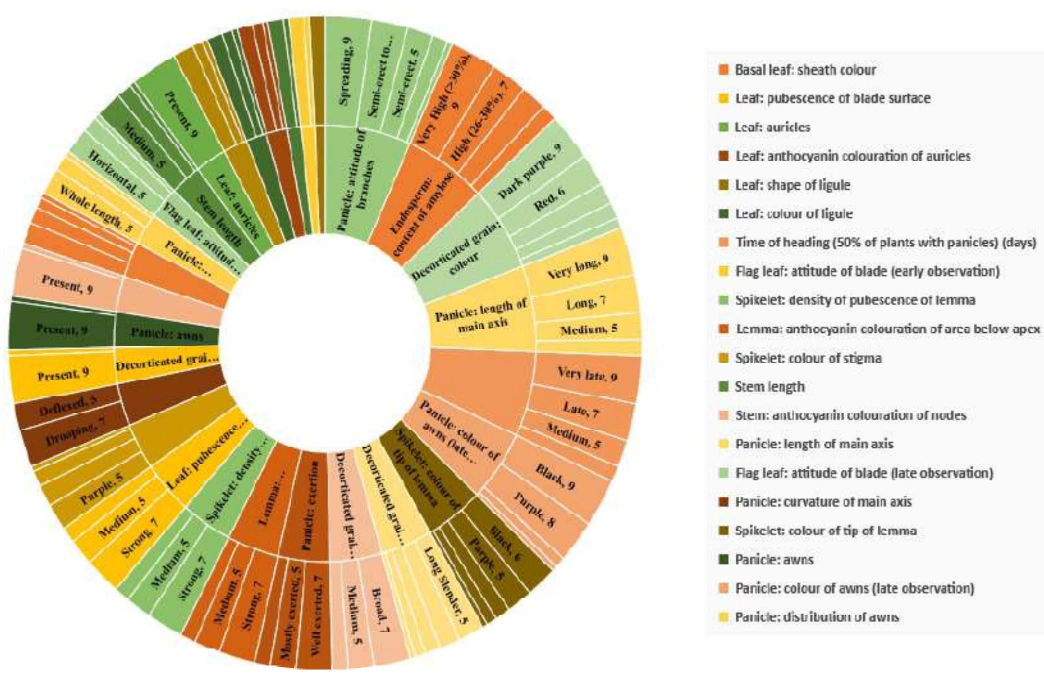

Fig. 1. Frequency distribution of morphological traits in 44 genotypes of rice.

Table 2. Analysis of variance, mean, range, standard error S.E (M), critical difference (C.D) and coefficient of variation (C.V) for yield and its components, quality and nutritional traits in rice (*Oryza sativa* L.)

Source of Variation	Replications	Treatments	Error	Mean	Range		S.E(M)	C.D	C.V
d.f.	2	43	86		Minimum	Maximum			
Days to 50 per cent flowering	8.553	308.859**	4.119	102.36	121.33	81	1.17	1.98	3.29
Productive tillers/ plant	0.218	8.273**	0.489	12.19	16.67	10.13	0.4	5.74	1.14
Plant height (cm)	12.046	1124.48**	5.172	117.46	147.8	84.8	1.31	1.94	3.69
Panicle length (cm)	0.375	23.446**	0.259	25.67	32.31	20.51	0.29	1.98	0.83
No. of Grains/ panicle	118.904	9333.249**	68.844	210.12	320.87	118.73	4.79	3.95	13.47
1000 grain weight (g)	0.036	60.453**	0.144	18.33	25.87	10.32	0.22	2.07	0.62
Grain yield/ plant (g)	21.527	83.117**	7.533	39.69	49.9	24.23	1.58	6.91	4.45
Hulling %	2.412	12.821**	0.812	81.45	86.4	75.19	0.52	1.11	1.46
Milling %	8.122	47.121**	3.134	69.7	74.8	54.85	1.03	2.55	2.89
Head rice recovery %	1.283	164.933**	4.973	59.52	70.67	36.49	1.29	3.75	3.62
Grain length (mm)	0.022	1.114**	0.007	5.39	7.11	4.01	0.05	1.56	0.14
Grain width (mm)	0.003	0.459**	0.001	2.05	2.85	1.39	0.02	1.44	0.05
L/ B ratio	0.007	0.701**	0.003	2.7	3.72	1.86	0.03	2.05	0.09
Protein (%)	0.056	3.285**	0.557	6.35	3.76	9.46	0.43	1.17	1.21
Iron content (ppm)	0.093	20.216**	0.077	13.38	8.8	19.5	0.2	2.04	0.68
Zinc content (ppm)	0.052	26.884**	0.024	14.22	9	24.4	0.4	1.12	1.11

d.f. = Degrees of freedom, ** = Significant at 1% level.

type. Among 44 genotypes, mostly exerted panicle was found in 17 genotypes, nine genotypes exhibited partial exertion, while 18 genotypes exhibited well exerted panicle.

Coming to the characters of grain, for decorticated grain length 37 genotypes had short length with seven genotypes showing medium length grain and decorticated grain width was distinct among genotypes with 23 genotypes displaying narrow grain width, 17 were medium width and four showed broad type. Among the 44 genotypes studied, nine varieties were short slender, 17 were short bold, 11 other genotypes were medium slender type, three genotypes (Kalabunt, Ramyagali, Asthothal) were long bold type while four genotypes possessed long slender type of grain shape. Pericarp was light brown for 20 genotypes, six were variegated brown, 10 possessed dark brown, five were red coloured and three had dark purple coloration. For amylose content in endosperm, five displayed low amylose content, 26 contained medium amylose content, 10 possessed high and very high content was observed in three genotypes with seven genotypes displaying distinct aroma while 37 genotypes showing no aroma.The landraces and advanced genotypes undertaken for this study registered wide range of distinctiveness for almost all the agro-morphological traits studied and similar frequencies has been reported earlier by studies of Lavanya et al. (2021), Singh et al. (2021), Priyanga et al. (2020), Gour et al. (2019), Manjunatha et al.(2018), Umarani et al. (2017), Kalyan et al. (2017), Sinha and Mishra (2013), Subbarao et al. (2013) and Chakrabarty et al. (2012). This study will be useful for breeders, researchers and farmers to identify and restore beneficial genes for crop improvement and also to seek protection under Protection of Plant Varieties and Farmers Rights Act.

The analysis of variance (ANOVA) also revealed significant differences among the genotypes for all characters, demonstrating the presence of significant amount of variability and intrinsic genetic variation in the genotypes studied. Coefficient of variation studies implied that the estimates of GCV for all the characters studied were slightly less than PCV estimates indicating slight influence of environment on the genotype performance. Similar finding was reported earlier by Sudeepthi et al. (2020). The results of analysis of variance are presented in Table 2.

CONCLUSION

Morphological descriptors were widely used in sequential fashion and were found convenient in discriminating different genotypes. Out of total 29 essential characters visually assessed using DUS descriptors, two traits were found monomorphic, six traits were dimorphic, ten traits were found trimorphic, seven traits resulted tetramorphic while four remaining traits decorticated grain: colour, decorticated grain: shape (in lateral view), panicle: attitude of branches, spikelet: color of tip of lemma were found polymorphic. The 44 genotypes under study exhibited wide range of variability for 27 essential characters of the 29 DUS characters studied. This study will be useful for restoration and conservation of beneficial genes for crop improvement.

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Comprehensive periodic evaluation of *Oryza sativa* germplasms for resistance against rice root-knot nematode, *Meloidogyne graminicola*

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ABSTRACT

Rice root knot nematode, Meloidogyne graminicola is an important nematode pest with a devastating potential that causes serious damage to rice crop. There is an intensive search for eco-friendly, sustainable alternative to the existing nematode management practices. Host plant resistance offers propitious results in managing this minuscule crop enemy. Preliminary screening of 1731 Oryza sativa germplasms followed by periodic evaluation of nine resistant / tolerant germplasms shed new insights on nematode resistance. We observed seasonal inconsistency in the resistance in previously reported germplasms 'Ramakrishna', 'TKM6', 'Abhisek', 'Laxman sal', 'Ratna', and 'TKM1'. Hence, we strongly recommend repeated screening of identified resistant/tolerant rice germplasm lines against M. graminicola in both winter and summer season to confirm the consistency in resistance scale. Further investigation is needed to nullify other chance factors like nematode pathotypes.

Key words: *Germplasm evaluation, nematode screening, paddy, temperature, nematode prebreeding*

INTRODUCTION

Meloidogyne graminicola commonly called rice root-knot nematode is a growing menace to rice which is a major source of nutrition for at least 3.5 billion people and staple food for more than half of the global population (Bridge et al., 2005; Mantelin et al., 2017; Win et al., 2011; Cabasan et al., 2012; Anonymous, 2021). It is a sedentary endoparasite which parasitizes crops of the Poaceae family worldwide and has been reported from all the rice growing ecosystems, ranging from rainfed to deepwater system (Prot and Mattias, 1995; Mantelin et al., 2017; Yao et al., 2020). This nematode causes up to 80% of crop loss when they reach sufficiently high population (Plowright and Bridge, 1990). They have a very short life cycle where they can complete it (J_2 - J_2) within 15 days at 27-37°C under Asian conditions (Jaiswal and Singh, 2010). Coupled with increased water scarcity and rice intensification, this nematode problem is flaring up in Asia (Soriano and Reversat 2003; Win et al., 2011; De Waele et al., 2013). The characteristic horse-shoe-shaped root gall is the hallmark of *M. graminicola* infestation where the above-ground parts of the infected plants show stunting, wilting, chlorosis, reduced tillering, and empty spikelet which ultimately leads to poor yield (Bridge et al., 2005).

Management of this minuscule crop pest is a herculean task before the nematologists. Traditional practices like crop rotation, fallowing, removing of alternate hosts like weeds have been proven to reduce the nematode population but they are impractical or economically unviable. The use of chemicals has so many issues like no or very few registered nematicides and their environmental impact. Although, biological control is a promising alternative, it is still in its infant stage. The use of resistant cultivars offers a sustainable solution to manage this shrewd microscopic enemy (De Waele et al., 2013; Yao et al., 2020). Hence, the search for a suitable resistance source is going on globally. In line with the global search, the present study has been designed to evaluate the germplasms available in NRRI, Cuttack, India for the resistance sources against *M. graminicola*.

MATERIALS AND METHODS

The research work was carried out in the net houses of ICAR-NRRI, Cuttack, located at 23.5 meters above MSL, 20.5°N latitude and 86°E longitudes. All the rice germplasms were obtained from the Institutes' germplasm collection and the *Meloidogyne graminicola* (ICAR-NRRI population) population maintained at the institute was used for screening.

Meloidogyne graminicola culture

Meloidogyne graminicola population isolated using single eggmass culture from the institute soil was used for the experiment. The isolated nematodes were mass multiplied and maintained on Annapurna, a susceptible rice line. The purity of nematode population was checked at regular intervals using posterior cuticular pattern (Eisenback et al., 1981). At the time of requirement of nematode population for inoculation, the infested rice plants were uprooted and washed gently in tap water, to remove the adhering soils. Then under a stereo microscope, the egg masses were removed from the roots and were carefully placed on modified Baermann funnel assembly (Christie and Perry, 1951) from which, the second stage juveniles were collected after 36 hours.

Growing of rice germplasm lines

The rice germplasm lines (*Oryza sativa*) were grown in earthen pots of 20 cm diameter with autoclaved soil. Three to four seeds were sown per pot and thinning was done after germination to maintain only one healthy plant per pot.

Nematode screening

Fifteen days after sowing, each pot with single plant was inoculated with approximately 100 second stage infective juveniles. Three replicates were maintained for each germplasm lines and the extent of gall formation was estimated at 45th day after nematode inoculation, based on the scale given by All India Coordinated Rice Improvement Project. Rating was done as 1 for no galling (highly resistant); 2 for 1-10% galling (resistant); 3 for 11-30% galling (tolerant); 4 for 31-50% galling (susceptible); 5 for more than 50% galling (highly susceptible). Annapurna and TN 1 were used as susceptible check. The cultivars were categorized as resistant or susceptible types on the basis of gall index (GI = [score of test cultivar/score of check] x 5). The whole experiment was conducted based on completely randomized block design (CRD). The pots were properly tagged and placed at random, and re-randomization was done once in a week to minimize the position effects. Due to the constraints in the availability of *M. graminicola* population, the screening was done in batches. The germplasm lines, which showed promising results were carried forward and screened again along with next batch to confirm the consistency of their response against *M. graminicola*.

RESULTS AND DISCUSSION

Screening for nematode resistance in germplasms of *Oryza sativa* from NRRI, Cuttack

In the preliminary screening, 1731 germplasms of *O. sativa* have been screened against *M. graminicola* for over 6 years. These include released varieties, landraces, breeding lines and several germplasm collections. Among all, 49 germplasms recorded tolerance (Table 1) to *M. graminicola*, while, 725 and 957 germplasms (Database-Rath et al, 2021) were reported to fall under susceptible and highly susceptible categories.

Based on the preliminary results and other previous reports, screening has been repeated for selected germplasms. Out of the nine germplasms screened repeatedly the germplasms namely MDU 2, Ramakrishna, Laxman sal, Ratna, and TKM 1 exhibited inconsistent responses throughout the screening period. While the other germplasms expressed susceptibility to *M. graminicola* (Table 2).

Periodic evaluation of rice germplasms revealed interesting, but contrasting results. We have observed susceptibility in germplasms which have been reported as resistant or tolerant previously, these include

Table 1. List of rice germplasm and their reaction to rice root-knot nematode (*Meloidogyne graminicola*).

Tolerant rice germplasm lines (Resistant scale 3 and 11-30% galling)
ADT 14 (AC. No. 40184), ADT 37 (BG 367-4) (AC. No. 40853), ARC 5158 (AC. No. 40341), AU-7/21-2 (AC. No. 40766), Basumati 370 , Bharathi (AC. No. 40218), BJ 1 (AC. No. 40130), Carreon (AC. No. 40187), EC 203650 (AC. No. 40768), GR 11 (AC. No. 40820), IET 4786 (AC. No. 40079), IR 38 (AC. No. 40462), Jhona 20 (AC. No. 40345), Kalinga 1 (AC. No. 40977), Kharish , Lal dangar , Laxman sal, Manhar (AC. No. 40827), Moianosingga (AC. No. 40735), MTU 15 (AC. No. 40247), Mugi, Palghar 1 (AC. No. 40836), Patnai (AC. No. 40349), PTB 21 (AC. No. 40630), Pusa 169 (AC. No. 40239), Sathi (AC. No. 40226), Sathia, Sebati, SGVT 3 (AC. No. 40246), Solani, SYE 1 (AC. No. 40826), TKM 6 (AC. No. 40129), TTB 4/7 (AC. No. 40245), V 20-B (AC. No. 40835), Zeera (AC. No. 40163), AC. No. 41023, AC. No. 41078, AC. No. 41108, AC. No. 41164, AC. No. 41297, AC. No. 41453, AC. No. 42403, AC. No. 42462, AC. No. 42497, AC. No. 42540, AC. No. 42611, AC. No. 42634, AC. No. 43019, AC. No. 43035.

Table 2. Gall index based resistant categorization of *O. sativa* germplasms.

Varieties	Previous reports	Gall index Year 1 (Dec)	Gall index Year 1 (Jul)	Gall index Year 2 (Dec)	Gall index Year 2 (Jul)	Gall index Year 3 (Dec)
Hamsa	R	5 (HS)	5 (HS)	5 (HS)	5 (HS)	5 (HS)
Ramakrishna	R	5 (HS)	5 (HS)	3 (T)	5 (HS)	5 (HS)
Abhisek	T	5 (HS)	5 (HS)	5 (HS)	5 (HS)	5 (HS)
Laxman sal	T	-	-	3 (T)	4 (S)	4 (S)
MDU-2	T	3 (T)	4 (S)	3 (T)	4 (S)	3 (T)
Tadukan	T	5 (HS)	5 (HS)	5 (HS)	5 (HS)	5 (HS)
TKM-1	T	3 (T)	4 (S)	3 (T)	4 (S)	3 (T)
TKM-6	T	5 (HS)	5 (HS)	5 (HS)	5 (HS)	5 (HS)
Zenith	T	5 (HS)	5 (HS)	5 (HS)	5 (HS)	5 (HS)
Crossa	HS	5 (HS)	5 (HS)	5 (HS)	5 (HS)	5 (HS)
IR64 (Check)	HS	5 (HS)	5 (HS)	5 (HS)	5 (HS)	5 (HS)
Peta	HS	5 (HS)	5 (HS)	5 (HS)	5 (HS)	5 (HS)
Ratna	HS	3 (T)	5 (HS)	5 (HS)	5 (HS)	5 (HS)
Tetep	HS	5 (HS)	5 (HS)	5 (HS)	5 (HS)	5 (HS)

#Scales in the parenthesis are resistance category based on gall index; HS - Highly susceptible; S - Susceptible; T - Tolerant; R - Resistant.

Ramakrishna, TKM6 (Jena et al., 2012 & 2013), Abhisek (Mhatre et al., 2017), Laxman sal (Berliner et al., 2014). Ramakrishna, an *indica* rice cultivar that was a derivative of TKM6 showed inconsistent resistance against *M. graminicola* in our studies. This is in contrast with the previous reports by Bose et al. (1998) and Jena et al., 2012 & 2013. Similar inconsistency was also observed in other germplasms namely Laxman sal, Ratna, and TKM 1. If we closely observe the results, we could see the inconsistency that occurred between seasons namely winter and summer. The germplasm lines screened during winter time (29^{o} C/15^{o}C - high/low temperature) tends to show tolerance against nematode compared to the susceptible response by the same lines in summer season (32^{o}C/25^{o}C - High/ Low temperature) at NRRI, Cuttack. Further, we suspect the daily minimum temperature is playing its role against nematodes than the maximum temperature. This was supported by the studies done by Yan et al., 2017, where they reported the daily minimum temperature and warming induced drying are most important factors affecting soil nematode community. So, we may conclude that climatic factors play an important role in nematode tolerance/resistance in these cultivars. Besides, there may be the existence of pathotypes in *M. graminicola i.e.*, the nematode population used in our study may have different pathogenic potential compared to the populations used in previous reports. Further, we strongly suggest that any resistant rice germplasm obtained while screening against *M. graminicola* during winter has to be checked for its consistency in summer.

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Status of false smut of rice in different districts of West Bengal

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ABSTRACT

False smut of rice which was considered a minor disease of rice is presently spreading in most of the rice growing areas of the world causing reduction in yield and quality of the produce. West Bengal is the largest producer with largest area under rice in India. No survey on severity of rice false smut disease in West Bengal has been conducted. Therefore, in attempt to get the idea of false smut disease situation in the state, a survey was conducted in 31 blocks from 8 different districts of West Bengal during the year 2017 from the end of October to first week of December. Number of infected tillers per m2 and number of smut balls per panicle was observed during the survey. False smut symptom was observed in all the plains of West Bengal whereas in hilly areas of the state was found to have no incidence of the disease. During the survey average number of infected tillers ranged from 2.00 to 14.60 numbers of infected tillers / m^2. Similarly average number of smutted ball / panicle ranged from 1.21 to 5.32 number of spore ball per panicle.

Key words: *False smut of rice, Ustilaginoidea virens, survey*

INTRODUCTION

Rice, a cereal crop which is largely consumed throughout the world, especially in the continent of Asia. Rice is a good source of minerals and vitamins such as iron, calcium, vitamin D, riboflavin, niacin and thiamine. Expect for its nutritive value the crop is also important culturally and religiously and is used in different festivals and religious activities. India is one of the largest producers of rice and holds the position of second largest producer in the world after China. In India, West Bengal is the largest producer of rice where the rice is grown throughout the year. Rice is grown in all the six agro-climatic zones of West Bengal and is the richest reservoir of rice bio-diversity and is also known as the rice bowl of the country (Debnath, 2011). All though rice is an important crop in India and west Bengal its production is largely hampered due biotic and abiotic factors. False smut disease of rice which is caused by *Ustilagonoidea virens* is emerging as an important biotic factor for reducing rice yield and quality. The disease was first reported from Tirunelveli in Tamilnadu by Cooke in 1878 (Ou, 1972). Since its first report, the disease has been observed in different countries around the world such as China, Philippines, Bangladesh, Myanmar, Japan, Brazil, Thailand etc. (Ou, 1972; Dodan and Singh, 1996). False smut disease of rice was considered of minor importance earlier however at present the disease is gaining much importance as there are different reports of causing huge yield loss of upto 75% (Rashmi et al., 2014). Another report on yield loss that ranged from 0.2 to 49 per cent in different regions with different rice varieties has been reported (Baruah et al., 1992; Biswas, 2001). Increase in disease severity and yield loss may be attributed to the change in weather condition throughout the world, indiscriminate use of nitrogenous fertilizer and growing adoption of hybrid varieties (Zhou et al., 2008; Haiyong, 2012). Although rice is grown largely in the State of West Bengal no survey report on occurrence and severity of false smut disease caused by *Ustilaginoidea virens* is reported from the state. Therefore in this present study, a survey was conducted on eight different districts of West Bengal to understand the false smut disease situation in the state.

MATERIALS AND METHODS

Roving method of survey was followed to check the incidence of false smut disease of rice (Balai et al., 2013) in the state of West Bengal from the end of October to first week of December during the year 2017. Incidence of false smut of rice was observed based on the symptoms described by Baite et al. (2014). A total of 31 blocks from eight different districts of West Bengal were surveyed for false smut disease of rice. In each district, one to five blocks were selected. In each selected block five one square meter areas were selected in fields of rice and observations on number of infected tillers/m^2 and number of smut balls/ panicle was recorded (Shivalingaiah and Umesha, 2011; Ladhalakshmi et al., 2012). The data were analyzed in SAS and presented as range and mean.

RESULTS AND DISCUSSION

During the survey typical symptom for false smut in the panicle of rice as described by (Ou 1972; Lee and Gunnell, 1992; Baite et al., 2014) *i.e.*, the individual grains of the infected panicles turned into the yellowish spore balls at young stage which later during maturity turned into greenish black in colour covered with dark green chlamydospores were observed in most of the rice fields visited during the survey (Fig. 1). From the survey conducted, it was revealed that in hilly regions which include two districts of West Bengal were found to have no or zero incidence of false smut disease. Where as in plains of West Bengal which includes another six districts, there was a significant variation in the level of false smut disease incidence from one field to another.

Number of infected tillers / m^2 were found to have in range between 1 -3 to 1 - 25. Similarly, the number of smut balls / panicle were found to have in range between 1 -3 to 1 -19. Survey studies have revealed that highest number of infected tillers / m^2 was found in the Shantipur block of district Nadia with a mean of 14.60 number of infected tillers / m^2 followed by Coochbehar-II block of Coochbehar district, Aamdanga block of north 24 Parganas, Dhupguri block of Jalpaiguri districts and Chakdah block of Nadia district with a mean of 13.60, 12.20, 10.20 and 10.00 number of infected tillers/ m^2 respectively. Lowest number of infected tiller/m^2 was observed in the Alipurdwar-II block of Alipurdwar district with the lowest mean of 2.00 number of infected tillers/ m^2 followed by Madho madarihat of Alipurdwar district, Habra-ll of North 24 parganas district, Polba of Hooghly district and Mathabanga-l Block of Coochbehar District with an average of 2.60, 2.80, 2.80 and 3.60 no. of infected tillers/m2 respectively. Similarly, the number

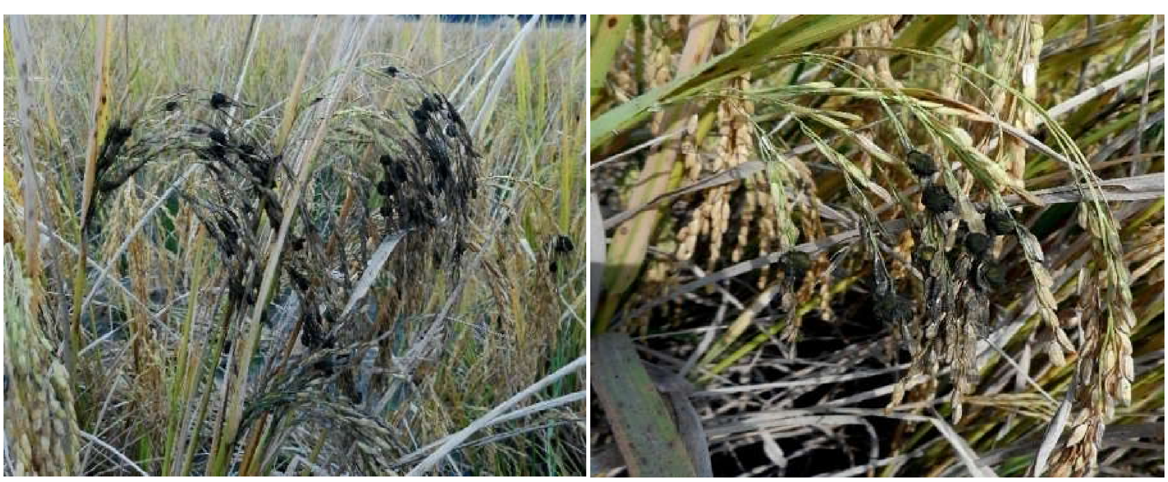

Fig. 1. Symptom of false smut of rice.

Table 1. Survey on incidence of false smut of rice in different districts of West Bengal.

Districts	Blocks/ Latitude/Longitude	No. of infected tillers per m²			No. of smut balls per infected tillers		
		RANGE	MEAN	SEM	RANGE	MEAN	SEM
Coochbehar	Coochbehar ll 26.4067°N, 89.38472°E	1 TO 25	13.60	1.427	1 TO 18	5.32	0.321
	Coochbehar 1 26.28132°N , 89.46361°E	3 TO 4	3.50		1 TO 3	1.64	
	Mathabanga ll 26.31397°N, 89.30074°E	3 TO 5	4.00		1 TO 6	1.89	
	Mathabanga 1 26.34382°N, 89.16653°E	2 TO 7	3.60		1 TO 4	2.00	
Alipurduar	Falakata 26.51136°N, 89.21876°E	2 TO 10	5.20	0.486	1 TO 6	1.75	0.202
	Madho madarihat 26.68071°N, 89.2678°E	1 TO 5	2.60		1 TO 3	1.31	
	Kalchini 26.6946°N, 89.4514°E	2 TO 6	3.60		1 TO 7	2.65	
	Alipurduar 1 26.50858°N, 89.38313°E	3 TO 9	5.60		1 TO 11	2.55	
	Alipurduar 11 26.54073°N, 89.68765°E	1 TO 3	2.00		1 TO 5	2.00	
Jalpaiguri	Dhupguri 26.58896°N, 88.99954°E	7 TO 14	10.20	0.705	1 TO 12	3.96	0.222
	Mainaguri 26.55636°N, 88.81419°E	3 TO 7	4.60		1 TO 8	2.10	
	Jalpaiguri 26.5320144°N, 88.6877595°E	2 TO 7	4.20		1 TO 5	1.63	
	Rajgunj 26.55717°N, 88.5191°E	2 TO 7	5.20		1 TO 7	2.50	
Nadia	Chakdah 23.08878°N, 88.55373°E	8 TO 12	10.00	0.837	1 TO 12	3.32	0.223
	Ranaghat 23.19187°N, 88.54798°E	4 TO 7	5.20		1 TO 6	1.83	
	Shantipur 23.26727°N, 88.44064°E	11 TO 19	14.60		1 TO 12	4.88	
	Haringhata 22.94852°N, 88.53632°E	3 TO 7	5.20		1 TO 5	1.82	
	Krishnanagar 23.40162°N, 88.51215°E	4 TO 7	6.00		1 TO 3	1.50	
Hooghly	Haripal 22.81831°N, 88.10302°E	7 TO 13	9.40	0.701	1 TO 11	4.20	0.252
	Magra 23.00061°N, 88.3841°E	3 TO 6	4.20		1 TO 6	1.85	
	Pandua 23.0874°N, 88.27319°E	5 TO 11	9.00		1 TO 19	3.04	
	Polba 22.95768°N, 88.30484°E	2 TO 4	2.80		1 TO 3	1.21	
	Dhanyakhali 22.97365°N, 88.10248°E	8 TO 13	9.80		1 TO 8	3.32	
North 24 Parganas	Aamdanga 22.80027°N, 88.5063°E	8 TO 15	12.20	1.013	1 TO 15	5.00	0.394
	Barrackpore 1 22.8609°N, 88.43181°E	4 TO 9	6.00		1 TO 9	2.91	
	Habra ll Guma 22.81442°N, 88.61073°E	2 TO 4	2.80		1 TO 5	1.29	
	Barasat l 22.74073°N, 88.53108°E	3 TO 16	7.00		1 TO 19	4.23	
Kalimpong	Kalimpong I 27.06366°N, 88.50611°E	0	0.00	0	0	0.00	0
	Kalimpong II 27.1586°N, 88.62149°E	0	0.00		0	0.00	
Darjeeling	Takdah 27.06154°N, 88.40759°E	0	0.00		0	0.00	

of spore balls per panicle was counted during the survey, the highest number of spore balls/panicle was observed in Coochbehar-II block of Coochbehar district with mean of 5.32 spore balls/panicle followed by Aamdanga of North 24 Parganas, Shantipur block of Nadia district, Barasat-l of North 24 Parganas and Haripal of Hooghly with an average of 5.00, 4.88 4.23 and 4.20 spore balls/ panicle respectively. The lowest number of false smut balls per panicle was found in Polba block of Hooghly district with mean of 1.21 no. of spore balls/panicle followed by Habra-ll of north 24 Parganas, Madho madarihat of Alipurdwar district, Coochbehar-1 of Coochbehar district and Rajgunj block of Jalpaiguri district with mean of 1.29, 1.31, 1.64 and 2.5 no. of spore balls/panicle respectively (Table 1).

From the survey, it was observed that the hilly regions were free from the incidence of rice false smut whereas in plains false smut symptom was observed in mild to moderate form. There are many reasons which influence the incidence of false smut of rice such as the rice variety, temperature, relative humidity, rainfall, and other factors. False smut of rice and is favored by moderate temperature and high humidity (Bhargava, et al., 2018; Yang et al., 2011). Relative humidity below 92%, conidia of *Ustilaginoidea virens* cannot germinate (Singh, 2009) which may be the reason for zero incidences of false smut disease of rice in hills of West Bengal where both the temperature and humidity is much lower as compared to plains. Several surveys conducted at different places were reported to have a wide variation in the occurrence of false smut disease incidence (Baite et al., 2017; Rashmi et al., 2016; Singh

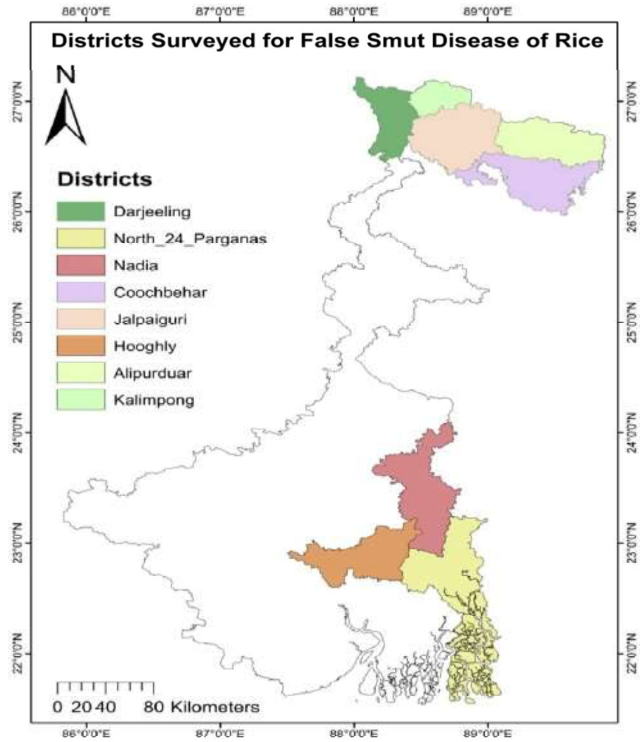

Fig. 2. West Bengal map showing districts surveyed for false smut disease.

et al., 2012). Studies have revealed that in the last few years, the incidence of false smut disease has spread throughout the country. A survey in Nalgonda district of Telangana and Ramanathapuram district of Tamilnadu has reported that maximum of 48 smut balls per panicle with disease severity of 12% to 45% (Indian Institute of Rice Research, Annual Report 2014-15). All India Co-ordinated Rice Improvement Project (2019 and 2020) in their production-oriented survey has also reported the progressive increase in the incidence of false smut disease. Occurrence and distribution of false smut disease of rice in various rice-growing regions of India during the years 1990-2000 and 2001 -2013 shown in districts two maps generated by using geographical information system have revealed a significant increase in the spread and incidence of false smut of rice throughout the rice-growing areas of India (Ladhalakshmi et al., 2018). The Disease incidence from 2% to 85% has also been reported (Ladhalakshmi et al., 2012) indicating a hefty challenge to the rice production and quality.

CONCLUSION

The survey conducted in 8 different districts of West Bengal for rice false smut disease revealed the occurrence of the disease in mild to moderate form in all the rice-growing areas except hilly regions. From the study, it can be concluded that the prevalent isolates of *Ustilaginoidea virens* in West Bengal are either less virulent or most of the rice varieties cultivated are resistant to the pathogen. However, this is the first survey conducted on the disease in the state, therefore, more surveys can be undertaken in the future, especially on districts that were not covered during the present study to come to a more precise conclusion.

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Evaluation of pesticide combinations against brown planthopper and sheath blight in rice

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ABSTRACT

Field experiment was conducted at Regional Agricultural Research Station, Maruteru, West Godavari (A.P.) during two kharif seasons of 2019 and 2020 to evaluate the compatibility of combinations of insecticides and fungicides against brown planthopper and sheath blight in rice. The results revealed that pymetrozine and triflumezopyrim as sole treatments are highly effective against brown planthopper (BPH), Nilaparvata lugens (Stal) by registering over 90% reduction in BPH population. While, pymetrozine and triflumezopyrim in combination with azoxystrobin and azoxystrobin + tebuconazole are highly effective against BPH and sheath blight, Rhizoctonia soloni Kuhn in by registering over 90% and >50% reduction in BPH population and sheath blight severity, respectively and registered 64.23% to 73.03% higher grain yields than untreated control. It was also found that there was no adverse effect of fungicides on the efficacy of insecticides or vice versa. The insecticides tested were physically compatible with fungicides and no phytotoxic symptoms observed on rice crop when pesticides were applied in combination. Thus, pymetrozine and triflumezopyrim are compatible with test fungicides and can be safely used as tank mix for the simultaneous management of BPH and sheath blightin rice.

***Key words:** BPH, Nilaparvata lugens, sheath blight, Rhizoctonia soloni, insecticides, fungicides, compatibility, rice*

INTRODUCTION

Rice (*Oryza sativa* L.) is an important staple food crop for more than half of the world population (Seni and Nayak, 2017). It alone provides 20% of the global dietary energy supply. Insect pests and diseases remain as the key biotic stresses limiting the rice production significantly. Among the insect pests infesting rice, brown planthopper (BPH), *Nilaparvata lugens* (Stal) considered as the major yield limiting factor in all rice growing countries both in tropics and temperate regions (Krishnaiah, 2014). Both nymphs and adults of the BPH suck plant sap from phloem cells resulting in "hopper burn" symptoms and causes almost 10 to 90 per cent yield losses in rice (Seni and Naik, 2017). In addition to direct damage, it also transmits rice grassy stunt virus (RGSV) and rice ragged stunt virus (RRSV). Among the disease attacking rice crop, sheath blight caused by *Rhizoctonia soloni* Kuhn, is one of the important destructive disease of rice occurs in all rice growing areas of the world (Teng et al., 1990). Depending upon the age of the plant, time of infection and severity, it causes yield loss to the extent of 5.9 to 69 per cent (Swamy et al., 2009; Bhukal et al., 2015). Use of resistant varieties is considered as one of the most important management strategies against insect pests and diseases and several resistant varieties were developed against brown planthopper (Jena et al., 2015). But, development of new biotypes in BPH made the resistant varieties as susceptible in short periods and forcing the farmers to rely on pesticides for their control. Non availability of resistant rice germplasm against sheath blight across the globe (Dubey et al., 2014; Pavani et al., 2020) made the farmers to depend on fungicides invariably for the management of sheath blight.

Further, occurrence of brown planthopper (BPH) along with sheath blight is a common phenomenon during *kharif* season in Godavari delta of Andhra Pradesh due to congenial weather conditions *viz*., high humidity, temperature and cloudiness. In such situation, use of combination of suitable insecticides and fungicides as tank mix is not only economical, time saving but also minimizes the cost on spraying operation. Therefore, it is essential to evaluate the new pesticide molecules with different modes of action on continual basis. Pymetrozine is a pyridine azomethine compound. The mode of action of pymetrozine in insects has not been precisely determined biochemically, but it may involve effects on neuro-regulation or nerve-muscle interaction. Physiologically, it appears to act by preventing hopper insects from inserting their stylus into the plant tissue. Triflumezopyrim is a mesoionic insecticide target the nicotinic acetylcholine receptor, inducing a physiological action which is distinct from that of neonicotinoids. Azoxystrobin belongs to group strobilurins or QOI fungicides which have a common mode of action to interfere with respiration and energy production in fungal cell by blocking electron transfer at the site of quinol oxidation in the cytochrome bc1 complex, thereby prevents ATP formation. Keeping this in view, the study was undertaken to evaluate the compatibility of selected insecticides (pymetrozine and triflumezopyrim) and fungicides (Azoxystrobin and Azoxystrobin + Tebuconazole) against BPH and sheath blight under field conditions.

MATERIALS AND METHODS

The experiments were conducted in the experimental farm of Regional Agricultural Research Station (RARS) (16.38° N, 81.44° E), Maruteru, Andhra Pradesh, India to assess the physical compatibility, phytotoxicity and efficacy of insecticides alone and combinations of them against brown planthopper and sheath blight during *kharif* 2019 and *kharif* 2020 in a Randomized Block Design (RBD) with nine treatments and each treatment replicated thrice. Rice variety, Swarna (MTU 7029) which was highly susceptible to both planthoppers and sheath blight used for the present investigation during both the seasons (*kharif* 2019 and *kharif* 2020). One to two seedlings per hill were planted with a spacing of 20 cm x 15 cm during *kharif* season with a help of a marked rope. The crop husbandry operations as recommended in the package of practices of Acharya N. G. Ranga Agricultural University, Andhra Pradesh were adopted. The treatments were: T_1 - Pymetrozine (Chess) 50 WG @ 0.60 g/l, T_2 - Triflumezopyrim (Pexalon) 10 SC @ 0.48 ml/l, T_3 - Azoxystrobin (Amistar) 25 SC @ 1.0 ml/l, T_4 - Azoxystrobin 11% + Tebuconazole 18.3% SC (Custodia) @ 1.5 ml/l, T_5 - Pymetrozine + Azoxystrobin @ 0.60 g +1.0 ml/l, T_6 - Pymetrozine + Azoxystrobin + Tebuconazole @ 0.60 g + 1.5 ml/l, T_7 - Triflumezopyrim + Azoxystrobin @ 0.48 ml +1.0 ml/l, T_8 - Triflumezopyrim + Azoxystrobin + Tebuconazole @ 0.48 ml + 1.5 ml/l and T_9 - untreated control (Water spray).

A) Evaluation of physical compatibility between insecticides and fungicides

The physical compatibility of four combinations involving two insecticides (Pymetrozine 50 WG & Triflumezopyrim 10 SC) and two fungicides (Azoxystrobin 25 SC & Azoxystrobin11% + Tebuconazole18.3% SC) were evaluated with jar compatibility test. In this test, 500 ml of standard hard water (0.304 g calcium chloride and 0.139 g of magnesium chloride hexahydrate in one litre of double distilled water) was taken in a one litre jar to which one insecticide and one fungicide were added in the order of pymetrozine followed by azoxystrobin, pymetrozine followed by azoxystrobin + tebuconazole, triflumezopyrim followed by azoxystrobin and triflumezopyrim followed by azoxystrobin + tebuconazole. The volume of insecticide and fungicide mixture was made up to one litre with hard water, agitated by shaking the jar and left undisturbed for 30 minutes. Observations were noted after 30 and 60 minutes with respect to foaming and sedimentation. Also, pH of insecticides and fungicides alone and in

Table 1. Rating chart for reaction based on the value of pH.

Reaction	PH
Extremely acidic	< 4.5
Very strongly acidic	4.5 - 5.0
Strongly acidic	5.1 - 5.5
Moderately acidic	5.6 - 6.0
Slightly acidic	6.1 - 6.5
Neutral	6.6 - 7.3
Slightly alkaline	7.4 - 7.8
Moderately alkaline	7.9 - 8.4
Strongly alkaline	8.5 - 9.0
Very strongly alkaline	>9.1

combinations were recorded and designated according to Table 1 (Bickelhaupt, 2012).

B) Evaluation of phytotoxicity on rice crop due to combination of insecticide and fungicide

Observations for phytotoxic symptoms such as injury to the leaf tip, yellowing, necrosis, wilting, vein clearing, hyponasty and epipnasty were recorded at 1, 5 and 10 days after spray based on the phytotoxicity scale (Table 2) prescribed by Central Insecticide Board and Registration Committee (C.I.B.R.C). The per cent injury was calculated by using the formula

$$= \frac{\text{Total grade points}}{\text{Max. grade x No. of leaves observed}} \text{ x } 100$$

C) Evaluation of efficacy of insecticidesand fungicides against BPH and sheath blight

The treatments were imposed twice at 60 and 80 days after transplanting (DAT) during *kharif* season when the population of brown planthopper crossed the economic threshold level. A spray fluid of 500 l/ha was used to ensure thorough coverage of the crop canopy with battery operated hand sprayer. Observation on nymphs and adults of BPH were taken directly from ten randomly selected hills per plot at one day before spray (Pre-treatment count) and ten days after each insecticide spray (Post-treatment). Incidence of sheath blight was also recorded on 10 hills selected at random one day before and ten days after treatment. The severity of the sheath blight was calculated as per cent disease index (PDI) or severity index (SI) (%) using the formula (IRRI, 2013).

=(sum of all disease ratings)/(Total number of ratings X maximum disease grade) x 100

Grain yield was recorded per plot leaving two border rows on all sides and expressed in terms of kg/ha.

Table 2. Phytotoxicity scale of CIBRC.

Scale	Phytotoxicity (%)	Scale	Phytotoxicity (%)
0	No phytotoxicity	6	51-60
1	1-10	7	61-70
2	11-20	8	71-80
3	21-30	9	81-90
4	31-40	10	91-100
5	41-50		

Data on BPH population and per cent disease severity were first converted in to square root transformations and angular transformations, respectively and analyzed using analysis of variance technique (ANOVA) (Gomez and Gomez, 1984). The treatment means were compared by least significant difference (LSD) method.

RESULTS AND DISCUSSION

Physical compatibility

The insecticides and fungicides tested were physically compatible since no precipitation or sedimentation was observed at 30 minutes and 60 minutes after mixing the insecticides and fungicides. The quality of water can be an important factor in optimum pest control. The effects of pH in spray water can diminish the effectiveness of some insecticides.

Among the pesticides tested for pH, the reaction of pymetrozine, triflumezopyrim and their combination with azoxystrobin and azoxystrobin + tebuconazole were neutral except pymetrozine + azoxystrobin combination (slightly alkaline) (Table 3).

Phytotoxicity

The observations made on phytotoxic symptoms like injury to the leaf tip, yellowing, wilting, vein clearing, necrosis, epinasty and hyponasty at 1, 5 and 10 days after spraying indicated that all the combinations of pesticides did not cause any phytotoxic effects on rice crop.

Efficacy of pesticides combinations against BPH and sheath blight

Results on bio-efficacy of insecticides and fungicides alone and in combination of them against BPH and sheath blightwere given in Table 4. Based on analysis of pooled data of *kharif* 2019 and *kharif* 2020, BPH population ranged from 36.17 to 406.83 per 10 hills at ten days after first spray and statistically found significant. Pymetrozine @ 0.60 g/l (T_1), triflumezopyrim @ 0.48 ml/l (T_2) alone and their combinations with fungicides (T_5, T_6, T_7 and T_8) recorded the lower population of BPH which were at par with each other and significantly superior to untreated control. On the other hand, rest of the treatments including untreated control registered higher

Table 3. PH range of insecticides, fungicides and after their physical mixing.

S. no.	Reaction	PH range	Pesticides
1	Neutral	6.6 - 7.3	Pymetrozine50 WG (7.10) Triflumezopyrim 10 SC (7.20) Azoxystrobin 25 SC (7.22) Azoxystrobin 11% + Tebuconazole18.3% SC (7.19) Pymetrozine 50 WG + Azoxystrobin 11% + Tebuconazole 18.3% SC (7.18) Triflumezopyrim 10 SC + Azoxystrobin 25 SC (7.33) Triflumezopyrim 10 SC + Azoxystrobin 11% + Tebuconazole 18.3% SC (7.34)
2	Slightly alkaline	7.4 - 7.8	Pymetrozine50 WG + Azoxystrobin 25 SC (7.42)

BPH population. Similar trend was also noticed at ten days after second spray.

Based on the mean data of two sprays, pymetrozine, triflumezopyrim and their combinations with fungicides (T_5, T_6, T_7 and T_8) recorded the lower population of BPH and it ranged from 20.25 to 31.58 hoppers per 10 hills compared to that recorded in control (414.67 hoppers/10 hills).

Based on per cent reduction in BPH population over control, combination of triflumezopyrim (0.48 ml/l) and azoxystrobin + tebuconazole (1.5 ml/l) (T_8) recorded the highest per cent reduction (95.12%) followed by combination of pymetrozine (0.60 g/l) and azoxystrobin + tebuconazole (1.5 ml/l) (T_6), triflumezopyrim (0.48 ml/l) (T_2), pymetrozine (0.60 g/l) (T_1), combination of triflumezopyrim (0.48 ml/l) and azoxystrobin (1.0 ml/l) (T_7) and combination of pymetrozine (0.60 g/l) and azoxystrobin (1.0 ml/l) (T_5) with 94.11%, 93.19%, 92.81%, 92.58% and 92.38% reduction over control, respectively.

Based on the above results, it was observed that the efficacy of pymetrozine and triflumezopyrim did not affected by the fungicides, azoxystrobin and azoxystrobin + tebuconazole as their combinations, *i.e.*, T_5, T_6, T_7 and T_8 proved as effective as T_1 (Pymetrozine alone) and T_2 (Triflumezopyrim alone) against BPH. This was in agreement with observations of Seni and Naik, 2017; Singh et al., 2018; Adhikari et al., 2019; Rehman et al., 2020, who reported that pymetrozine showed higher toxicity to BPH and WBPH in rice. Ranjit Kumar et al., 2017; Sarao and Jhansi Lakshmi, 2019; Chander et al., 2020 also reported that triflumezopyrim was the most effective against BPH.

Similarly Pooled data of two seasons (*kharif*, 2019 and *kharif*, 2020) (Table 4) revealed that azoxystrobin @ 1.0 ml/l (T_3), azoxystrobin + tebuconazole (T_4) @ 1.5 ml/l and their combinations with insecticides (T_5, T_6, T_7 and T_8) recorded lower sheath blight severity (31.48% to 38.89%; 21.48% to 23.89%) and significantly superior compared to control (62.59%; 63.33%) at ten days after first and second sprays, respectively.

Based on the mean data of two sprays, azoxystrobin, azoxystrobin + tebuconazole and their combinations with insecticides (T_5, T_6, T_7 and T_8) recorded less sheath blight severity and it varied from 26.48% to 31.20% compared to that recorded in control (62.96% sheath blight severity).

Based on per cent reduction in sheath blight severity over control, combination of triflumezopyrim (0.48 ml/l) and azoxystrobin + tebuconazole (1.5 ml/l) (T_8) recorded highest per cent reduction (57.94%) followed by combination of pymetrozine (0.60 g/l) and azoxystrobin (1.0 ml/l) (T_5), azoxystrobin 11% + tebuconazole 18.3% SC (1.5 ml/l) (T4), combination of triflumezopyrim (0.48 ml/l) and azoxystrobin (1.0 ml/l) (T_7), combination of pymetrozine (0.60 g/l) and azoxystrobin + tebuconazole (1.5 ml/l) (T_6) and azoxystrobin 25 SC (1.0 ml/l) (T3) with 54.85%, 54.12%, 53.09%, 53.09% and 50.44% reduction over control, respectively. These results are in agreement with reports of earlier workers. Bhuvaneswari et al. (2014) reported that azoxystrobin 25% SC @ 1.0 ml/l and trifloxystrobin 25% + tebuconazole 50% WG @ 0.4 g/l were found effective against sheath blight. Bhuvaneswari et al. (2017) also reported that azoxystrobin 11% + tebuconazole 18.3% SC @ 2.0 ml/l, 1.5 ml/l and 1.0 ml/l was found effective against sheath blight. Azoxystrobin 5.6% + tebuconazole 10% +

Table 4. Effect of sole treatment of insecticides and fungicides and their combinations on BPH and Sheath blight during *kharif*2019 and *kharif* 2020 (Pooled data).

Tr. no.	Treatment particular	Dose (g or ml/l)	BPH (No./10 hills)*		Mean	Reduction over control (%)	Sheath blight severity (%)**		Mean	Reduction over control (%)
			10 DAS (1st Spray)	10 DAS (2nd Spray)			10 DAS (1st Spray)	10 DAS (2nd Spray)		
T_1	Pymetrozine 50 WG	0.60 g/l	37.33(6.09)a	22.33(4.72)a	29.83	92.81	63.15(52.62)b	60.93(51.33)b	62.04	1.47
T_2	Triflumezopyrim10 SC	0.48 ml/l	36.17(6.01)a	20.33(4.49)a	28.25	93.19	62.59(52.30)b	61.85(51.88)b	62.22	1.18
T_3	Azoxystrobin 25 SC	1.0 ml/l	398.33(19.93)b	525.00(22.81)b	461.67	11.33	38.89(38.47)a	23.52(28.95)a	31.20	50.44
T_4	Azoxystrobin 11% + Tebuconazole 18.3% SC	1.5 ml/l	402.33(20.04)b	479.17(21.85)b	440.75	6.29	35.19(36.37)a	22.59(28.37)a	28.89	54.12
T_5	Pymetrozine + Azoxystrobin	0.60 g + 1.0 ml/l	42.67(6.49)a	20.50(4.47)a	31.58	92.38	33.70(35.45)a	23.15(28.72)a	28.43	54.85
T_6	Pymetrozine + Azoxystrobin Tebuconazole	0.60 g + 1.5 ml/l	30.67(5.53)a	18.17(4.23)a	24.42	94.11	35.37(36.31)a	23.70(29.13)a	29.54	53.09
T_7	Triflumezopyrim + Azoxystrobin	0.48 ml +1.0 ml/l	44.33(6.65)a	17.17(3.98)a	30.75	92.58	35.19(36.38)a	23.89(29.26)a	29.54	53.09
T_8	Triflumezopyrim + Azoxystrobin + Tebuconazole	0.48 ml + 1.5 ml/l	27.17(5.19)a	13.33(3.65)a	20.25	95.12	31.48(34.07)a	21.48(27.58)a	26.48	57.94
T_9	Untreated control (water spray)	-	406.83(20.15)b	422.50(20.51)b	414.67	-	62.59(52.31)b	63.33(52.99)b	62.96	-
		F test	**Sig.**	**Sig.**			**Sig.**	**Sig.**		
		CD (0.05)	1.48	2.46			5.91	5.93		
		CV (%)	8.00	14.05			8.21	9.40		

*Values in the parentheses are square root transformed values; **Values in the parentheses are arc sine values; DAS-Days after spray.
Means followed by same letter are not significantly different by LSD method (p=0.05%).

Table 5. Effect of insecticides alone and in combination with fungicides on grain yield during *kharif* 2019 and *kharif* 2020.

Tr. no.	Treatment particular	Dose (g or ml/l)	Grain yield (kg/ha) *Kharif* 2019	*Kharif* 2020	Pooled	Increase over control (%)
T_1	Pymetrozine 50 WG	0.60 g/l	4338^{bc}	4014^{bc}	4176^{bc}	19.42
T_2	Triflumezopyrim10 SC	0.48 ml/l	5434^{b}	4059^{bc}	4747^{b}	35.74
T_3	Azoxystrobin 25 SC	1.0 ml/l	2563de	4691^{a}	3627^{cd}	3.72
T_4	Azoxystrobin 11% + Tebuconazole 18.3% SC	1.5 ml/l	2407^{e}	4588^{ab}	3700^{cd}	5.80
T_5	Pymetrozine + Azoxystrobin	0.60 g +1.0 ml/l	7199^{a}	4761^{a}	5980^{a}	71.00
T_6	Pymetrozine + Azoxystrobin + Tebuconazole	0.60 g + 1.5 ml/l	6925^{a}	4596^{ab}	5761^{a}	64.74
T_7	Triflumezopyrim + Azoxystrobin	0.48 ml +1.0 ml/l	6764^{a}	4723^{a}	5743^{a}	64.23
T_8	Triflumezopyrim + Azoxystrobin + Tebuconazole	0.48 ml + 1.5 ml/l	7308^{a}	4793^{a}	6051^{a}	73.03
T_9	Untreated control (water spray)	-	3678^{cd}	3721^{c}	3497^{d}	-
		F test	**Sig.**	**Sig.**	**Sig.**	
		CD (0.05)	1267.18	605	654.00	
		CV (%)	14.13	7.87	7.86	

Means followed by same letter are not significantly different by LSD method (p=0.05%).

prochloraz 20% EC @ 3.5 ml/l and 3.0 ml/l were found effective against sheath blight by recording less disease incidence (7.57%, 7.92%) and disease severity (9.69%, 11.87%), respectively as against 63.81% and 55.44% in control (Bhuvaneswari et al., 2020).

Effect of pesticide combinations on grain yield

The pooled data on the grain yield of two seasons (*kharif* 2019 & *kharif* 2020) revealed that triflumezopyrim (0.48 ml/l) and azoxystrobin + tebuconazole (1.5 ml/l) (T_8) recorded the highest grain yield of 6051 kg/hawith 73.03% yield increase over untreated control followed bypmetrozine (0.60 g/l) and azoxystrobin (1.0 ml/l) (T_5) (5980 kg/ha), pymetrozine (0.60 g/l) and azoxystrobin + tebuconazole (1.5 ml/l) (T_6) (5761 kg/ha) and triflumezopyrim (0.48 ml/l) and azoxystrobin (1.0 ml/l) (T_7) (5743 kg/ha) recorded 71.00%, 64.74% and 64.23% increase in grain yield over untreated control, respectivelyand at par with each other and significantly superior to other treatments *i.e*., sole insecticide or fungicide treatments (T_1, T_2, T_3 and T_4) including control (3497 kg/ha) as they offer protection against BPH and sheath blight simultaneously (Table 5).

CONCLUSION

Based on the results from the present investigation, pymetrozinealone, triflumezopyrim alone as well as their combination with azoxystrobin and azoxystrobin+ tebuconazole are highly effective against BPH indicating that there was no adverse effect of fungicides on the efficacy of insecticides or vice versa. Thus, pymetrozine in combination with azoxystrobin and azoxystrobin + tebuconazole and triflumezopyrim in combination with azoxystrobin and azoxystrobin + tebuconazole are physically compatible and safely used as tank mix for the simultaneous management of BPH and sheath blight in rice.

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Response of nutrient management on growth, yield and nutrient uptake of hybrid rice in Gangetic plains of West Bengal

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ABSTRACT

A field experiment was conducted at Regional Research Sub-Station (RRS), under Bidhan Chandra Krishi Viswavidyalaya, Chakdaha, Nadia, West Bengal during rainy seasons of 2017 and 2018 to study the effect of different nutrient management on growth, yield and nutrient uptake of hybrid rice. The experiment was laid out in factorial randomized block design with 20 treatment combinations having 4 varieties (3 hybrid varieties and 1 high yielding variety) and 5 combinations of nutrient management in three replications. The treatment combination of Ajay variety with 50% recommended dose of nitrogen (RDN) + 50% RDN from mustard cake + full recommended dose of phosphorus (RDP) and potassium (RDK) recorded the highest plant height but significantly greater values of leaf area index at 75 days after transplanting (DAT), leaf area duration at 30-90 DAT, dry matter accumulation and crop growth rate at 60-75 DAT were recorded in the treatment combination of Arize 6444 with 75% RDN + 25% nitrogen through mustard cake + 20 kg $ZnSO_4$ /ha. In terms of yield attributes and yield treatment combination of hybrid variety Arize 6444 when combined with either of the fertilizer treatment i.e., 50% RDN + 50% RDN from mustard cake + full (RDP) and (RDK) or 75% RDN + 25% RDN from mustard cake + RDP and RDK + 20 kg $ZnSO_4$ ha^{-1} recorded significantly (p= 0.05) best results. Hence, this combination could be more effective in augmenting growth, yield and nutrient uptake in the Gangetic plains of West Bengal.

Key words: *Growth and yield attributes, hybrid rice, nutrient management, nutrient uptake, yield*

INTRODUCTION

Increased and sustainable production of rice is essential for food security in India. The hybrid rice produces 6.0-7.0 tons/ha with 30% yield advantage over conventional varieties (Krishnakumar et al., 2005). Although the country as a whole and the state too are doing well in terms of production with inbred and high yielding varieties but it is still lagging far behind in terms of hybrid rice production. Rice hybrids with short duration and higher yield potentials are being developed to replace the inbred cultivars (Gupta et al., 2011). It, therefore, necessitates the adoption of advanced agro-techniques for narrowing the yield gap. Secondly, slow growth in rice production and the ceiling on yield can be broken by adopting hybrid rice technology which can boost the present rice yield by 15-20% with the present level of input use. Any attempt to boost the rice production in West Bengal depends mainly on the large-scale adoption of hybrid rice cultivars during the wet season, availing the advantages of monsoon rain and a large cultivated area. (Banerjee and Pal, 2012). Out of the few options left with us, large scale adoption of hybrid rice technology can be effective to keep a steady supply of rice to the entire state (Banerjee et al., 2019; Pal et al., 2020). The important strategies towards increasing rice productivity include exploitation of local hybrids and improved nutrient management practices (Talathi et al., 2009).

The rising cost of fertilizers and the need to conserve plant nutrients by recycling them focuses attention on organic materials as sources of fertilizer elements. The continuous unbalanced use of fertilizers in cropping systems often leads to disappropriate nutrient availability and adverse effect on physico-chemical properties of soil which finally results in declined crop yields (Talathi et al., 2009; Vijayakumar et al., 2021). Soil fertility decline is nowadays more alarming in intensively rice cultivated regions (Kumar et al., 2014a). Therefore, maintaining soil fertility at high levels through balanced use of fertilizers, organic manures with other agronomic practices is an assured way to attain and sustain higher rice productivity (Banerjee and Pal, 2012). Desirable quantity of nutrients drawn from a sustainable source and applied at an appropriate time favourably influences the nutrient uptake, growth and yield of hybrid rice (Kumar et al., 2014). The nutrients, their sources, method and time of application form an important component of fertilizer management strategies (Mondal et al., 2019). Interaction among the sources and their levels also helps in determining the proportion in which these nutrients have to be applied for maximum benefit. Integrated nutrient management (INM) has been shown to considerably improve rice yields by minimizing nutrient losses to the environment and by managing the nutrient supply, thereby resulting in high nutrient use efficiency and cost reduction (Parkinson, 2013). INM approach is flexible and minimizes the use of chemicals but maximize use efficiency of fertilizer and improve the soil health (Jana et al., 2020).

It has also been recognized that growing high yielding as well as hybrid cultivars of rice with repeated use of fertilizers, containing only major nutrients may necessitate the application of micronutrients for sustained crop production (Arif et al., 2012). Zinc, being the third most important plant nutrient assumes significance in modern agriculture after N and P, limiting the growth and yield of rice. In addition to N, P and K, it also supplies considerable amount of secondary and micronutrients and improves growth and productivity of various crops (Sarkar et al., 2021). But information on conjunctive use of organic manures (oil cake) and chemical fertilizers for hybrid rice in eastern India is meagre. Considering all these points, an investigation was carried out to evaluate the effect of INM in hybrid rice on crop productivity, nutrient use efficiency and soil fertility for sustainability.

MATERIALS AND METHODS

Study site and soil

A field experiment was conducted during *kharif* seasons (2017 and 2018) at Regional Research Sub-Station (RRS), under Chakdaha, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal, to study the response of nutrient management in different varieties of hybrid rice. The soil of the experimental site was sandy loam in texture with bulk density 1.40 Mg m^{-3} (0-15cm). The soil was neutral in reaction (pH 7.5), medium in soil organic carbon (0.68%), total nitrogen (0.052%), available phosphorus (16.8 kg/ha) and Ammonium acetate extractable potassium (126.9 kg ha^{-1}). The moisture content at FC and PWP was 20 and 8%, respectively.

Treatment details and crop management practices

The experiment was laid out in Factorial Randomized Block Design with two factors *viz*., variety (4 levels) and fertilizer (5 levels) replicated thrice with 20 treatment combinations: *i.e*., 4 Varieties are V_1 - Arize 6444, V_2 - Ajay, V_3 - Chakra 5001, V_4 - Khitish (IET 4094) [Control] and 5 fertilizer levels are F_1- conventional practice (60: 30: 30 N: P_2O_5 : K_2O kg ha^{-1}) [Control], F_2 - 100% recommended dose of fertilizer (80: 40: 40 N, P_2O_5 and K_2O kg ha^{-1}), F_3 - 75% RDN + 25% nitrogen through mustard cake, F_4 - 75% RDN + 25% nitrogen through mustard cake + 20 kg $ZnSO_4$ ha^{-1}, F_5 - 50% RDN + 50% nitrogen through mustard cake, phosphorus and potassium applied at recommended dose. Nitrogen, phosphorus and potash were applied in the form of urea, single super phosphate and muriate of potash as per treatment. 1/4th N, full dose of P_2O_5 and K_2O were applied as basal during final land preparation and ½ N was top dressed at active tillering stage (21 days after transplanting) and rest at panicle initiation stage. Mustard cake was applied as per treatment. The size of the individual plot was 6 m × 5 m. The rice seedlings were uprooted from the nursery bed and transplanted in the main field with a spacing of 20 cm × 15 cm with 2-3 seedlings per hill without damaging the seedlings. All other agronomic management practices were done uniformly for all the experimental units during rice growing season (Banerjee and Pal, 2009).

Observation taken

The root sample was collected by core sampler and accordingly washed by double distilled water and data were measured according to standard protocol (Mondal et al., 2020). The crop was harvested when the plant become yellowish to brown and had around 14 % grain moisture content during last week of October. The observations on growth parameters, yield attributes and yield of the transplanted rice were recorded through standard procedures (Vijayakumar et al., 2019a, b). Plant samples from each treatment were collected, oven dried, and grind for analysing total recoveries of N, P and K separately for grain and straw at harvesting following standard procedures.

Economics analysis

The net return was calculated by subtracting the cost of cultivation from the gross revenue and the benefit cost ratio was calculated by dividing the gross revenue into the cost of cultivation.

Statistical analysis

The experimental data were analysed by using analysis of variance (ANOVA) technique appropriate to factorial randomized block design (SPSS v26). The critical differences at 5% level were calculated for testing the significant differences among the treatments mean by Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

Growth attributes

Nutrient management showed significant (p=0.05) effect on all growth parameters *i.e*., plant height, leaf area index, leaf area duration, dry matter accumulation, crop growth rate, root length, root volume and root dry weight of different hybrid rice varieties (Table 1). Maximum crop height (102.3 cm) was observed under the treatment V_2F_5, however, variety IET 4094 showed lowest height (92.49 cm) in farmer's practice *i.e*., 60: 30: 30 kg NPK ha^{-1}. Significantly (p=0.05) greater values of LAI at 75 days after transplanting (DAT), LAD at 30-90 DAT, dry matter accumulation and CGR at 60-75 DAT were recorded in the V_1F_4 treatment combination. The results are in the line with Huang et al., 2008. On the other hand, V_4F_1 *i.e*., combination of IET 4094 with Farmer's practice @ 60: 30: 30 kg NPK ha^{-1} recorded the least value of various growth parameters. In case of LAI, LAD and dry matter accumulation V_1F_3 combination recorded at par with V_1F_4. The variation in the height among the different rice hybrids recorded during different growth stages of the crop might be due to differences in their genetic

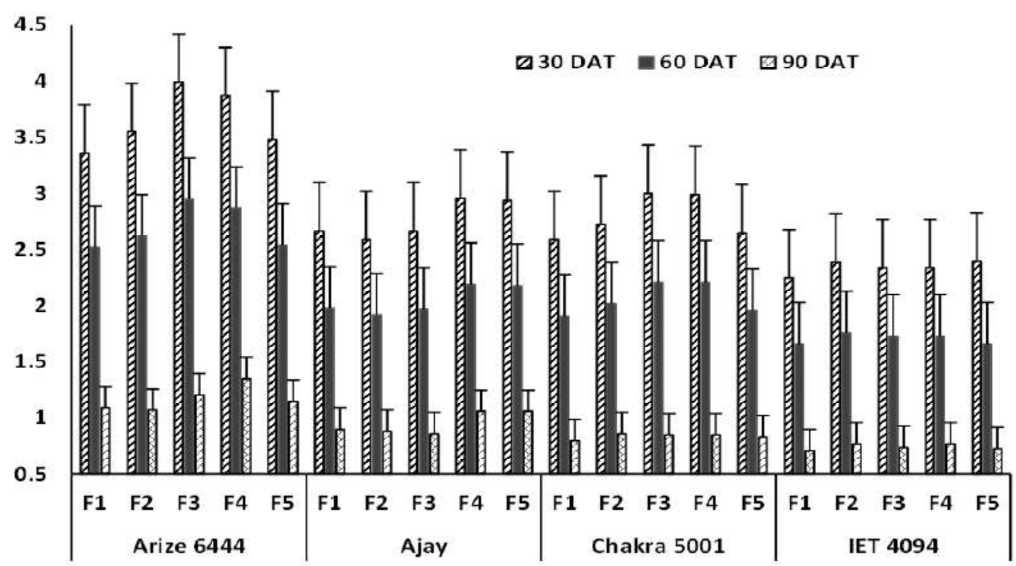

Fig. 1. Interaction effects of variety and fertilizer on third leaf N concentration

Table 1. Effects of variety and nutrient management on growth attributes of hybrid rice during *kharif* seasons (Pooled).

Variety	Fertilizer application	Plant height (cm) at 90 DAT	LAI at 75 DAT	LAD at 30-90 DAT	Dry matter accum- ulation ($g\ m^{-2}$) at 90 DAT	CGR ($g\ m^{-2}\ day^{-1}$) at 60-75 DAT	Root length (cm) at 90 DAT	Root volume ($cc\ hill^{-1}$) at 90 DAT	Root dry weight ($g\ m^{-2}$) at 90 DAT
V_1, Arize 6444	F_1, N_{60} P_{30} K_{30}	99.82^{E}	4.57_{B}	188.54^{B}	1034.67^{C}	27.22^{CD}	24.04^{D}	7.53^{D}	269.00^{E}
	F_2, N_{80} P_{40} K_{40}	100.80_{CD}	4.76^{B}	197.05^{B}	1054.55^{BC}	26.57^{CD}	24.15^{D}	7.57^{D}	269.00^{E}
	F_3, N_{60} P_{40} K_{40} + N_{20} through MC	101.60^{B}	5.35^{A}	221.74^{A}	1170.31^{A}	29.99^{B}	24.17^{D}	7.58^{D}	69.20^{DE}
	F_4, F_3 + 20 kg $ZnSO_4$	101.80^{AB}	5.21^{A}	215.68^{A}	1195.12^{A}	33.67^{A}	24.34^{D}	7.63^{D}	270.80^{C}
	F_5, N_{40} P_{40} K_{40} + N_{40} through MC	101.80^{AB}	4.62^{B}	191.96^{B}	1085.68^{B}	28.62^{BC}	24.24^{D}	7.60^{D}	269.50^{D}
V_2, Ajay	F_1, N_{60} P_{30} K_{30}	100.20_{DE}	3.59^{D}	148.64^{E}	858.22^{EF}	22.32^{E}	24.96^{C}	7.83^{C}	271.90^{B}
	F_2, N_{80} P_{40} K_{40}	100.90_{C}	3.49^{DEF}	144.42^{EF}	842.09^{EFG}	21.77^{EF}	24.98^{C}	7.83^{C}	271.90^{B}
	F_3, N_{60} P_{40} K_{40} + N_{20} through MC	101.90^{AB}	3.58^{D}	148.33^{E}	860.98^{EF}	21.41^{EF}	25.96^{B}	8.14^{B}	272.30^{A}
	F_4, F_3 + 20 kg $ZnSO_4$	101.80^{AB}	3.99^{C}	165.11^{CD}	966.53^{D}	26.42^{D}	26.33^{AB}	8.25^{AB}	272.40^{A}
	F_5, N_{40} P_{40} K_{40} + N_{40} through MC	102.30_{A}	3.96^{C}	163.89^{CD}	952.52^{D}	26.32^{D}	26.40^{A}	8.28^{A}	272.30^{A}
V_3, Chakra 5001	F_1, N_{60} P_{30} K_{30}	95.43^{H}	3.47^{DEFG}	143.65^{EFG}	808.33^{GH}	19.86^{FGH}	23.28^{E}	7.30^{E}	267.90^{GH}
	F_2, N_{80} P_{40} K_{40}	95.60^{H}	3.66^{CD}	151.68^{DE}	844.03^{EFG}	21.31^{EF}	23.33^{E}	7.32^{E}	68.00^{FGH}
	F_3, N_{60} P_{40} K_{40} + N_20 through MC	97.62_{FG}	4.01^{C}	166.14^{C}	887.97^{E}	21.27^{EF}	23.34^{E}	7.32^{E}	268.20^{FG}
	F_4, F_3 + 20 kg $ZnSO_4$	98.14^{F}	4.00^{C}	165.89^{CD}	886.50^{E}	21.09^{EFG}	23.48^{E}	7.36^{E}	268.30^{F}
	F_5, N_{40} P_{40} K_{40} + N_{40} through MC	97.04_{G}	3.55^{DE}	147.16^{E}	826.58^{FG}	20.55^{EFG}	23.08^{EF}	7.24^{EF}	267.80^{H}
V_4, IET 4094	F_1, N_{60} P_{30} K30	92.49^{J}	3.01^{H}	124.75^{H}	719.78^{I}	17.77^{I}	21.12^{I}	6.62^{I}	265.40^{J}
	F_2, N_{80} P_{40} K_{40}	93.25^{I}	3.21^{EFGH}	132.68^{FGH}	759.17^{HI}	19.11^{GHI}	22.18^{H}	6.96^{H}	266.10^{I}
	F_3, N_{60} P_{40} K_{40} + N_{20} through MC	93.44^{I}	3.14^{FGH}	130.08^{FGH}	743.26^{I}	18.31^{HI}	22.54^{GH}	7.07^{GH}	265.80^{I}
	F_4, F_3 + 20 kg $ZnSO_4$	95.31_{H}	3.14^{GH}	129.88^{GH}	756.72^{I}	19.11^{GHI}	22.71^{FG}	7.12^{FG}	266.10^{I}
	F_5, N_{40} P_{40} K_{40} + N_{40} through MC	93.53^{I}	3.01^{H}	124.65^{H}	728.63^{I}	18.13^{HI}	22.29^{GH}	6.99^{GH}	266.10^{I}

MC: Mustard cake; LAI: leaf area index; LAD: leaf area duration; CGR: crop growth rate; DAT: days after transplanting; Different letters in each column in superscript form depict the significant differences among the treatments means using DMRT analysis ($p<0.05$).

characteristics. This could be attributed to the fact that organic products provided plant growth promoting substances like micro nutrient, organic acids and thereby accelerated soil biological activities. Similar results were also reported by Sana et al., 2020. Root parameters of hybrid rice revealed that at 90 DAT, treatment V_2F_5 to be the superior treatment combination with 26.40 cm root length, 8.28 cc $hill^{-1}$ root volume and 272.30 g m^{-2} root dry weight respectively. This might be due to 50% nitrogen and 50% N through organic source. However, V_4F_1 combination recorded the least root length (21.12 cm), root dry weight (6.62 cc $hill^{-1}$) and root volume (265.40 g m^{-2}) respectively. To conclude hybrid rice varieties, have larger and deeper root systems than conventional varieties. The superficial roots of hybrids were more developed and heavier than those of the inbred. Similar results were also reported by Islam et al., 2009. The overall interaction of variety with fertilizer clearly indicated that combination of organic and inorganic nitrogen sources has advantageous effect over sole chemical application of nitrogen. The reason could be the slow release of nutrients from organics ensures continuous supply of nutrients, without much losses of nitrogen as in the case of nitrogenous fertilizer (Pathak et al., 2009). Moreover, organic acids produced from organic compounds due to decomposition, act as sources of micronutrients (Pandey et al., 2007).

Third leaf N concentration

The third leaf nitrogen concentration of different hybrid rice varieties at 30, 60 and 90 DAT varied significantly ($p = 0.05$) among the different nutrient management practices (Fig. 1). At 30 DAT and 60 DAT variety Arize 6444 with 75% Recommended dose of nitrogen + 25% nitrogen through mustard cake (V_1F_3) recorded the highest treatment combination with respective values of 3.99 % and 2.95% followed by V_1F_4 combination. Treatment V_4F_1 and V_4F_5 both recorded the least value and thus found statistically at par among themselves.

Table 2. Effects of variety and nutrient management on yield attributes and yield of hybrid rice during *kharif* season (Pooled).

Variety	Fertilizer application	Effective tillers m^2	Filled panicle grains^{-1} m^{-2}	Fertility % panicle	Panicle length (cm)	Panicle weight (g)	Test weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest Index (%)
V$_1$, Arize 6444	F$_1$, N$_{60}$ P$_{30}$ K$_{30}$	259.50^{A}	89.64^{F}	71.56^{BC}	28.75^{BCD}	3.58^{AB}	22.71^{B}	7.01^{B}	5.82^{C}	54.65^{B}
	F$_2$, N$_{80}$ P$_{40}$ K$_{40}$	259.50^{A}	89.43^{F}	70.40^{BC}	29.00^{ABC}	3.58^{AB}	22.67^{B}	6.93^{B}	5.88^{C}	54.11^{B}
	F$_3$, N$_{60}$ P$_{40}$ K$_{40}$ + N$_{20}$ through MC	261.90^{A}	97.01^{C}	78.40^{AB}	29.17^{AB}	3.63^{A}	22.88^{A}	7.23^{A}	5.15^{D}	58.37^{A}
	F$_4$, F$_3$ + 20 kg ZnSO$_4$	262.10^{A}	104.90^{A}	80.07^{A}	29.33^{AB}	3.63^{A}	22.90^{A}	7.29^{A}	5.36^{D}	57.56^{A}
	F$_5$, N$_{40}$ P$_{40}$ K$_{40}$ + N$_{40}$ through MC	262.00^{A}	90.35^{E}	76.74^{AB}	30.58^{A}	3.67^{A}	22.90^{A}	7.43^{A}	5.18^{D}	58.95^{A}
V$_2$, Ajay	F$_1$, N$_{60}$ P$_{30}$ K$_{30}$	248.00^{C}	87.16^{I}	57.90^{DEF}	26.67^{EF}	3.37^{BCDE}	21.76^{E}	6.42^{D}	6.86^{B}	48.33^{D}
	F$_2$, N$_{80}$ P$_{40}$ K$_{40}$	248.60^{C}	88.00^{H}	58.53^{DEF}	26.83^{EF}	3.38^{BCDE}	21.94^{D}	6.52^{CD}	6.77^{B}	49.10^{CD}
	F$_3$, N$_{60}$ P40 K$_{40}$ + N$_{20}$ through MC	250.30^{BC}	96.25^{D}	61.84^{D}	27.25^{CDE}	3.38^{BCDE}	22.28^{C}	6.63^{CD}	6.62^{B}	50.11^{C}
	F$_4$, F$_3$ + 20 kg ZnSO$_4$	252.40^{B}	88.50^{G}	64.08^{CD}	27.33^{CDE}	3.38^{BCDE}	22.24^{C}	6.62^{CD}	6.68^{B}	49.79^{CD}
	F$_5$, N$_{40}$ P$_{40}$ K$_{40}$ + N$_{40}$ through MC	250.30^{BC}	103.60^{B}	61.19^{D}	27.67^{BCDE}	3.40^{BCDE}	22.30^{C}	6.61^{CD}	6.60^{B}	50.06^{CD}
V$_3$, Chakra 5001	F$_1$, N$_{60}$ P$_{30}$ K$_{30}$	250.20^{BC}	85.31^{J}	59.59^{DEF}	26.33^{EF}	3.42^{BCDE}	22.21^{C}	6.63^{CD}	6.70^{B}	49.72^{CD}
	F$_2$, N$_{80}$ P$_{40}$ K$_{40}$	249.60^{BC}	82.69^{M}	59.20^{DEF}	26.83^{EF}	3.48^{ABC}	21.15^{G}	6.67^{C}	6.79^{B}	49.54^{CD}
	F$_3$, N$_{60}$ P$_{40}$ K$_{40}$ + N$_{20}$ through MC	248.80^{C}	83.63^{L}	58.74^{DEF}	27.00^{DE}	3.46^{ABCD}	21.39^{F}	6.55^{CD}	6.79^{B}	49.06^{CD}
	F$_4$, F$_3$ + 20 kg ZnSO$_4$	250.00^{BC}	85.46^{J}	60.16^{DE}	27.33^{CDE}	3.47^{ABC}	22.23^{C}	6.61^{CD}	6.67^{B}	49.76^{CD}
	F$_5$, N$_{40}$ P$_{40}$ K$_{40}$ + N$_{40}$0 through MC	252.80^{B}	83.92^{K}	60.41^{D}	27.67^{BCDE}	3.50^{ABC}	21.24^{G}	6.69^{C}	6.64^{B}	50.14^{C}
V$_4$, IET 4094	F$_1$, N$_{60}$ P$_{30}$ K$_{30}$	237.00^{F}	64.63^{P}	29.30^{H}	23.35^{H}	3.21^{E}	19.64^{K}	4.51^{G}	7.73^{A}	36.86^{G}
	F$_2$, N$_{80}$ P$_{40}$ K$_{40}$	241.40^{DE}	73.14^{O}	48.94^{G}	23.67^{GH}	3.25^{DE}	20.00^{J}	4.83^{F}	7.46^{A}	39.30^{EF}
	F$_3$, N$_{60}$ P$_{40}$ K$_{40}$ + N$_{20}$ through MC	240.90^{E}	73.06^{O}	49.20^{G}	24.42^{GH}	3.29^{CDE}	19.89^{J}	4.79^{F}	7.58^{A}	38.74^{F}
	F$_4$, F$_3$ + 20 kg ZnSO$_4$	244.50^{D}	75.56^{N}	51.97^{EFG}	25.17^{FG}	3.34^{CDE}	20.38^{H}	5.10^{E}	7.42^{A}	40.72^{E}
	F$_5$, N$_{40}$ P$_{40}$ K$_{40}$ + N$_{40}$ through MC	244.30^{D}	75.44^{N}	51.33^{FG}	25.17^{FG}	3.33^{CDE}	20.18^{I}	4.95^{EF}	7.34^{A}	40.28^{EF}

MC: mustard cake; Different letters in each column in superscript form depict the significant differences among the treatments means using DMRT analysis ($p<0.05$).

At 90 DAT, V$_1$F$_4$ recorded the highest values of 1.35% whereas V$_1$F$_3$ ranked second in terms of N concentration in the third leaf with value of 1.21 %. The least however recorded with V$_4$F$_1$ combination with 0.71%. However, decreasing TLN due to degradation of chlorophyll (Chl) and carotenoid (Caro) content in leaf.

Yield Attributes and yield

The yield components, like number of effective tillers/ m2, panicle length, fertility %, panicle weight and number of filled grains/panicle varied significantly ($p=0.05$) among the different nutrient management practices; but, the test weight of grain did not vary much among them (Table 2). The interaction effect revealed that maximum effective tillers m^{-2}, filled grains per panicle and fertility % were found in V$_1$F$_4$ with 262.1, 104.90 and 80.07 % respectively followed by V$_1$F$_5$ combination. Maximum panicle length and panicle weight recorded by treatment combination V$_1$F$_5$ with 30.58 cm and 3.67 g respectively followed by V$_1$F$_4$ and V$_1$F$_3$ (both found to be statistically at par with each other but significant with other treatment). The least value recorded with V$_4$F$_1$ treatment combination.

Nutrient management practices showed significant effect on grain and biomass yield of different rice varieties. The hybrid variety Arize 6444 when combined with either of the fertilizer treatment i.e. 50% RDN + 50% RDN from mustard cake + RDP and

Table 3. Effects of variety and nutrient management on economics of hybrid rice during *kharif* seasons (Pooled).

Variety	Fertilizer application	Cost of cultivation ($\times 10^3$ Rs. ha^{-1})	Gross return) ($\times 10^3$ Rs. ha^{-1})	Net return ($\times 10^3$ Rs. ha^{-1})	B:C ratio
V_1, Arize 6444	F_1, N_{60} P_{30} K_{30}	44.5	116.8	116.8	2.63
	F_2, N_{80} P_{40} K_{40}	45.6	115.6	115.5	2.54
	F_3, N_{60} P_{40} K_{40} + N_{20} through MC	53.0	119.8	119.8	2.26
	F_4, F_3 + 20 kg $ZnSO_4$	63.0	120.9	120.9	1.92
	F_5, N_{40} P_{40} K_{40} + N_{40} through MC	60.4	123.0	123.0	2.04
V_2, Ajay	F_1, N_{60} P_{30} K_{30}	44.5	108.2	108.2	2.43
	F_2, N_{80} P_{40} K_{40}	45.6	109.7	109.7	2.41
	F_3, N_{60} P_{40} K_{40} + N_{20} through MC	53.0	111.3	111.3	2.10
	F_4, F_3 + 20 kg $ZnSO_4$	63.0	111.2	111.2	1.77
	F_5, N_{40} P_{40} K_{40} + N_{40} through MC	60.4	111.0	111.0	1.84
V_3, Chakra 5001	F_1, N_{60} P_{30} K_{30}	44.5	111.4	111.4	2.50
	F_2, N_{80} P_{40} K_{40}	45.6	112.1	112.1	2.46
	F_3, N_{60} P_{40} K_{40} + N_{20} through MC	53.0	110.2	110.2	2.08
	F_4, F_3 + 20 kg $ZnSO_4$	63.0	111.0	111.0	1.76
	F_5, N_{40} P_{40} K_{40} + N_{40} through MC	60.4	112.3	112.3	1.86
V_4, IET 4094	F_1, N_{60} P_{30} K_{30}	40.8	78.3	78.3	1.92
	F_2, N_{80} P_{40} K_{40}	41.9	83.2	83.2	1.99
	F_3, N_{60} P_{40} K_{40} + N_{20} through MC	49.3	82.7	82.7	1.68
	F_4, F_3 + 20 kg $ZnSO_4$	59.3	87.5	87.5	1.48
	F_5, N_{40} P_{40} K_{40} + N_{40} through MC	56.7	85.0	85.0	1.50

MC: mustard cake.

RDK (F_5) or 75% RDN + 25% RDN from mustard cake + RDP and RDK + 20 kg $ZnSO_4$ ha^{-1} (F_4) or 75% RDN + 25% RDN from mustard cake + RDP and RDK (F_3) shows greater productivity of 7.43, 7.29 and 7.23 t ha^{-1} respectively. Variety V_4 (IET 4094) when combined with sole chemical farmers' treatment *i.e.*, NPK @ 60:30:30 kg ha^{-1} recorded the least productivity with 4.51 t ha^{-1}. Most of the fertilizer treatments either integrated nitrogen management or sole chemical fertilization when combined amongst the varieties V_2 (Ajay) and V_3 (CHAKRA 5001) gives insignificant values. INM with organic manures and chemical fertilizers helped in accumulation of foliage N, improved growth and controlled senescence of the whole plant that could ultimately lead to higher dry matter production in meeting the need of larger sink in hybrid rice (Huang et al., 2008). Similar increased yield due to conjunctive use of organic and inorganic nitrogen was reported by Majumdar et al., 2007; Mondal et al., 2020. In case of straw highest recorded group combined V_4 (IET 4094) variety with all the integrated and non-integrated nutrient treatments namely F_1, F_2, F_3, F_4 and F_5. The group that performs the least includes treatment comprising integrated nutrient management namely F4, F_5 and F_3 with V_1. In an integrated nitrogen management system Mandal and Adhikary (2005) recorded highest straw yield. Treatment combinations of Arize 6444 with integrated nutrients namely F_5, F_3 and F_4 gives highest harvest indexes of 58.95, 58.37 and 57.56% respectively, however these treatment combinations are at par with each other. The lowest mean harvest index of 36.86% recorded with V_4F_1.

Economic analysis

The economics of hybrid rice cultivation followed a trend similar to that of the crop productivity. The results showed very striking effect of nutrient management practices on economics of hybrid rice cultivation (Table 3). The nutrient management practices showed significant effect on gross and net returns from different varieties of hybrid rice cultivation. The highest gross and net returns were recorded from the crop with V_1F_5 combination. The fertilizer treatment F_1 and F_2 when combined with V_1 variety gives highest B:C ratio of 2.63 and 2.54 respectively. V_2F_1 and V_2F_2 also recorded comparable B:C ratio of 2.43 and 2.41 followed by V_1F_3 with respective values of 2.26. The least B:C ratio is

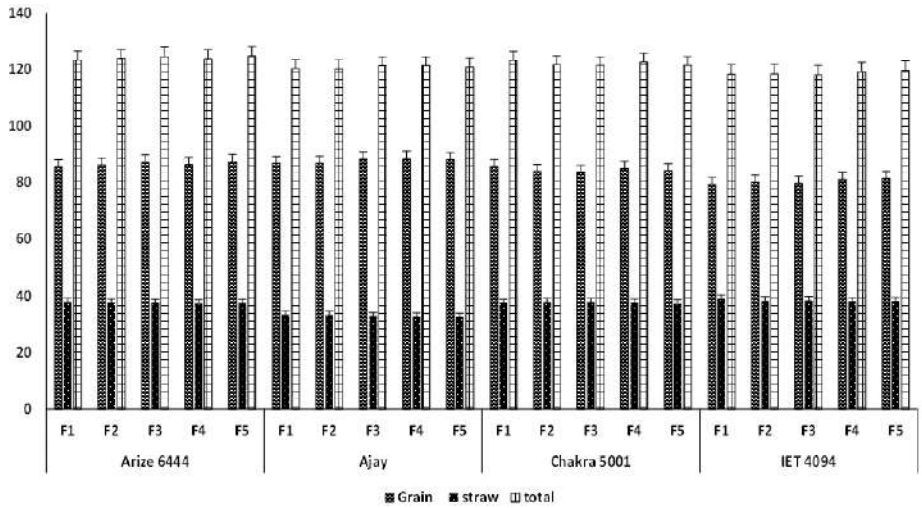

Fig. 2. Interaction effects of variety and fertilizer on nitrogen uptake (kg/ha).

obtained with V_4 variety when combines with either of the fertilizer treatments F_3, F_5 and F_4.

Nitrogen uptake by grain and straw

The N, content in grain and straw did not vary much due to the different nutrient management practices in different varieties (Fig . 2). V_2F_4 yields the highest uptake of N by the grains and that of the lowest found with the V_4F_1 with respective values of 88.72 and 79.46 kg N ha^{-1} being the highest and the least. Significantly higher uptake of nutrient, particularly with F_4 could be attributed to soil application of Zn might be due to a synergistic effect of N on plant Zn accumulation and similar findings were also reported by Farooq et al. (2018). The highest recorded N uptake for straw was found with treatment combination V_4F_1. Nutrient supply through integration of both organic and chemical sources tended to increase the nutrient content in both grain and straw as compared to those of supplying nutrients through only chemical fertilizers. This might be due to balanced supply of plant nutrients through both organic manures and chemical sources (Panigrahi et al., 2014).

CONCLUSION

Thus, it concludes that rice hybrid Arize 6444 in combination with 75% RDN + 25% N from mustard cake and 20 kg $ZnSO_4$ ha^{-1} could achieve higher productivity and better economic returns. Therefore, Integrated application of nitrogenous fertilizer with good management practices while cultivating Arize 6444 hybrid could be more effective in augmenting yield and soil health of rice in the Gangetic plains of West Bengal.

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Site specific nutrient management through nutriexpert in rice

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ABSTRACT

A field experiment was conducted at Regional Agricultural Research Station, Maruteru, Andhra Pradesh during kharif season of 2016 to study the site-specific nutrient management approaches for enhancing productivity and profitability in rice (Oryza sativa L.). Nutriexpert is a decision support tool developed by the International Plant Nutrition Institute (IPNI). Application of fertilizers based on the Nutriexpert was (112-31-58) higher nitrogen, lower phosphorus and potassium than the recommended dose of fertilizers (90-60-60) during kharif season for rice. The treatments included recommended fertilizer (T1), Site Specific Nutrient Management (SSNM) based on Nutrient expert (T2), SSNM based on Leaf Colour Chart (50% N as basal and rest 50% based on LCC (T3), T2 minus Nitrogen (T4), T2 minus Phosphorus (T5), T2 minus Potassium (T6), Absolute control (without N, P and K) (T7) and Farmer's Practice (T8) . The results revealed that the highest grain yield (6317 kg ha $^{-1}$) and straw yield (7663 kg ha^{-1}) of rice was recorded in T2- SSNM (NE) which is significantly superior over all other fertilizer treatments. Application of major nutrients based on nutriexpert recorded higher uptake of nitrogen (128.50 kg ha^{-1}), phosphorus (27.15 kg ha^{-1}), and potassium(137.32 kg ha^{-1}). Nutrient omission and control treatments recorded significantly lowest grain and straw yields of rice and also nutrient uptake. Hence, nutriexpert not only saves the fertilizers but also helps in increased grain and straw yield of rice.

Key words: *Nutriexpert, rice, grain and straw yield and nutrient uptake*

INTRODUCTION

The conventional blanket fertilizer recommendation causes low fertilizer use efficiency and imbalanced use of fertilizers (Kumar et al., 2014). Estimation of field specific fertilizer requirements needs site-specific knowledge of crop nutrient requirements, indigenous nutrient supply, and recovery efficiency of applied fertilizer. Thus, there is the requirement of the site specific nutrient management technique (SSNM). SSNM is an approach for "feeding" crops with nutrients as and when needed and thus can improve NUE, crop yield and farmers' income It advocates the optimal use of existing indigenous nutrient sources and timely application of fertilizers at optimal rates. For more rapid adoption of SSNM technology by farmers, efforts were made in the consolidation of SSNM research conducted over the last decade across Asia into a simple delivery system by International Plant Nutrition Institute (IPNI) in the form of NutriExpert (NE). Nutriexpert is a simple computer based decision support system (DSS) or delivery tool that can rapidly provide nutrient recommendations for N, P and K for crops for individual farmer's fields in presence or absence of soil testing results.(Gupta et al., 2016; Qureshi et al., 2016; Kumar et al., 2014; Kumar et al., 2015a; Kumar et al., 2015b). NutriExpert involves the principles of SSNM to calculate fertilizer N, P, and K rates for individual fields based on a target yield set for each field. It also used expected growth duration of the rice variety, crop establishment method, and age of transplanted seedlings to calculate days after rice establishment for each of three applications of fertilizer N, P and K.

Rice and rice based cropping systems (RBCS) are the most important production systems widely cultivated under diverse soil and agro ecological conditions including large tracts of soils with *in situ* problems and management induced nutrient stresses. Changing climatic conditions such as shifts in rainfall distribution and its intensity, changes in temperature regimes in many vulnerable areas are likely to influence agricultural productivity through their impact on land and water resources. However, nutrient management is a major component of a soil and crop management system. Knowing the required nutrients for all stages of growth and understanding the soil's ability to supply those needed nutrients is critical to profitable crop production. Knowing the required nutrients for all stages of growth and understanding the soil's ability to supply those needed nutrients is critical to profitable crop production. Keeping the above facts in view, the present experiment has been planned to conduct with objectives: (i) To assess of impact of nutrient management approaches on yield of rice (ii) To compare yield and nutrient uptake of rice with fertilizer recommendation based on nutriexpert with the existing blanket recommendation and farmers practice.

MATERIALS AND METHODS

A field experiment was conducted during *kharif*, 2016 at Regional Agricultural Research Station, Maruteru, West Godavari district, Andhra Pradesh with eight treatments and three replications in a randomized block design. The treatments included T1-Recommended Dose of Fertilizers (90-60-60 Kg NKP per Ha),T2-Fertilizer application based on SSNM using Nutriexpert (112-31-58 Kg NPK per Ha), T3 is T2 based on LCC (50% N as basal and rest 50% N based on LCC) , T4-T2 minus Nitrogen, T5- T2 minus Phosphorus, T6- T2 minus Potassium,T7-Absolute control (without fertilizers) and T8- Farmer's Practice (Application of nitrogen more than recommended dose and potassium less tha recommended dose and use of complex fertilizers as topdressing). Application of fertilizers based on the Nutriexpert was assessed and found to be (112-31-58) higher nitrogen, lower phosphorus and potassium than the recommended dose of fertilizers (90-60-60) during *kharif* season.

Nitrogen was applied through urea in three equal splits (1/3rd basal+1/ 3rd at tillering+1/3rd at panicle initiation stage). Phosphorus was applied through SSP as basal and potassium as muriate of potash. Initial soil was analysed for chemical properties and presented in Table 1. Data on yield attributes was collected during crop growth period and yield data was collected at the time of harvesting.

Table 1. Initial soil properties.

% Clay	38
% Silt	28
% Sand	34
Texture	Clay loam
pH	6.09
Organic carbon (%)	1.05
CEC (cmol (p+)/kg)	48.6
EC (dS/m)	0.57
Available nitrogen (Kg ha^{-1})	157.0
Available phosphorus (Kg ha^{-1})	48.0
Available potassium (Kg ha^{-1})	249.0

Soil samples were collected after harvest of rice crop. Soil analysis was conducted using standard procedures. Soil pH and electrical conductivity (EC) were measured with the help of pH and EC meter, respectively using soil and water suspension in 1:2.5 ratio. Soil organic carbon (OC) was determined by Walkley and Black (1934) method. The available nitrogen (N) was determined by the alkaline potassium permanganate ($KMnO_4$-N) method (Subbiah and Asija 1956). Available phosphorus (P) was extracted with 0.5M $NaHCO_3$ and determined by using ascorbic acid reduction in an acidic medium (Olsen et al., 1954). Available potassium (K) was extracted with neutral normal ammonium acetate solution by displacement of the exchangeable cations and estimated by flamephotometer (Jackson, 1973). Nitrogen in plant sample was determined by micro kjeldahl method .Other nutrients like phosphorus and potassium was determined by using diacid digestion of plant sample and respective uptakes were calculated (Piper, 1966). Nutrient uptake (kg ha^{-1}) was worked out with the help of the per cent concentration of the nutrients was multiplied by respective grain and straw yield.

The statistical analysis of data collected through various observations of different parameters of rice on was carried out in RBD design through software as described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Grain and straw yield

Data from the Table 2 revealed that, the grain and straw yield of rice was influenced by different fertilizer

Table 2. Effect of site specific nutrient management of rice through nutriexpert on rice yield (Kg ha^{-1}).

S. no.	Grain yield (kg ha^{-1})	Straw Yield (kg ha^{-1})
T1	5914	7461
T2	6317	7663
T3	5890	7220
T4	3989	5437
T5	5241	6632
T6	5328	6973
T7	2978	4413
T8	4967	6576
Mean	5078	5875
C.V (%)	12.3	16.5
C.D (0.05)	469	512

T1 - Recommended dose of fertilizers (90-60-60 NPK (kg ha^{-1})); T2 - SSNM based on nutrient expert (112-31-58 NPK Kg ha^{-1}); T3 - SSNM based on LCC; (The dose of nutrient based on the nutrient expert, 50% N as basal and rest 50% based on LCC); T4 - T2 minus nitrogen; T5 - T2 minus phosphorus; T6 - T2 minus potassium; T7 - Absolute control (without N: P: K); T8 - Farmers practice (110-72-45 NPK Kg ha^{-1})

treatments in rice. Application of fertilizer enhanced the yield of rice significantly compared to the unfertilized crop. The highest grain yield of rice (6317 kg ha^{-1}) and straw yield (7663 kg ha^{-1}) was recorded in T2- SSNM (NE) being significantly superior over all other fertilizer treatments. The increase in application of fertilizer nitrogen could increase number of tillers, panicles and spikelet per panicle, and consequently, increased grain and straw yield. However, it remained at par with the grain and straw yield obtained under recommended dose of fertilizer and fertilizers applied based on Nutriexpert using LCC treatments. Treatment omitting either N, P or K resulted in a marked yield loss, indicating the significance of replenishment of these nutrients for achieving high yield targets. Compared with fertilizer application using nutriexpert, reduction in rice grain yield was 36 %, 17% and 15% in -N, -P and -K plots, respectively. This indicates that nitrogen plays a very important role in increased production of grain and straw yield of rice. Control plot recorded a grain yield loss of 53% as compared to the fertilizer application using nutriexpert.

These results are in conformity with findings of other researchers (Kabir et al., 2011), Dobermann (2003), Biradar et al. (2006) and Maheshwari et al. (2007). Singh et al. (2000) compared SSNM in rice and wheat with farmer's fertilizer practice and found that average increase in rice and wheat yield was achieved by SSNM as nutrient expert.

The Site Specific Nutrient Management through Nutriexpert approach adjusts inputs of fertilizers based on a supply of indigenous nutrients originating from soil, plant residues, manures, and irrigation water. The timing and rates of fertilizer application were dynamically adjusted to match specific needs of the rice variety, field, and season (These factors helps in improved nutrient management and balanced nutrition of rice crop and there by increased nutrient uptake resulted in higher grain and straw yield of rice (Sheela Sharma et al., 2019).

Wang et al. (2001) found that the performance of SSNM has consistently improved grain yield by about 10-15 per cent compared to the farmers' fertilizer practice. The yield levels of 7.5 t ha^{-1} or more seem achievable and sustainable through introduction of SSNM. Mishra et al. (2003) conducted experiment on SSNM in hybrid rice revealed that the highest grain yield of 9.7 t ha^{-1} was obtained with 150:60:120 N, P_2O_5, K_2O kg ha^{-1} with 6 kg Zn ha^{-1} and 7 kg Mn ha^{-1}. The rice yields in SSMM plots ranged between 6.8 to 7.1 t ha^{-1} which were 0.7 to 0.8 t ha-1 greater than state recommendation (SR) and 0.2 to 0.3 t ha^{-1} greater than common farmers practice (FP). Biradar et al. (2006) conducted an experiment with nutrient 30 application on the basis of SSNM principles resulted in significantly higher grain yield over FP The yield increases under SSNM shows the promise for yield improvement can be achieved through SSNM approach.

Nutrient uptake (Kg ha^{-1})

Nitrogen uptake (Kg ha^{-1}) by grain and straw indicated that the uptake of nitrogen by rice was more in grain as compared to straw. The uptake of nitrogen in rice grain varied from 31.86 to 80.23 Kg ha^{-1} and that of uptake in straw ranged from 21.18 to 48.28 Kg ha^{-1}. In the treatments with omission of nitrogen fertilizer and control recorded lowest nitrogen uptake, as there was reduction in grain and straw yield.

Data pertaining to nitrogen uptake by rice as influenced by different fertilizer treatments are presented in Table 3. Results revealed that application of major nutrients based on NE recorded higher uptake of nitrogen (128.50 Kg ha^{-1}) followed by T3- SSNM

Table 3. Effect of site specific nutrient management of rice through nutriexpert on rice nutrient uptake (Kg ha $^{-1}$).

S. no.	Nutrient uptake by grain (Kg ha^{-1})			Nutrient uptake by straw (Kg ha^{-1})			Total nutrient uptake (Kg ha^{-1})		
	N	P	K	N	P	K	N	P	K
T1	72.15	15.38	20.11	41.78	11.19	97.74	113.93	26.57	117.85
T2	80.23	16.42	20.85	38.32	10.73	116.48	118.54	27.15	137.32
T3	67.15	15.31	17.67	34.66	10.11	113.35	101.80	25.42	131.02
T4	49.06	10.77	13.16	28.82	7.61	84.82	77.88	18.38	97.98
T5	66.56	12.58	14.67	39.79	7.30	104.12	106.35	19.87	118.80
T6	66.60	14.39	9.06	43.93	9.76	101.11	110.53	24.15	110.17
T7	31.86	7.74	6.25	21.18	6.18	61.34	53.05	13.92	67.59
T8	62.58	13.91	9.44	46.03	9.21	100.61	108.62	23.11	110.05
Mean	54.84	11.68	13.65	29.38	7.05	77.55	84.22	18.73	91.20
C.V (%)	14.45	7.00	11.78	34.30	12.49	12.39	34.30	12.49	12.39
C.D (0.05)	0.27	0.03	0.03	0.30	0.03	0.29	0.30	0.03	0.29

T1 - Recommended dose of fertilizers (90-60-60 NPK (kg ha $^{-1}$)); T2 - SSNM based on nutrient expert (112-31-58 NPK Kg ha $^{-1}$); T3 - SSNM based on LCC; (The dose of nutrient based on the Nutrient Expert, 50% N as basal and rest 50% based on LCC); T4 - T2 minus nitrogen; T5 - T2 minus phosphorus; T6 - T2 minus Potassium; T7 - Absolute control (Without N: P: K); T8 - Farmers practice (110-72-45 NPK Kg ha $^{-1}$)

LCC (117.08 Kg ha^{-1}) and T1- RDF (115.42 Kg ha^{-1}) and minimum N uptake was observed in control (53.05 Kg ha^{-1}) and nitrogen omission treatment. Application of fertilizers in a balanced manner and increased nitrogen application increased the nutrient concentration in rice grain and straw and helped in higher dry matter production, which resulted in higher nutrient uptake in treatment received fertilizers based on nutriexpert. The results are in conformity with the findings of Dobermann (2002) an increase of nitrogen uptake under different SSNM treatments in rice.

P uptake by grain and straw by rice was significantly affected with application of different treatments. It is obvious from the Table that uptake of P by rice was more in grain than straw. The uptake of P in rice grain varied from 7.74 to 16.42 kg ha^{-1} and that of uptake in straw ranged from 6.18 to 11.73 kg ha^{-1}. In the treatments with omission of posphorus fertilizer and control recorded lowest posphorus uptake, as there was reduction in grain and straw yield.

The increase P uptake might be due to the improved synchrony between plant P demand and supply from soil and fertilizer. Higher uptake of P with application of Phosphorus by rice has been observed by Bhuiyan et al. (1986). Reductions in P uptakes with omission of N and K have also been reported by Mishra et al. (2007) for rice crop.

K uptake by grain and straw by rice was more in straw as compared to grain. The uptake of potassium in rice grain varied from 6.25 to 20.85 kg ha^{-1} and that of uptake in straw ranged from 61.34 to 116.48 kg ha^{-1}. In the treatments with omission of potassium fertilizer and control recorded lowest potassium uptake, as there was reduction in grain and straw yield.

Higher uptake of K with application of Potassium by rice has been observed by Bhuiyan et al. (1986). Reductions in K uptakes with omission of N and K have also been reported by Mishra et al. (2007). Sakeena and Salam (1989) also reported that application of potassium along with all other nutrients increase potassium uptake significantly in all treatments.

Soil nutrient status

Data pertaining to available N, P, K (Kg ha^{-1}) in soil after harvest of rice as influenced by different SSNM treatments are presented in Table 4 revealed that available nitrogen in soil at harvest stage found higher under SSNM on nutrient expert (188 Kg ha^{-1}) followed by SSNM on LCC (178.67 Kg ha^{-1}) .The minimum available content of soil at harvest stage in Control (149.0 Kg ha^{-1}) treatment. Similar trend found in available phosphorus higher under SSNM on nutrient expert (54.73 Kg ha^{-1}) followed by SSNM on LCC (51.83 Kg ha^{-1}) based treatment, RDF (51.00 Kg ha^{-1}). The minimum available phosphorus content of soil at harvest stage in control (36.87 Kg ha^{-1}) and minus P treatment (37.57 Kg ha^{-1}) and the available potassium

Table 4. Effect of site specific nutrient management of rice through nutriexpert on post harvest soil nutrient status.

Treatments	pH	E.C (dS/m)	OC (%)	Available nutrients (Kg ha^{-1})		
				N	P_2O_5	K_2O
T1	6.33	0.51	1.18	174.67	54.00	275.22
T2	6.37	0.53	1.26	188.00	42.73	311.06
T3	6.40	0.51	1.29	178.67	43.83	305.03
T4	6.29	0.55	1.11	161.33	52.50	275.00
T5	6.37	0.48	1.16	168.00	37.57	285.08
T6	6.22	0.46	1.22	170.67	51.50	263.83
T7	6.28	0.40	1.09	160.00	36.87	243.56
T8	6.35	0.44	1.27	180.00	47.30	259.06
Mean	6.33	0.49	1.20	172.67	45.79	277.23
C.D (0.05)	NS	NS	NS	32.91	5.09	71.68
C.V (%)	2.26	16.35	8.36	12.27	6.16	16.87

T1 - Recommended dose of fertilizers (90-60-60 NPK (kg ha^{-1})); T2 - SSNM based on Nutrient Expert (112-31-58 NPK Kg ha^{-1}); T3 - SSNM based on LCC; (The dose of nutrient based on the Nutrient Expert, 50% N as basal and rest 50% based on LCC); T4 - T2 minus nitrogen; T5 - T2 minus phosphorus; T6 - T2 minus potassium; T7 - Absolute control (Without N: P: K); T8 - Farmers practice (110-72-45 NPK Kg ha^{-1}).

content of soil at harvest stage found higher under SSNM on nutrient expert (311.06 Kg ha^{-1}) followed by SSNM on LCC (305.03 Kg ha^{-1}), RDF (288.22 Kg ha^{-1}) and the minimum available potassium content of soil at harvest stage in Control (243.56 Kg ha^{-1}) treatment. In all the omission treatments soil available nutrient status was found to be low as compared to the treatments receiving fertilizers. Similar improved soil available nutrient status was observed in increasing levels of N and K fertilizers applied to rice reported by Babou et al. (2009). The results are in conformity with the findings of More et al. (2010) while study the impact of integrated nutrient management on residual fertility status of soil.

CONCLUSION

Site specific nutrient management of rice through nutriexpert helps in finding the required dosage of fertilizers to be applied to the rice for all stages of growth and understanding the soil's ability to supply those needed nutrients, which is critical to profitable crop production. In present study, results revealed that the highest grain yield of rice (6317 kg ha^{-1}) and straw yield (7663 kg ha^{-1}) was recorded in T2- SSNM (NE) being significantly superior over all other fertilizer treatments. Compared with fertilizer application using nutriexpert, reduction in rice grain yield was 36 %, 17% and 15% in -N, -P and -K plots, respectively. Control plot recorded a grain yield loss of 53% as compared to the fertilizer application using nutriexpert. These results hold promise as an example showing higher yields could be achieved with balanced use of nutrients as per crop requirement. Hence, the site specific nutrient management with the use of nutriexpert not only saves the fertilizers but also helps in increased grain and straw yield of rice.

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Crop productivity and soil health in relation to the microbial population as influenced by different organic biostimulants in summer rice cultivation

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ABSTRACT

This study aims to determine the effect of several types of seaweed extracts on growth and yield of rice. On summer rice, three types of bio-stimulants (Soligro, Opteine, and Biozyme) along with vermi-wash were applied in different formulations i.e. granular and foliar application and at different growth stages (Basal, Tillering, and Panicle initiation Stage) along with recommended dose of fertilizer (RDF). The highest grain yield was found under 100% RDF+ Opteine liquid at 30 DAT (Days after transplanting) and 60 DAT treatment resulting in an increase by 35.03% grain yield over control but the straw yield was highest under the application of 100% RDF+ Soligro Granule at 30 and 60 DAT. Nutrient uptake (N, P and K) by grain and straw and soil microbial population were found maximum under 100% RDF + Soligro Granule at 30 DAT and 60 DAT.

Key words: *Bio-stimulant, growth parameters, rice, seaweed extract and yield parameters*

INTRODUCTION

More than half of the world's population depends on rice (*Oryza sativa* L.) which is grown in more than 100 countries; among which Asia produce 90% of the total global production of rice. By providing 21% of global human per capita energy and 15% of per capita protein it holds 2nd position among food crops. Under the current rate of population growth (1.5%), the rice requirement by 2025 would be about 125 Mt in the country (Kumar et al., 2009). The green revolution has boosted up the indiscriminate use of different fertilizers nationwide. We are facing a great challenge in maintaining the sustainability of rice farming due to faulty agricultural practices, increased scarcity and competition for water resources, stagnant or declining yield levels, higher fertilizer cost, soil degradation, and negative environmental impact due to the increasing use of agrochemicals for rice production.

There is an immediate need to decrease the use of chemical inputs without negatively affecting crop yield or the farmers' income. Modern agriculture is searching for new tools that would allow doing so and no doubt seaweed extract can serve as a better alternative. Being an economic and low volume organic source of fertilizer use of seaweed extracts has gained popularity in organic and sustainable agriculture (Craigie, 2011; Dwivedi et al., 2014; Saha et al., 2013; Layek et al., 2015).

Unlike, synthetic chemicals, extracts derived from seaweeds are biodegradable, non-toxic, non-polluting, and most importantly non-hazardous (Khan et al., 2009). Enhanced root growth, leaf growth, yield, tolerance to different plant stresses, and increase in plant resistance to infections or insect attacks are some of the beneficial effects of seaweeds. About 15 Mt of seaweed products are produced every year across the globe, amongst which a considerable portion is used as nutrient supplements or bio-stimulants to improve plant growth and productivity (FAO, 2006).

Seaweed extracts are marketed as liquid fertilizers and biostimulants since they contain many plant growth hormones such as IAA and IBA, growth stimulators such as auxin, gibberellins cytokinin and betaines, macronutrients such as Ca, K, and P, micronutrients like Fe, Cu, Zn, B, Mn, Co, and Mo (Khan et al., 2009; Strik et al., 2004) and wetting agents/ mucilaginous colloids (*e.g*., carrageenan, agar, alginic acid, laminarin, and mannitol). It helps in retaining moisture and nutrients in the upper layers of soil (Subbarao et al., 2007). Seaweed extracts also have nitrogen, phosphorus, and a higher amount of water-soluble potash, other minerals, and trace elements in a readily absorbable form by plants. Seaweeds also have an enhancing effect on the biological activity (respiration and nitrogen mobilization) of soil (Haslam and Hopkins, 1996; Selvaraj et al., 2004) which promotes microbial diversity, thereby creating an environment suitable for root growth (Sarwar et al., 2008). It accelerates photosynthesis and further develops healthy foliage. Seaweed extract enlarges fruit size, increases the yield and improves the quality of the produce. The high fibre content of the seaweed acts as a soil conditioner and assists moisture retention.

Research on soil microbial study in relation to crop production and soil health is quite meagre. On this account, a research trial on 'crop productivity and soil health in relation to the microbial population as influenced by different biostimulants in summer cultivate was undertaken.

MATERIALS AND METHOD

Experimental site and soil information

In the Boro season of 2017-18 and 2018-19, the field experiment was carried out on Inceptisols at 'C' Block Farm of Bidhan Chandra Krishi Viswavidyalaya (22° 57'N latitude and 88° 20'E longitude with an altitude of 9.75 m above mean sea level) of Nadia district, of West Bengal in India. The site was situated in New Alluvial Zone. The texture of the soil was sandy clay loam with pH 7.04, organic carbon 0.45%, Soil available nitrogen 188.9 kg ha^{-1}, available P 26.29 kg ha^{-1}, and available K 248.72 kg ha^{-1}. Annual rainfall is about 1396 mm. Temperature ranges from 21.5 °C to 37 °C during the cropping period.

Experimental designs and treatments

The experiment was laid out in a Randomized Block Design (RBD) having three replications with 10 treatments. The plot size was 4m x 3m. The treatment details are given in Table 1 below.

Cultural practices

In the first week of February manual transplanting of Satabdi rice variety was done at a spacing of 20×15 cm using 2-3 seedlings $hill^{-1}$ (21 days old). Urea (46:0:0), single superphosphate (0:16:0), and muriate of potash (0:0:60) were used as sources for N, P, and K, respectively. Irrigation was applied as and when required. Based on the economic threshold level of pests and diseases plant protection measures were taken up. All necessary management practices were conducted following the standard recommendation for rice crops. Rice was harvested manually from the net plot area (4 m × 3 m) by cutting the above-ground biomass and leaving 20-cm stubble height using a sickle. The harvested produce was left on the concrete floor for sun drying for 5-7 days before threshing. After cleaning and drying operation at 14% moisture content the grain yield was recorded.

Plant sampling and analysis

In 5 randomly selected plants, the root length between the collar region and the tip of the root was measured at 30 and 60 days. The mean was calculated and expressed in centimetres. At 30 and 60 DAT root volumes were also taken with the help of the volumetric method and the treatment-wise mean values were recorded.

At the maturity, stage the yield parameters (panicles $hill^{-1}$, effective grains $panicle^{-1}$, and test weight) were measured from randomly selected five hills in each plot. From the net plot area of 4 × 3 m, the post-harvest data on grain and straw yields and harvest index (HI) were recorded. Plant samples were oven-dried at 70±2 °C, ground and sieved through a 0.5-mm sieve, and analyzed for total N by a micro-Kjeldahl method (Bremner and Mulvaney, 1982). The P concentration of plant tissues after digestion in HNO_3 and $HClO_4$ was determined by the ammonium molybdate method (Olsen and Sommers, 1982) and that of K by flame photometry (Jackson, 1973). By multiplying the N, P, and K concentrations of grains and straw with their respective yield in kilogram per hectare and summing up the two values nutrient uptake (for the aboveground biomass only) was estimated.

Table 1. Treatment details.

Treatment	Dose ha^{-1}	Time of application
T_1 - Control	No fertilizer	
T_2 -100% RDF	NPK 120:60:60 kg @[RDF]	Entire P and K and 1/2 of N as basal; top dressing of 1/4 th N at 30 DAT and 1/4th N at 60 DAT stage
T_3 -100% RDF+ Soligro granule	10 kg	Fertilizer application as in T_1 + Soil applications of Soligro granule at Basal
T_4 - 100% RDF+ Soligro granule	10 kg	Fertilizer application as in T_1 + Soil applications of Soligro granule at Basal and 30 DAT
T_5 - 100% RDF+ Soligro granule	10 kg	Fertilizer application as in T_1 + Soil applications of Soligro granule at 30 DAT and 60 DAT
T_6 - 100% RDF+ Opteine liquid	625 ml	Fertilizer application as in T_1 + Foliar applications of Opteine liquid at 30 DAT
T_7 - 100% RDF+ Opteine liquid	625ml	Fertilizer application as in T_1 + Foliar applications of Opteine liquid at 30 DAT and 60 DAT
T_8 - 100% RDF+ Biozyme liquid	625 ml	Fertilizer application as in T_1 + Foliar applications of Biozyme liquid at 60 DAT
T_9 - 100% RDF+ Biozyme liquid + Vermiwash	Biozyme 650 ml Vermiwash 10 lit	Fertilizer application as in T_1 + Foliar applications of Biozyme liquid and Vermiwash at 60 DAT
T_{10} - 100% RDF+ Vermiwash	10 lit	Fertilizer application as in T_1 + Foliar applications of Vermiwash at 60 DAT

Soligro granule is a soil health product produced from Ascophyllum nodosum powered by Acadian Bio Switch containing an exclusive mixture of beneficial bioactive compounds such as polysaccharides, organic acids that invigorate soil environment, particularly by promoting the activities of beneficial soil micro-organisms.
Biozyme, are highly nutritious bio-stimulant prepared from Ascophyllum nodosum extract powered by UPL containing organic nitrogen, proteins, amino acid, humic acid, carbohydrates, potassium, magnesium, calcium and traces of auxins, cytokinin, enzymes, betaines, and vitamins etc.
Opteine liquid is a liquid product made from natural seaweed filtrate of Ascophyllum nodosum that should be applied as a foliar spray.

Soil sampling and analysis

From a depth of 0 to 15 cm initial as well as post-harvest composite soil samples were collected (500 g composite sample, one sample from each plot). Three soil samples were collected from each plot and composited for soil analysis. After air-drying and processing with a 2 mm sieve, samples were analyzed for soil pH by Thomas (1996), soil organic carbon (SOC) by Nelson and Sommers (1996), available N by the alkaline permanganate method (Stanford and Smith, 1978), available P by Bray method (Kuo, 1996) and available K by neutral normal NH_4OAC extraction method (Knudsen et al., 1982).

Soil microbial analysis

The total microbial population (bacteria, actinomycetes and fungi) of soil after harvesting of crops were enumerated following the serial dilution and pour plate method (Zuberer, 1994). The different growth media used for counting the microbial population were: Jensen's media, nutrient agar, actinomycetes isolation agar and rose Bengal agar for Azotobacter, total bacteria, actinomycetes and fungi respectively. The colonies were counted following the formula (Pepper et al., 2004)

Statistical analysis

All data were statistically analyzed following the standard procedures as described by Gomez and Gomez (1984). The data were treated for analysis of variance and least significant difference (P = 0.05) to compare the effect of different biostimulants on root growth, yield and soil health.

RESULT AND DISCUSSION

Effect of different bio-stimulants on the growth of root

Root length increased and varied from 12.71 to 15.60 cm with the variation of 22.74% and from 17.0 to 20.64 cm with a variation of 21.41% at 30 DAT and 60 DAT respectively. Biostimulant in granular form applied in the soil at basal and 30 DAT with 100% RDF recorded the highest value (Table 2). Biostimulant treatment had a significant effect on root growth by modifying root confirmation and root development (Berlyn and Russo, 1990; Nardi et al., 2006; Petrozza et al., 2013).

The root volume of transplanted summer rice at 30 and 60 DAT varied with the different bio-stimulant application. With the advancement of plant growth, the root volume has been seen to increase. At 30 DAT and at 60 DAT root volume of rice varied from 13.20 to 18.43 cc $hill^{-1}$ with the variation of 39.62% and from 20.38 to 25.82 cc $hill^{-1}$ with a variation of 26.11 % respectively. Application of soligro granule at basal and 30 DAT was found to show a maximum root volume of 25.82 cc $hill^{-1}$ whereas, the least value of root volume was recorded by control treatment.

With the application of seaweed extracts in a sprayable form either to the roots or foliage, the root-growth-promoting activity was observed (Biddington and Dearman, 1983; Finnie and van Staden, 1985). According to Temple and Bomke (1990), seaweeds are a rich source of polysaccharides that may affect soil aggregation directly or indirectly after decomposition by soil microorganisms. High bulk density creates unfavorable growing conditions for roots and restricts water to upper soil layers, thereby cutting off access to water and nutrients stored deeper in the soil (Abu-Hamdeh, 2004). The reduced root length in control plants could be because of this reason.

Seaweed may also contain high salt, which may be a reason for enhanced plant nutrient content (*e.g.*, K^+) (Ruperez, 2002) causing better root development. Since the granular form resulted in better overall improvement when compared to the powder form, it is quite evident that the form of seaweed biomass added to the soil plays an important role. Rayorath et al. (2009) also reported that in Arabidopsis leaves, the foliar application of seaweed extract at very low concentration improved the root growth and volume, which would have stimulated the cell division of root cells and produced more lateral root growth and root biomass

Table 2. Effect of different bio-stimulants on root volume and root length of rice pooled of two year data 2017-18 and 2018-19.

Treatment	Root volume (cc $hill^{-1}$)		Root length (cm)	
	30 DAT	60 DAT	30 DAT	60 DAT
T_1	13.20	20.38	12.71	17.00
T_2	14.49	21.23	13.43	17.39
T_3	18.43	24.93	14.94	18.93
T_4	17.26	25..82	15.60	20.64
T_5	16.08	24.637	14.47	16.21
T_6	16.26	22.89	14.06	18.92
T_7	16.61	24.19	14.09	18.44
T_8	15.83	24.25	13.99	17.73
T_9	14.99	22.11	13.84	18.39
T_{10}	15.50	23.34	14.29	17.40
SEm (±)	0.41	0.41	0.40	0.72
CD at 5%	1.21	1.22	1.18	2.14

T_1 - Control(no fertilizer), T_2 - 100% RDF, T_3 - 100% RDF + Soil applications of Soligro granule at Basal, T_4 - 100% RDF + Soil application of Soligro granule at Basal and 30 DAT, T_5 - 100% RDF + Soil application of Soligro granule at 30 DAT and 60 DAT, T_6 - 100% RDF + Foliar applications of Optein liquid at 30 DAT, T_7 - 100% RDF + Foliar applications of Optein liquid at 30 DAT and 60 DAT, T_8 - 100% RDF + Foliar applications of Biozyme liquid at 60 DAT, T_9 - 100% RDF + Foliar applications of Biozyme liquid and vermiwash at 60 DAT, T_{10} - 100% RDF + Foliar applications of vermiwash at 60 DAT.

Effect of different bio-stimulants on grain and straw yield of rice

Bio-stimulants prepared from the extracts of seaweed Ascophyllum nodosum improved significantly the grain yield of rice due to the improvement in yield attributing characters. The highest grain yield (4.51 t ha^{-1}) was recorded in T_7 treatment [100% RDF + Foliar applications of Optein liquid at 30 DAT and 60 DAT] which was significantly higher than other treatments (Table 3). Besides inorganic fertilizers, the application of bio-stimulants at 30 and 60 DAT coincided with the critical physiological growth stages which facilitated the crop to put forth better growth characteristics as well as increased yield components which in turn yielded

Table 3. Effect of different bio-stimulants on grain and straw yields of rice pooled of two year data 2017-18 and 2018-19.

Treatment	Grain and straw yields				Harvest index (%)
	Grain yield (t ha^{-1})	Grain yield increase over control (%)	Straw yield (t ha^{-1})	Straw yield increase over control (%)	
T_1	3.34	-	5.50	-	37.77
T_2	3.88	16.17	5.98	8.73	39.36
T_3	4.03	20.66	6.15	11.82	39.60
T_4	4.19	25.45	6.77	23.09	38.24
T_5	4.25	27.25	6.83	24.18	38.32
T_6	4.16	24.55	6.20	12.73	40.14
T_7	4.51	35.03	6.73	22.36	40.13
T_8	4.2	25.75	6.46	17.45	39.61
T_9	4.30	28.74	6.42	16.73	40.10
T_{10}	4.17	24.85	6.33	15.09	39.73
SEm (±)	0.049	-	0.085	-	0.362
CD at 5%	0.146	-	0.251	-	1.076

T_1 - Control(no fertilizer), T_2 - 100% RDF, T_3 - 100% RDF + Soil applications of Soligro granule at Basal, T_4 - 100% RDF + Soil application of Soligro granule at Basal and 30 DAT, T_5 - 100% RDF + Soil application of Soligro granule at 30 DAT and 60 DAT, T_6 - 100% RDF + Foliar applications of Optein liquid at 30 DAT, T_7 - 100% RDF + Foliar applications of Optein liquid at 30 DAT and 60 DAT, T_8 - 100% RDF + Foliar applications of Biozyme liquid at 60 DAT, T_9 - 100% RDF + Foliar applications of Biozyme liquid and vermiwash at 60 DAT, T_{10} - 100% RDF + Foliar applications of vermiwash at 60 DAT.

the highest grain yield. The increase in yield in combined bio-stimulants and fertilizers treated plots was 35.03% in T_7, 28.74% in T_9 and 27.25% in T_5 over the control T_1 (no fertilizer), which produced the lowest grain yield (3.34 t ha^{-1}). A similar type of observation was made by Biswas et al. (2020a).

Foliar application of an aqueous extract of seaweed gives positive results on the growth and yield of pea and black gram (Ramamoorty et al., 2006 a, b, 2007). Seaweed extracts not only increase the vegetative growth of the plant but it also triggers the early flowering, fruiting in crops and ultimately on grain yield. Zodape et al. (2011) also reported that foliar application of a liquid extract of Kappaphycus spp. increase the yield of tomato. Application of seaweed extract enhanced the early growth and yield attribute properties in legume plants and 12-25% higher yield than that of control (Sethi and Adhikary, 2008). Similar results in the case of sesame were reported by Pramanick et al. (2014).

Application of 100% RDF+ Soil application of Soligro granule at 30 DAT and 60 DAT (T_5) recorded the highest straw yield of 6.83 t ha^{-1}, followed by T_4 (6.77 t ha^{-1}) and T_7 (6.73 t ha^{-1}). The lowest straw yield was recorded in control plot (5.50 t ha^{-1}). The higher straw yields obtained in bio-stimulants applied plots was due to the greater production of dry matter. The results are in line with Dwivedi et al. (2014), who proved that in Black gram, the foliar application of 15% Kappaphycus sap and RDF resulted in an increase by 49.2% grain yield compared to RDF to control (water spray+ RDF).

Effect of different bio-stimulants on available soil nutrients after harvest of the crop

A significant variation in available soil nitrogen, phosphorus, and potassium in different treatments was found after the harvesting of summer rice (Table 4).

Table 4. Effect of different bio-stimulants on nutrient uptake by grain and straw of rice pooled of two year data 2017-18 and 2018-19.

Treatment	Grain uptake (kg ha^{-1})			Straw uptake (kg ha^{-1})		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
T_1	35.4	6.2	27.34	21.55	5.25	85.63
T_2	58.85	7.53	30.48	47.78	6.12	98.32
T_3	62.12	9.62	33.59	52.28	7.51	110.38
T_4	65.71	10.21	35.41	51.65	8.72	122.56
T_5	64.63	9.82	38.58	52.83	9.64	125.78
T_6	72.36	8.07	33.36	51.27	7.35	115.87
T_7	78.63	12.34	43.91	59.85	11.38	135.63
T_8	72.38	11.73	40.28	56.85	10.79	132.56
T_9	67.65	10.31	37.39	54.39	9.73	123.36
T_{10}	68.72	9.87	33.13	52.28	8.37	112.36

T_1 - Control(no fertilizer), T_2 - 100% RDF, T_3 - 100% RDF + Soil applications of Soligro granule at Basal, T_4 - 100% RDF + Soil application of Soligro granule at Basal and 30 DAT, T_5 - 100% RDF + Soil application of Soligro granule at 30 DAT and 60 DAT, T_6 - 100% RDF + Foliar applications of Optein liquid at 30 DAT, T_7 - 100% RDF + Foliar applications of Optein liquid at 30 DAT and 60 DAT, T_8 - 100% RDF + Foliar applications of Biozyme liquid at 60 DAT, T_9 - 100% RDF + Foliar applications of Biozyme liquid and vermiwash at 60 DAT, T_{10} - 100% RDF + Foliar applications of vermiwash at 60 DAT.

Table 5. Effect of different bio-stimulants on the balance sheet of available soil N (kg ha $^{-1}$) at harvest of rice pooled of two year data 2017-18 and 2018-19.

Treatment	Innitial available N (1) (Kg ha^{-1})	Total applied N (2) (Kg ha^{-1})	Total available N (3 = 2+1) (Kg ha^{-1})	Total N uptake (Grain + straw) (4) (Kg ha^{-1})	Net available N (5=3-4) (Kg ha^{-1})	Balance of available N after harvest (6) (Kg ha^{-1})	Build up or depletion of available N (7 = 6-5) (Kg ha^{-1})
T_1	188.9	0	142.4	56.95	188.9	131.95	10.45
T_2	188.9	120	188.01	106.63	308.9	202.27	-14.26
T_3	188.9	120	204.62	114.4	308.9	194.5	10.12
T_4	188.9	120	215.53	117.36	308.9	191.54	23.99
T_5	188.9	120	208.94	117.46	308.9	191.44	17.5
T_6	188.9	120	189.25	123.63	308.9	185.27	3.98
T_7	188.9	120	192.07	138.48	308.9	170.42	21.65
T_8	188.9	120	186.64	129.23	308.9	179.67	6.97
T_9	188.9	120	207.31	122.04	308.9	186.86	20.45
T_{10}	188.9	120	192.82	121	308.9	187.9	4.92
SEm (±)	-	-	-	-	-	2.58	-
CD at 5%	-	-	-	-	-	7.67	-

T_1 - Control (no fertilizer), T_2 - 100% RDF, T_3 - 100% RDF + Soil applications of Soligro granule at Basal, T_4 - 100% RDF + Soil application of Soligro granule at Basal and 30 DAT, T_5 - 100% RDF + Soil application of Soligro granule at 30 DAT and 60 DAT, T_6 - 100% RDF + Foliar applications of Optein liquid at 30 DAT, T_7 - 100% RDF + Foliar applications of Optein liquid at 30 DAT and 60 DAT, T_8 - 100% RDF + Foliar applications of Biozyme liquid at 60 DAT, T_9 - 100% RDF + Foliar applications of Biozyme liquid and vermiwash at 60 DAT, T_{10} - 100% RDF + Foliar applications of vermiwash at 60 DAT.

Table 6. Effect of different bio-stimulants on the balance sheet of available soil P2O5 (kg ha $^{-1}$) at harvest of rice pooled of two year data 2017-18 and 2018-19.

Treatment	Initial available P_2O_5 (1) (Kg ha^{-1})	Total applied P_2O_5 (2) (Kg ha^{-1})	Total available P_2O_5 (3 = 2+1) (Kg ha^{-1})	Total P_2O_5 uptake (Grain +straw) (Kg ha^{-1}) (4)	Net available P_2O_5 (kg ha^{-1}) (5 = 3 - 4)	Balance of available P_2O_5 after harvest (6) (Kg ha^{-1})	Build up or depletion of available P_2O_5 (Kg ha^{-1})(7 = 6-5)
T_1	26.29	0	25.81	12.2	26.29	14.09	11.72
T_2	26.29	60	37.19	13.53	86.29	72.76	-35.57
T_3	26.29	60	40.45	15.62	86.29	70.67	-30.22
T_4	26.29	60	45.26	16.21	86.29	70.08	-24.82
T_5	26.29	60	42.34	15.82	86.29	70.47	-28.13
T_6	26.29	60	38.54	14.07	86.29	72.22	-33.68
T_7	26.29	60	38.98	18.34	86.29	67.95	-28.97
T_8	26.29	60	37.51	17.73	86.29	68.56	-31.05
T_9	26.29	60	40.07	16.31	86.29	69.98	-29.91
T_{10}	26.29	60	35.22	15.87	86.29	70.42	-35.2
SEm (±)	-	-	-	-	-	0.68	-
CD at 5%	-	-	-	-	-	2.03	-

T_1 - Control (no fertilizer), T_2 - 100% RDF, T_3 - 100% RDF + Soil applications of Soligro granule at Basal, T_4 - 100% RDF + Soil application of Soligro granule at Basal and 30 DAT, T_5 - 100% RDF + Soil application of Soligro granule at 30 DAT and 60 DAT, T_6 - 100% RDF + Foliar applications of Optein liquid at 30 DAT, T_7 - 100% RDF + Foliar applications of Optein liquid at 30 DAT and 60 DAT, T_8 - 100% RDF + Foliar applications of Biozyme liquid at 60 DAT, T_9 - 100% RDF + Foliar applications of Biozyme liquid and vermiwash at 60 DAT, T_{10} - 100% RDF + Foliar applications of vermiwash at 60 DAT.

The available nitrogen in the soil varied from 162.41 to 215.53 kg ha^{-1} with a variation of 32.70%. The available nitrogen was found to be maximum (215.53 kg ha^{-1}) in the plot fertilized with 100% RDF + soil application with soligro granule at basal and 30 DAT (T_4) followed by T5 treatment. The lowest available nitrogen (162.41 kg ha^{-1}) was recorded from the control plot because

Table 7. Effect of different bio-stimulants on the balance sheet of available soil K_2O (kg ha^{-1}) at harvest of rice pooled of two year data 2017-18 and 2018-19.

Treatment	Initial available K_2O (1) (Kg ha^{-1})	Total applied K_2O (2) (Kg ha^{-1})	Total available K_2O (3 = 2+1) (Kg ha^{-1})	Total K_2O uptake (Grain + straw) (Kg ha^{-1}) (4)	Net available K_2O (kg ha^{-1}) (5 = 3-4)	Balance of available K_2O after harvest (6) (Kg ha^{-1})	Build up or depletion of available K_2O (Kg ha^{-1}) (7 = 6-5)
T_1	248.72	0	167.41	167.41	248.72	81.31	86.1
T_2	248.72	60	207.1	267.1	308.72	41.62	165.48
T_3	248.72	60	209.34	269.34	308.72	39.38	169.96
T_4	248.72	60	220.23	280.23	308.72	28.49	191.74
T_5	248.72	60	213.86	273.86	308.72	34.86	179
T_6	248.72	60	185.35	245.35	308.72	63.37	121.98
T_7	248.72	60	191.33	251.33	308.72	57.39	133.94
T_8	248.72	60	183.69	243.69	308.72	65.03	118.66
T_9	248.72	60	207.56	267.56	308.72	41.16	166.4
T_{10}	248.72	60	199.08	259.08	308.72	49.64	149.44
SEm (±)	-	-	-	-	-	2.87	-
CD at 5%	-	-	-	-	-	8.54	-

T_1 - Control(no fertilizer), T_2 - 100% RDF, T_3 - 100% RDF + Soil applications of Soligro granule at Basal, T_4 - 100% RDF + Soil application of Soligro granule at Basal and 30 DAT, T_5 - 100% RDF + Soil application of Soligro granule at 30 DAT and 60 DAT, T_6 - 100% RDF + Foliar applications of Optein liquid at 30 DAT, T_7 - 100% RDF + Foliar applications of Optein liquid at 30 DAT and 60 DAT, T_8 - 100% RDF + Foliar applications of Biozyme liquid at 60 DAT, T_9 - 100% RDF + Foliar applications of Biozyme liquid and vermiwash at 60 DAT, T_{10} - 100% RDF + Foliar applications of vermiwash at 60 DAT.

there is no external nutrient application.

In case of phosphorus availability in the soil, it was found to vary from 25.81 to 45.26 kg ha^{-1} with a variation of 75.35%. The treatment T_4 was recorded with the highest available phosphorus followed by treatment T_5 and T_3 and the lowest available phosphorus recorded in the control plot (T_1).

The available potassium in the soil varied from 167.41 to 220.23 kg ha^{-1} which was having a variation of 31.55 %. The highest available potassium value was observed from the T_4 (220.23 kg ha^{-1}) followed by treatment (213.86 kg ha^{-1}) and the lowest data was obtained in the control plot without any fertilizer treatment (167.41 kg ha^{-1}).

T_4 treatment showed the highest value of available N, P_2O_5, and K_2O as maybe because of their capability to improve soil properties and structure that lead to the enhancement of soil fertility (Ayuso et al., 1996) Sharif, Khattak, and Sarir (2002). The granular form of seaweed extract promotes the plant root and shoots growth and increases the activities of microbes in the soil (Prakash 2009) which in turn increase the soil availability of nutrient. The moisture-holding capacity, as well as nutrient status in soil, increased with the application of seaweed extract (Mishra, 2013; Saha et al., 2013). It acts as a soil conditioner for several important crops due to their microbial substances and soil improvement ability (Thirumaran et al., 2006, 2009a and 2009b).

Fertilizers derived from seaweeds (Fucus, Laminaria¸ Ascophyllum, Sargassum etc.) are biodegradable, non-toxic, non-polluting and non-hazardous to human, farm animals and birds (Dhargalkar and Pereira, 2005).

Effect of different bio-stimulants on uptake of nutrients by crop

Seaweed extracts along with RDF had an influencing role in the uptake of N, P, and K in rice crop. In comparison with others, it was found that at 30 DAT and 60 DAT the application of 100% RDF + Foliar applications of optein liquid, the nitrogen, phosphorus, and potassium uptake by crop were significantly higher with comparison to other. The control plot was recorded with the lowest nitrogen, phosphorus and potassium uptake by the crop. These results are closely similar to the findings of Pramanick et al. (2013), who noted that the foliar application of seaweed sap improved the nutrient uptake capacity of crops. When the treated plants were compared to non-treated ones it was seen that the presence of marine bioactive substances in seaweed sap improves stomata uptake efficiency in the former one (Mancuso et al., 2006). This result also was probably due to larger root mass production enabling the plants to acquire more nutrients from larger soil volume (Barison and Uphoff, 2011).

The balance sheet of N, P, and K influenced by different bio-stimulants

The balance sheet of N, P, and K was worked out at harvest and presented in Table 5, Table 6 and Table 7. It has been observed that the depletion of nitrogen (N) was caused due to application of RDF (T_2). Under the T_6 treatment (3.98 kg ha^{-1}) minimum build-up of nitrogen was obtained. It has been observed that the maximum build-up of nitrogen (N) (23.99 kg ha^{-1}) was achieved by the application of RDF + soligro granules at basal and 30 DAS (T_4) followed by T_7 and T_9 treatment. From the data of phosphorus (P), T_2 treatment (-35.57) showed the highest depletion, however, treatment of RDF + soligro granule at basal and 30 DAS (T_4) recorded the minimum depletion (-24.82). Under any treatments, potassium (K) depletion did not occur. The highest build-up of potassium balance (46.5) was observed under T_4 treatment followed by T_5 and T_3, whereas the minimum build-up balance (86.1) was recorded from T_1 treatment (control).

Microbial status

A different formulation of seaweed extract was seen to affect the microbial population in the post-harvest soil. Before transplanting, initially the population of fungi, bacteria and actinomycetes were 42.4 x 10^3, 3.46 x 10^5, and 4.12 x 10^5 CFU gram^{-1} respectively (Table 8). Among the treatments, T_5 registered a higher microbial population of 51 x 10^5 of bacteria, 45.6 x 10^3 of fungi, and 5.6 x 10^5 of actinomycetes per gram of soil after harvesting the crop, respectively. It was found that soil physical properties (soil moisture and structural stability), and soil microbial mediated processes are consequently benefited by the application of organic amendments (Liu, 2005). This might be due to the gradual mineralization of organic matter, resulting in the release of nutrients at the optimum level for the better proliferation of soil micro-flora (Mahajan et al., 2007; Selvi et al., 2005). The positive and significant relationship of organic carbon with micro-organisms indicates that the high organic matter build-up with the regular addition of crop residue increases the fungal population of soil (Mahajan et al., 2007). Enhanced proliferation of the fungal population in the soil is

Table 8. Effect of different bio-stimulants on the microbial population of soil after harvest of rice pooled of two year data 2017-18 and 2018-19.

Treatment	Bacteria (10^5) (CFU)			Fungi (10^3) (CFU)			Actinomycetes (10^5) (CFU)		
	Initial	Flowering	After harvesting	Initial	Flowering	After harvesting	Initial	Flowering	After harvesting
T_1	3.46	43	33	42.4	63	28.2	4.12	66	3.8
T_2	3.46	51	39	42.4	68	34.5	4.12	78	4.2
T_3	3.46	72	45	42.4	85	38.2	4.12	87	5.2
T_4	3.46	75	48	42.4	96	44.32	4.12	98	5.4
T_5	3.46	79	51	42.4	95	45.6	4.12	95	5.6
T_6	3.46	65	43	42.4	82	37.48	4.12	82	4.8
T_7	3.46	68	38	42.4	83	42.1	4.12	79	4.5
T_8	3.46	57	40	42.4	84.5	37.5	4.12	83	4.9
T_9	3.46	55	34	42.2	91	36.89	4.12	89	4.6
T_{10}	3.46	59	36	42.4	79	35	4.12	90	4.7

T_1 - Control (no fertilizer), T_2 - 100% RDF, T_3 - 100% RDF + Soil applications of Soligro granule at Basal, T_4 - 100% RDF + Soil application of Soligro granule at Basal and 30 DAT, T_5 - 100% RDF + Soil application of Soligro granule at 30 DAT and 60 DAT, T_6 - 100% RDF + Foliar applications of Optein liquid at 30 DAT, T_7 - 100% RDF + Foliar applications of Optein liquid at 30 DAT and 60 DAT, T_8 - 100% RDF + Foliar applications of Biozyme liquid at 60 DAT, T_9 - 100% RDF + Foliar applications of Biozyme liquid and vermiwash at 60 DAT, T_{10} - 100% RDF + Foliar applications of vermiwash at 60 DAT.

encouraged by a cellulolytic micro-organism that degraded plant residues in the soil. The actinomycetes population has also been found to increase due to the application of inorganic fertilizer and organic manure. This might be due to the activity of various soil micro-organisms, which manifest the gradual exhaustion of assimilable organic nutrients from compost and crop residue. The results of the present findings are in agreement with the finding of Mahajan et al. (2007). The least count of bacteria (33 x 105), fungi (28.2 x 103), and actinomycetes (3.8 x 105) CFU g^{-1} of soil are obtained from the control plot (T_1). A favourable microbial activity and enhanced soil microbial biomass (SMB) including total bacterial population can be obtained by the addition of organic inputs because of the proper supply of organic carbon and improved soil physical properties (Kenchaiah, 1997).

CONCLUSION

Based on the study, it may be concluded that to enhance the productivity, maintain and sustain the soil health in rice cultivation during *boro* season in the New Alluvial Zone of West Bengal application of 100% RDF + Soligro granules at basal and 30 DAT could be recommended.

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System based phosphorus management improved the productivity, profitability and nutrient uptake of rainfed rice (*Oryza sativa* L.) - greengram (*Vigna radiata* L.) cropping system

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ABSTRACT

The effect of system based phosphorus management on crop productivity, profitability and nutrient uptake of rainfed rice-greengram cropping system was studied under medium land situation at ICAR-NRRI, Cuttack, Odisha. The experiment was carried out in both kharif and rabi season of the years 2019-20 and 2020-21. The experiment was laid out in a split plot design with four nutrient management practices in rice viz. recommended dose of fertilizer (RDF), RDF + 25% additional phosphorus(P) through FYM, RDF + 25% additional phosphorus(P) through fertilizer and 75% of RDF (RDF_{75}) in main plots and five nutrient management practices in greengram viz. Control, RDF, RDF + PSB inoculation (RDF+ PSB), RDF + Foliar spray of 2% DAP (RDF + FS) and RDF + PSB inoculation + Foliar spray of 2% DAP (RDF + PSB + FS) in subplots and replicated thrice. Effect of system based phosphorus management had significant effect on productivity, profitability and nutrient uptake by the system. Application of 25 % additional phosphorous to rice through fertilizer improved the rice equivalent yield (REY) and P uptake of the rice - greengram system by 6.6 and 7.1% compared to the application of recommended dose of phosphorus to rice. The same treatment also resulted in significantly highest net returns and B:C ratio from the cropping system compared to all other treatments including application of 25% additional phosphorus through FYM. However, application of PSB and foliar spray of 2% DAP along with recommended dose of phosphorus to greengram improved the REY and P uptake of the system to the tune of 23.4 and 21.3%, respectively, compared to non fertilized plots where as 6.2 and 9.6%, respectively, over recommended dose of P to greengram with highest net return and B:C ratio. Further, application of 25% additional phosphorus through FYM or fertilizer along with RDF to rice followed by application of PSB and foliar spray of 2% DAP along with RDF to greengram produced the highest grain and straw yield, nutrient uptake, gross return, net return and B:C ratio.

Key words: *Rice, greengram, phosphorus management*

INTRODUCTION

Rice-greengram cropping system is one of the prominent cropping systems in Eastern India especially under rainfed situation. Greengram is also a major pulse crop of Odisha. It is a short duration crop, tolerant to photoperiod, thermal variations and low soil moisture condition: thus has scope for expansion in time and space during *rabi* season. It provides additional income, improves soil fertility and ensures efficient land utilization. It is grown both in *kharif* and *rabi* season covering an area of 8.69 lakh hectare of which, *rabi* greengram grown mostly after rice occupies 6.44 lakh hectare with total production of 4.14 lakh tonnes. However, the productivity is low *i.e.*, 477 kg ha^{-1} and is lesser compared to national average of 497 kg ha^{-1} and very less to 667 kg ha^{-1} in states like Punjab (IIPR,

2019) leading to low horizontal expansion of the system in the state. Being a phosphorus demanding crop, it requires phosphorus as much as requirement of rice in rainfed condition. Neglected phosphorus fertilization in dry season is one of the reasons of lower yield. Besides, greengram crop is removed from field after harvesting.

Phosphorus is an important essential nutrient. It channels energy for all biochemical processes in plant cell. It promotes better root growth, encourages effective tillering and stimulates early flowering, maturity and good grain development (Amanullah and Inamullah, 2016). Further, enhanced response to applied nitrogen could be realized only when adequate amount of phosphorus is available. Therefore, phosphorus availability from soils to the plant is the key to sustain higher yields. Plant utilizes less amounts of phosphatic fertilizers that are applied and the remaining portion is rapidly converted in to insoluble complexes in the soil (Vassilev and Vassileva, 2003). Slow mobility of added phosphorus and its fixation results in low crop recoveries in the order of 20-25%. The phosphorus requirement of second crop can be met through application of additional phosphorus to *kharif* crop since the quantity of phosphorus absorbed by a crop from fertilizers is usually quite low. However, the phosphatic fertilizers have residual value, and the succeeding crop gets benefited from this residual phosphorus. A large share of phosphorus remaining in soil after the first crop is not fixed but is indeed available to the subsequent crops (Nichols et al., 2012). The dynamics of phosphorus should be considered in a cropping system rather than a single crop for efficient and judicious management of phosphorus. Integrated approach of providing phosphorus though organic and inorganic source along with diversification of methods of application like inoculation of seed with Phosphate Solubilizing Bacteria (PSB) and application of phosphorus through foliar application in form of 2% DAP has the potential to increase the system productivity and profitability since PSB solubilize the insoluble phosphorus and increases its availability in the soil and in turn can improve the overall phosphate use efficiency (Ghosh and Joseph, 2008) while foliar nutrition enhance easy and rapid assimilation of nutrients. Keeping these in view, the experiment was conducted to study the effect of sequential phosphorus management on productivity, nutrient uptake, and economics of rice - greengram cropping system.

MATERIALS AND METHODS

A field experiment was carried out at research farm, ICAR-National Rice Research Institute, Cuttack, Odisha, (20.45^o N, 85.93^o E and 24 m above sea level) during both *kharif* and *rabi* seasons in 2019-20 and 2020-21 to assess the effect of system based phosphorus management in rainfed rice (*Oryza sativa* L.) - greengram (*Vigna radiata* L.) cropping system. The general climate of this region is dry moist, sub humid and the region receives 1300 - 1500 mm mostly during June-October (*kharif* season). The experiment was laid out in split plot design with four nutrient management methods in rice i.e. recommended dose of fertilizer (RDF), RDF + 25% additional phosphorus of RDF through FYM, RDF + 25% additional phosphorus of RDF through Fertilizer and 75% RDF as main plot and five nutrient management methods in greengram i.e. Control, RDF, RDF + PSB inoculation, RDF + Foliar spray of 2% DAP at flowering and RDF + PSB inoculation + Foliar spray of 2% DAP at flowering as sub plots and replicated thrice. The rice variety 'Sahbhagidhan' and greengram variety 'Virat' were used in the experiment. The field was ploughed twice with power tiller. Rice was transplanted in *kharif* season at the spacing of 15 cm x 15 cm while that of spacing in greengram was 30 cm x 10 cm. The nutrient management in both the crop was done according to the treatment with RDF of 80:40:40 and 20:40:20 kg N : P_2O_5 : K_2O ha^{-1} in rice and greengram, respectively. Additional 25 % phosphorus (10 kg P_2O_5) was applied through FYM in the second treatment and through DAP fertilizer in the third treatment to rice. The quantity of FYM was calculated by considering its phosphorus and moisture content and was applied as basal in both years. In the first year, the moisture and P content of FYM were 18.7% and 0.194%, while in the second year the same were 20.0% and 0.197%, respectively. Phosphorus was applied through DAP. Additional phosphorus through fertilizer was applied as basal along with RDF. The nitrogen and potash associated with the FYM and nitrogen with DAP was adjusted by deducting from RDF.

Harvesting of both the crops was done manually by taking sample from unit area. The economics of individual crops were calculated taking the incurred cost and total return into account. The nutrient (N, P & K) uptake of individual crop was calculated by determining the nutrient content in grain and straw multiplied by the grain and straw yield respectively. The system grain and straw yield in terms of rice equivalent yield was calculated adding yield of rice with rice equivalent yield of greengram. Similarly, the system economics and total nutrient uptake by the system were calculated adding the economic parameters and nutrient uptake by both the crops and were statistically analysed in split plot design as described by Gomez and Gomez (1984).

RESULT AND DISCUSSION

System yield

Nutrient management in rice and greengram had significant effect on system grain yield in both the cropping years (Table 1). Among the main plot treatments, the highest grain yield (7.46, 7.56 & 7.51 t ha^{-1}) was recorded under the RDF+25% additional phosphorus through FYM, which was closely followed by RDF + 25% additional phosphorus through fertilizer. Application of additional phosphorus through either FYM or fertilizer recorded significantly higher yield over RDF during both the years. The system grain yield of RDF treatment was found to be superior over RDF_{75} that recorded the lowest yield (6.42, 6.20 & 6.31 t ha^{-1}). Application of additional phosphorus increased the number of effective tillers and percentage of filled grains resulting in higher yield of rice from unit area. Similarly, the residual effect of additional phosphorus was proved to be effective in increasing yield of greengram especially under control by encouraging increased root length, number of pods plant-1 and number of seed pod^{-1}. The higher system yield with application of additional phosphorus recorded higher yields in rice and greengram. The results obtained in the present study corroborate the findings of Prasad and Rana (2000), Gobarah et al. (2006), Hasan and Ismail (2016).

Among different nutrient management treatments in greengram, the highest grain yield (7.54, 7.64 and 7.60 t ha^{-1}) was recorded under RDF + PSB inoculation + Foliar spray of 2% DAP which was significantly higher than all other treatments during both the years. Neither PSB inoculation nor foliar spray of 2% DAP improved the yield individually but their combination recorded significant yield difference over RDF indicating a synergistic effect of the above treatments. RDF recorded significantly higher yield compared to control, which recorded the lowest yield (6.43, 5.89 and 6.16 t ha^{-1}). The highest system yields under RDF + PSB inoculation + Foliar spray of 2% DAP in greengram attributed to increasing yield of greengram. PSB helped in phosphorus solubilisation in

Table 1. Effect of system based phosphorus management on yield of rice-greengram cropping system

Treatments	System grain yield (t ha^{-1})			System straw yield (t ha^{-1})		
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
Nutrient management in rice						
RDF	7.04	6.96	7.00	10.52	10.35	10.43
RDF + 25% P(FYM)	7.46	7.56	7.51	11.16	11.04	11.10
RDF + 25% P (FERT)	7.41	7.52	7.46	11.00	10.91	10.96
RDF_{75}	6.42	6.20	6.31	9.79	9.47	9.63
SEm ±	0.08	0.09	0.04	0.11	0.15	0.08
CD	0.29	0.31	0.12	0.39	0.53	0.27
Nutrient management in greengram						
Control	6.43	5.89	6.16	9.42	8.82	9.12
RDF	7.10	7.22	7.16	10.57	10.55	10.56
RDF + PSB	7.18	7.27	7.22	10.91	10.79	10.85
RDF + FS	7.17	7.26	7.21	10.82	10.85	10.83
RDF + PSB + FS	7.54	7.66	7.60	11.37	11.21	11.29
SEm ±	0.11	0.15	0.10	0.33	0.44	0.31
CD	0.32	0.42	0.29	0.96	1.27	0.89
Interaction	NS	NS	NS	NS	NS	NS

RDF: Recommended Doses of Fertilizer, FYM: Farm Yard Manure, FERT: Fertilizer, PSB: Phosphorus Solubilizing Bacteria, FS: Foliar sprayof 2% DAP.

soil while foliar spray of 2% DAP helped in providing nutrient during the critical period of growth. Similar findings in rice pulse cropping system were also reported by Kausale et al. (2009), Singh and Singh (2012) and Singh et al. (2013).

Straw yield of system was varied significantly with respect to nutrient management in rice and green gram (Table 1). Among the main plot treatments, highest straw yield (11.10 t ha^{-1}) was recorded under the treatment, RDF + 25% additional phosphorus through FYM which was statistically at par with RDF + 25% additional phosphorus through fertilizer. In first year, 25% additional phosphorus when applied through FYM recorded significantly higher straw yield over RDF, however in second year and when pooled over two years, additional phosphorus irrespective of source recorded significantly higher yield over RDF which itself was superior over RDF_{75}. The lowest yield (9.63 t ha^{-1}) was recorded in RDF_{75}.This might be due to the higher availability of phosphorus in organic form, which was compensated in second year due to phosphorus build up in soil. These findings were similar to the findings of Kumar et al. (2016) and Cong (2017).

Among the sub plot treatments, highest straw yield (11.29 t ha^{-1}) was recorded under the treatment RDF + PSB inoculation + 2% DAP foliar spray which was statistically at par with all other treatments except control which, recorded the lowest straw yield (9.12 t ha^{-1}) PSB and foliar application of 2% DAP either individually or collectively had no significant effect over RDF. However, straw yield under RDF was significantly higher over RDF_{75}. Similar findings in rice pulse cropping system were also reported by Panwar et al. (2002).

System economics

Critical analysis of result (Table 2) showed that system based phosphorus management had significant effect on system economics. The highest gross return (Rs. 158444 /-) was recorded under RDF + 25% additional phosphorus through FYM which was at par with RDF + 25% additional phosphorus through fertilizer. However, when pooled over two years, highest net return (Rs. 98701/-) of both the years was recorded under RDF + 25% additional phosphorus through fertilizer which was at par with RDF + 25% additional phosphorus through FYM. Application of 25% additional phosphorus irrespective of sources recorded significantly higher gross and net return as compared to RDF which itself was significantly higher over RDF_{75}. The highest B:C ratio was recorded under RDF + 25% additional phosphorus through fertilizer which

Table 2. Effect of system based phosphorus management on economics of rice-greengram cropping system.

Treatments	Gross return (Rs.)			Cost of Cultivation (Rs.)			Net returns (Rs.)			B:C Ratio		
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
Nutrient management in rice												
RDF	148901	147096	147998	58206	58206	58206	90695	88890	89792	1.56	1.52	1.54
RDF + 25% P (FYM)	157669	159219	158444	61026	61026	61026	96643	98193	97418	1.58	1.61	1.59
RDF + 25% P (FERT.)	156407	158327	157367	58666	58666	58666	97741	99661	98701	1.66	1.70	1.68
RDF_{75}	136159	131394	133776	57051	57051	57051	79108	74343	76725	1.38	1.30	1.34
SEm ±	1611	1621	615	-	-	-	1611	1621	615	0.03	0.03	0.01
CD	5576	5610	2129	-	-	-	5576	5610	2129	0.09	0.10	0.04
Nutrient management in greengram												
Control	135485	124575	130030	55911	55911	55911	79574	68664	74119	1.42	1.22	1.32
RDF	149970	152163	151067	58981	58981	58981	90989	93182	92086	1.54	1.58	1.56
RDF + PSB	152112	153542	152827	59131	59131	59131	92981	94411	93696	1.57	1.59	1.58
RDF + FS	151718	153385	152551	59756	59756	59756	91961	93629	92795	1.54	1.57	1.55
RDF + PSB + FS	159635	161379	160507	59906	59906	59906	99729	101473	100601	1.66	1.69	1.68
SEm ±	2039	2556	1800	-	-	-	2039	2554	1801	0.03	0.04	0.03
CD	5875	7356	5188	-	-	-	NS	7356	5188	NS	0.13	0.09
Interaction	NS	NS	NS	-	-	-	NS	NS	NS	NS	NS	NS

RDF : Recommended doses of fertilizer, FYM : Farm yard manure, FERT : Fertilizer, PSB : Phosphorus solubilizing bacteria, FS: Foliar spray of 2% DAP

Table 3. Effect of system based phosphorus management on nutrient uptake by rice-greengram cropping system.

Treatments	N (kg ha^{-1})			P (kg ha^{-1})			K (kg ha^{-1})		
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
Nutrient management in rice									
RDF	122.32	121.41	121.87	33.21	32.12	32.66	124.73	125.72	125.23
RDF + 25% P(FYM)	130.73	131.73	131.23	35.14	35.27	35.20	130.88	136.63	133.75
RDF + 25% P (FERT)	128.77	130.85	129.81	34.80	35.13	34.97	129.62	134.83	132.23
RDF_{75}	110.69	108.54	109.61	29.86	28.77	29.32	114.30	112.86	113.58
SEm ±	1.75	1.35	1.33	0.54	0.46	0.35	1.44	1.15	1.21
CD	6.05	4.67	4.62	1.86	1.59	1.21	5.0	4.0	4.17
Nutrient management in greengram									
Control	109.46	101.42	105.44	31.26	27.39	29.32	115.07	105.13	110.10
RDF	123.24	124.33	123.78	32.20	32.70	32.45	123.71	130.88	127.29
RDF + PSB	127.17	127.05	127.11	34.19	33.55	33.87	128.08	131.05	129.57
RDF + FS	125.52	127.14	126.33	33.48	34.47	33.97	126.85	133.31	129.79
RDF + PSB + FS	130.24	135.73	132.98	35.12	36.01	35.57	131.29	137.18	134.24
SEm ±	2.16	1.97	1.59	0.77	0.65	0.52	3.54	3.71	2.45
CD	6.21	5.67	4.58	2.20	1.87	1.49	10.19	0.68	7.04
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS

RDF: Recommended doses of fertilizer, FYM: Farm yard manure, FERT: Fertilizer, PSB: Phosphorus solubilizing bacteria, FS: Foliar spray of 2% DAP.

was significantly higher over all other treatments. Though highest gross return was recorded under RDF + 25% additional phosphorus through FYM, due to higher cost of FYM, highest net return and B:C ratio was recorded under RDF + 25% additional phosphorus through fertilizer.

Among the nutrient management practices of greengram, highest gross return (Rs. 160507/-), net return (Rs. 100601/-) and B:C ratio (1.68) were recorded under the treatment RDF+ PSB inoculation + 2% DAP foliar spray, which was significantly higher than all other treatments. The lowest net return (Rs. 74119/-) and B:C ratio (1.32) were recorded under control. Similar findings were also reported by Kumar et al. (2008). The interaction effect of nutrient management in rice and greengram on economics of system was not significant.

System nutrient uptake

Highest nutrient (N, P and K) uptake was recorded under RDF + 25% additional phosphorus through FYM which was closely followed by RDF + 25% additional phosphorus through fertilizer but significantly higher than RDF and RDF_{75} (Table 3). The highest N, P and K uptake by the system was 131.23, 35.27 and 133.75 kg ha^{-1}, respectively. The highest nutrient uptake under the treatments applied with 25% additional phosphorus might be due to effect of phosphorus on root development and nutrient mobilisation, increase in system yield where as lowest nutrient uptake under RDF_{75} was due to low system yield and lower nutrient content of plant owing to lower fertilizer application.

Among the sub plot treatments, the highest nutrient uptake (132.98, 35.57 & 134.24 kg ha^{-1} of N, P and K, respectively) was recorded under the treatment RDF + PSB inoculation + 2% DAP foliar spray. With respect to N and P, the combine effect of PSB inoculation and foliar spray of 2% DAP was significantly higher over RDF. However with respect K, it did not prove its superiority. Nutrients uptake under RDF was significantly higher over control. Similar findings were also reported in rice - pulse cropping system by Kausale et al. (2009).

CONCLUSION

In rice - greengram cropping system, the greengram crop is grown without fertilization and removed from field after harvesting while rice grown under either fully fertilized or sub optimal fertilization condition in rainfed situations of Eastern India. Application of 25% additional phosphorus through FYM or inorganic fertilizer to rice crop improved the phosphorus uptake and rice equivalent yield of rice - greengram cropping system.

However, the net returns and B:C ratio was higher when the additional phosphorus was supplied through inorganic fertilizers instead of FYM. Further, application of phosphate solubilising bacteria and foliar spraying of 2% DAP at flowering with recommended dose of phosphorus to greengram also improved the system yield. This treatment also recorded highest net returns and B:C ratio. It is thus concluded to apply 25% additional phosphorus as inorganic fertilizer to rice and use phosphate solubilising bacteria along with recommended dose of phosphorus and 2% DAP spray at flowering to greengram crop for attaining higher yield and remuneration from rice - greengram cropping system.

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Effect of drip irrigation regimes and nitrogen levels on growth, yield and economics of aerobic rice (*Oryza sativa* L.)

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ABSTRACT

Water supply to agriculture especially rice will be affected in the future because of climate change and increased demand of water for non-agricultural use. To sustain rice production, focus should be on water saving rice production systems such as aerobic rice, which may further reduce water requirement when combined with drip irrigation. Hence, a field experiment to study the influence of drip irrigation regimes and nitrogen levels on growth, yield and economics of aerobic rice was conducted at Tirupati, Andhra Pradesh, during the rabi seasons of 2019-20 and 2020-21. Four main plot treatments consisting of irrigation regimes based on pan evaporation i.e., drip irrigation at 1.25 Epan, 1.50 Epan, 1.75 Epan, 2.00 Epan and four sub plot treatments comprising of four doses of nitrogen i.e., 75 % RDN (90 kg N ha^{-1}), 100 % RDN (120 kg N ha^{-1}), 125 % RDN (150 kg N ha^{-1}) and 150 % RDN (180 kg N ha^{-1}) were tested in split plot design replicated thrice. Significantly higher plant height, number of tillers, yield attributes, grain yield, straw yield and gross returns were recorded with drip irrigation regime of 2.0 Epan over other irrigation regimes, but was comparable with drip irrigation at 1.75 Epan. While, higher net returns and B:C ratio were recorded with drip irrigation regime of 1.75 Epan which was at par with 2.0 Epan and 1.5 Epan. Aerobic rice grown with 180 kg N ha^{-1} proved to be superior with respect to plant height, number of tillers m^{-2}, panicle weight, grain yield, straw yield, gross returns and net returns which was however comparable with 150 kg N ha^{-1} in case of panicle number, filled grains per panicle, test weight and B:C ratio. Among the interaction combinations, drip irrigation regime of 2.0 Epan along with 180 kg N ha^{-1} resulted in superior plant height, tillers m^{-2}, yield attributes, grain yield, straw yield, gross returns, net returns and B:C ratio which was statistically at par with drip irrigation regime of 1.75 Epan along with 180 kg N ha^{-1} except in case of tiller number.

Key words: *Aerobic rice, drip irrigation regimes, nitrogen levels, yield, economics*

INTRODUCTION

Rice is the staple food for three-fourths of the Indian population and is cultivated under varied climatic and soil conditions and diverse ecologies. Traditional puddled transplanted rice farming uses around 2000 mm of water and require 3000-5000 litres of water to produce 1 kg of grain (IRRI, 2001). It is labour, water, and energy intensive and less lucrative (Kumar and Ladha, 2011). Water supply to agriculture may be impacted due to increased demand for domestic, municipal, industrial, and environmental purposes in the near future. Shortage of water for irrigation may affect the rice production severely, particularly in the light of climate change (Vijayakumar et al., 2022). The increasing water scarcity threatens the sustainability of rice production systems. In order to ensure India's food security, it's critical to boost rice output, especially under the limited water supply (Goud et al., 2022). Therefore, a more efficient method of rice cultivation with higher water productivity is the need of hour. In this direction, water saving rice production system such as aerobic rice can drastically reduce the unproductive water out-flows and increase water-use efficiency (WUE) (Vijayakumar et al., 2018). The yields expected from aerobic rice system are lower than those obtained under lowland flooded conditions, but double or triple than that of upland conditions. Rice plants under aerobic system undergo several cycles of wetting and drying conditions affecting the final crop yield. Growing aerobic rice under drip irrigation meets the water requirement as per the crop need and improve water use efficiency (Parthasarathi et al., 2018).

Despite the fact that nitrogen accounts for more than 70% of total fertiliser (N + P + K) applied to rice, research over the last three decades has clearly demonstrated that crop nitrogen fertiliser utilisation is generally low, with less than 40% of applied nitrogen being used by the crop (Cassman et al., 1998). Improving nitrogen use efficiency of rice is a critical goal in sustainable production systems. The relative efficiency of rice in nitrogen fertilizer use is directly related to water management, crop growth stage at nitrogen application, nitrogen source and the chemical transformations that occur after nitrogen application in the soil. Water deficit during crop growth may limit nitrogen movement in the soil and may reduce its uptake and use efficiency (Benjamin et al., 1997). Conversely, excessive irrigation may cause leaching and denitrification and consequently lower nitrogen use efficiency (Lehrsch et al., 2001). As the nitrogen uptake and use efficiency varies with irrigation regime, there is a need to standardize the nitrogen dose for optimum yield of aerobic rice at different drip irrigation regimes.

MATERIAL AND METHODS

A two-year field experiment was conducted during the *rabi* seasons of 2019-20 and 2020-21 at the wetland farm of S.V. Agricultural College, Tirupati of Acharya N.G. Ranga Agricultural University, which is located at 13.5°N latitude, 79.3°E longitude, and an altitude of 189.2m above mean sea level in Andhra Pradesh's Southern Agro-climatic zone. During the crop growth period, a total rainfall of 221.6 mm and 322.0 mm was received during 2019-20 and 2020-21, respectively. The weekly mean maximum temperature during the crop growth period ranged from 27.3 to 35.0°C during 2019-20 and from 27.3 to 39.4°C during 2020-21, while the weekly mean minimum temperature ranged from 16.3 to 23.4°C during 2019-20 and from 14.9°C to 25.4°C during 2020-21. The weekly mean relative humidity varied from 49.0 to 85.0 per cent during 2019-20 and from 45.6 to 87.2 per cent during 2020-21. The weekly mean evaporation ranged from 3.1 to 7.8 mm day^{-1} during 2019-20 and from 1.4 to 7.9 mm day^{-1} during 2020-21. The weekly mean bright sunshine hours ranged from 2.4 to 9.7 hours day^{-1} during 2019-20 and from 1.6 to 9.4 hours day^{-1} during 2020-21. The soil of the experimental field (before starting of the experiment) was sandy clay loam in texture, slightly alkaline in reaction (pH 7.7), low in organic carbon (0.40), available nitrogen (75.0 kg ha^{-1}) and P_2O_5 (16.2 kg ha^{-1}) and medium in available K_2O (314.9 kg ha^{-1}).

The field experiment was laid out in split plot design with three replications. The treatments include four main plots consisting of irrigation regimes based on pan evaporation *i.e.*, Drip irrigation at 1.25 Epan, 1.50 Epan, 1.75 Epan, 2.00 Epan and four sub plots comprising of four doses of nitrogen *i.e.*, 75 % RDN (90 kg N ha^{-1}), 100 % RDN (120 kg N ha^{-1}), 125 % RDN (150 kg N ha^{-1}) and 150 % RDN (180 kg N ha^{-1}). The crop was sown by dibbling dry seeds manually on November 12th during the first year and on November 19th during the second year of experiment, following inter-row spacing of 20 cm and intra-row spacing of 10 cm. A popular fine rice cultivar, NLR-34449 (Nellore Mahsuri) was used. The recommended dose of fertilizer (RDF) was 120-60-40 kg NPK ha^{-1}. Nitrogen was applied as urea in three equal splits at 15 DAS, tillering and panicle initiation stages. Entire recommended phosphorus as SSP was applied as basal and potassium as MOP was applied in two splits, 50 per cent as basal and the remaining 50 per cent at panicle initiation. In addition, $ZnSO_4$ and $FeSO_4$ @ 25 kg ha^{-1} were applied before sowing. All the plots were sprayed twice with chelated form of iron and zinc micronutrients at 20 and 40 DAS to control micronutrient deficiency. Crop was supplied with water from borewell through surface drip irrigation using 7.5 HP motor. The water from main line was supplied to sub mains (40 mm), which was regulated by control valves. Sub mains were fitted with lateral drip lines of 16 mm diameter through grommet, start connector and joiners. Laterals were installed at a spacing of 60 cm serving three rows of crop. The water from laterals was delivered through in-line emitters spaced at 40 cm with a discharge of 4 l hr^{-1}. Two common irrigations were scheduled until 20 days after sowing to all the experimental plots to ensure uniform germination and establishment. Irrigation was given on every alternate day based on cumulative pan evaporation for the previous 2 days after multiplying with pan coefficient of 0.7. The required quantity of water for different irrigation treatments was supplied by measuring with water meter. The quantity of water was calculated as follows

Volume (l ha^{-1}) = Epan x Kpan x Area (m^2)

Where Epan = Pan evaporation

Kpan = Pan coefficient (0.70)

All other crop management practices were carried out as per the standard recommendation. Plant height was recorded from five tagged hills by measuring the length from the basal node of the plant to the base of the top most leaf at 30, 60, 90 DAS and up to base of panicle at harvest. In each net plot, one square metre area was marked and the number of tillers were counted. The straw from net plot area was harvested manually at ground level and dried for a week. After sun drying, the net plot grain (at 14% moisture) and straw yields were recorded and expressed in kg ha^{-1}. The cost of cultivation (COC) was calculated based on the expenditure on inputs at the prevailing market price and was presented as kg ha^{-1}. Similarly, gross returns (GR) were calculated by multiplying the grain and straw yields with their respective prevailing market prices and expressed as Rs. ha^{-1}.

Gross returns (Rs. ha^{-1}) = [Grain yield (kg ha^{-1}) × Cost of one kg grain] + [Straw yield (kg ha^{-1}) × Cost of one kg straw]

Net returns were calculated by subtracting the cost of cultivation from the gross returns and presented as Rs. ha^{-1}.

Net returns (Rs. ha^{-1}) = Gross returns (Rs. ha^{-1}) - Cost of cultivation (Rs. ha^{-1})

The benefit : cost ratio was worked out by using the following formula.

B:C ratio = Gross returns (Rs. ha^{-1}) / (Cost of cultivation (Rs. ha^{-1})

During the study period the cost of paddy was 18.15 Rs. kg^{-1} during 2019-20 and 18.68 Rs. kg^{-1} during 2020-21, while the straw cost was 3 Rs. kg^{-1}.

The data recorded on various parameters was statistically analyzed by the method of analysis of variance as per the procedure outlined for split plot design given by Gomez and Gomez (1984). Statistical significance was tested with 'F' value at 0.05 level of probability and the critical difference was worked out where ever the effects were significant.

RESULTS AND DISCUSSION

Effect of drip irrigation regimes and nitrogen levels on growth parameters

Plant height and number of tillers

Drip irrigation regime of 2.0 Epan recorded significantly higher plant height and tiller number m^{-2} over lower irrigation regimes, which was however comparable with 1.75 Epan. Increasing irrigation regime from 1.25 Epan to 1.5 Epan, 1.75 Epan and 2.0 Epan resulted in an increase in plant height by 6.6 %, 9.1 % and 10.0 % and tiller number by 8.1%, 11.0% and 11.8%, respectively (Table 1). Scheduling drip irrigation at 2.0 Epan improved plant height and number of tillers by 3.2 and 3.4 %, respectively over drip irrigation regime of 1.5 Epan. Maximum plant height at higher irrigation regimes over lower regimes was due to the supply of adequate moisture over entire crop period which might have enhanced cell division and elongation activities by improving plant water status and nutrient uptake, leading to an increase in stem internodal length. These findings are consistent with the work of Bhardwaj et al. (2018) and Natarajan et al. (2020). The higher number of tillers m^{-2} with the drip irrigation regime of 2.0 Epan was attributed to supply of adequate moisture in the root zone matching the crop demand resulting in improved root growth, nutrient absorption, translocation and assimilation of nutrients leading to luxurious vegetative growth through supply of more photosynthates. On the other hand, crop performance was poor with irrigation regime of 1.25 Epan in relation to tiller number, owing to the development of water stress due to an insufficient supply of moisture. Similar results were reported by Duary and Pramanik (2019) and Natarajan et al. (2020).

Among the nitrogen levels, superior plant height and tiller number m^{-2} were recorded with the application of 180 kg N ha^{-1} followed by 150, 120 and 90 kg N ha-

Table 1. Plant growth (two year pooled data) of aerobic rice as influenced by irrigation regimes, nitrogen levels and their interaction under drip irrigation.

Treatments	Plant height (cm) at 90 DAS					No. of tillers m^{-2} at 90 DAS				
	1.25 Epan	1.50 Epan	1.75 Epan	2.00 Epan	Mean (N)	1.25 Epan	1.50 Epan	1.75 Epan	2.00 Epan	Mean (N)
90 kg N ha^{-1}	31.4	32.0	31.7	31.6	31.7	331.0	344.3	341.1	336.3	**338.2**
120 kg N ha^{-1}	32.7	33.8	34.3	34.2	33.7	350.0	365.3	372.8	369.2	**364.3**
150 kg N ha^{-1}	32.1	35.2	36.1	36.6	35.0	344.8	380.2	392.7	398.8	**379.1**
180 kg N ha^{-1}	31.8	35.6	37.6	38.4	35.8	339.2	385.7	408.8	421.5	**388.8**
Mean (I)	**32.0**	**34.1**	**34.9**	**35.2**		**341.3**	**368.9**	**378.8**	**381.5**	
		SEm±		**CD (P=0.05)**			**SEm±**		**CD (P=0.05)**	
I		0.28		1.0			2.54		8.8	
N		0.21		0.6			2.01		5.9	
N at I		0.41		1.2			4.01		11.7	
I at N		0.45		1.0			4.30		9.9	

^{1} with significant difference among each other. Increasing nitrogen dose from 90 kg ha^{-1} to 120 kg ha^{-1}, 150 kg ha^{-1} and 180 kg ha^{-1} resulted in an increase in plant height by 6.3%, 10.4% and 12.9 % and tiller number by 7.7%, 12.1% and 15.0%, respectively. Aerobic rice grown with 180 kg N ha^{-1} recorded 2.3 % and 2.6 % higher plant height and number of tillers m^{-2}, respectively over 150 kg N ha^{-1}. Greater plant height at higher nitrogen doses was due to adequate supply of nitrogen, which is an essential component of proteins and chlorophyll and aids in the maintenance of higher auxin levels, resulting in greater plant height. Similar findings were reported by Maheswari et al. (2007) and Natarajan et al. (2020). More number of tillers at higher doses of nitrogen might be due to supply of required nitrogen at maximum tillering stage, which is imperative for profuse tillering.

Interaction between irrigation regimes and nitrogen levels showed significant variation in plant height and tiller number of aerobic rice. At any irrigation regime, increase in nitrogen dose significantly interacted, resulting in an increased plant height and tiller number, except with the drip irrigation regime of 1.25 Epan, wherein the increase in plant height was observed only up to 120 kg N ha^{-1} and thereafter there was a decline. At any nitrogen level, increase in irrigation regime resulted in a significant variation in plant height and tiller number except with 90 kg N ha^{-1} wherein no significant variation was observed with respect to plant height. However, increase in plant height and tiller number was observed only up to 1.5 Epan at 90 kg N ha^{-1} and 1.75 Epan at 120 kg N ha^{-1} and declined thereafter. Among the different treatment combinations, scheduling drip irrigation at 2.0 Epan in combination with 180 kg N ha^{-1} resulted in significantly higher plant height and tiller number over remaining treatment combinations. Drip irrigation regime of 2.0 Epan along with 180 kg N ha^{-1} improved plant height and tiller number by 4.9 and 5.7 %, respectively over scheduling drip irrigation at 2.0 Epan along with 150 kg N ha^{-1}. Higher plant height and tiller number with drip irrigation regime of 2.0 Epan in combination with 180 kg N ha^{-1} could be attributed to sufficient supply of soil moisture and nitrogen, which might have stimulated crop growth. The significant interaction between irrigation regimes and nitrogen levels in relation to plant height and tiller number was consistent with the findings of Padmaja and Reddy (2018) and Karthika and Ramanathan (2019), respectively. At irrigation regime of 1.25 Epan, with increase in nitrogen level above 120 kg ha^{-1}, tiller number was declined due to reduced nitrogen uptake because of osmotic stress. Prasertsak and Fukai (1997) and Halvorson et al. (2005) also revealed that, high application of fertilizer nitrogen may reduce rather than stimulate crop growth under dry soil conditions.

Effect of drip irrigation regimes and nitrogen levels on yield attributes, yield and harvest index

Yield attributes

The higher stature of yield attributes *viz*., number of panicles m^{-2}, panicle weight, filled grains per panicle and test weight were recorded with drip irrigation regime of 2.0 Epan, which was however on par with 1.75 Epan and significantly superior to lower irrigation regimes

(Table 2). Maximum panicle number observed at higher drip irrigation regimes might be due to maintenance of adequate soil moisture that has resulted in an increased leaf area, thereby improving photosynthesis and assimilate production which ultimately led to production of higher number of productive tillers. Maximum panicle weight at higher drip irrigation regimes was due to better partitioning and translocation of photosynthates to the sink because of sufficient moisture availability resulting in better filling of grains (Jagadish et al., 2019). Among the different nitrogen levels, application of nitrogen at 180 kg N ha^{-1} produced significantly higher values of all the yield attributes which was however comparable with 150 kg N ha^{-1} and superior to lower nitrogen doses, with the exception of panicle weight wherein significant variation was observed between 180 and 150 kg N levels. Maximum panicle number at higher nitrogen rates might be due to favourable root growth and adequate availability and uptake of nitrogen, which has role in panicle formation. Higher panicle weight, filled grains per panicle and test weight at higher nitrogen levels might be due to increase in chlorophyll content of leaves at higher nitrogen levels which led to higher photosynthetic rate and ultimately plenty of photosynthates available during panicle development. Among the interaction treatments, drip irrigation schedule of 2.0 Epan along with 180 kg N ha^{-1} registered higher yield attributes which was however at par with 1.75 Epan along with 180 kg N ha^{-1} and significantly superior to remaining treatment combinations. This might be due to the combined effect of adequate moisture under high nitrogen level, leading to better partitioning and translocation of photosynthates from source to sink (Ramadass and Ramanathan, 2017).

Grain and straw yield

Among the irrigation regimes, scheduling drip irrigation at 2.0 Epan resulted in higher grain and straw yields, which was however comparable with drip irrigation at 1.75 Epan and significantly superior to that of 1.5 Epan and 1.25 Epan. There was a progressive and significant increase in grain and straw yields with increase in irrigation regime. Increasing the irrigation regime from 1.25 Epan to 1.5 Epan, 1.75 Epan and 2.0 Epan resulted in an average increase of 13.9, 20.1 and 21.2 per cent grain yield and 11.8, 16.6 and 18.3 per cent straw yield, respectively over the lower irrigation regime (Table 3).

Table 2. Yield attributes (two-year pooled data) of aerobic rice as influenced by irrigation regimes, nitrogen levels and their interaction under drip irrigation.

Treatments	Number of panicles m^{-2}					Panicle weight (g)					Filled grains per panicle					Test weight (g)				
	1.25 Epan	1.50 Epan	1.75 Epan	2.00 Epan	Mean (N)	1.25 Epan	1.50 Epan	1.75 Epan	2.00 Epan	Mean (N)	1.25 Epan	1.50 Epan	1.75 Epan	2.00 Epan	Mean (N)	1.25 Epan	1.50 Epan	1.75 Epan	2.00 Epan	Mean (N)
90 kg N ha^{-1}	228	231	231	229	**229**	1.62	1.70	1.67	1.64	**1.66**	98.7	102.6	102.1	100.8	**101.0**	12.78	12.92	12.86	12.86	**12.86**
120 kg N ha^{-1}	235	239	242	241	**239**	1.80	1.89	1.96	1.94	**1.90**	107.9	112.7	115.4	114.2	**112.5**	13.18	13.33	13.40	13.34	**13.31**
150 kg N ha^{-1}	233	244	250	254	**245**	1.75	2.07	2.22	2.32	**2.09**	105.0	119.9	127.6	131.5	**121.0**	13.06	13.53	13.77	13.87	**13.56**
180 kg N ha^{-1}	230	246	257	261	**248**	1.66	2.14	2.44	2.63	**2.21**	100.3	122.1	136.2	144.0	**125.6**	12.88	13.59	14.01	14.18	**13.67**
Mean (I)	**232**	**240**	**245**	**246**		**1.71**	**1.95**	**2.07**	**2.13**		**103.0**	**114.3**	**120.3**	**122.6**		**12.97**	**13.34**	**13.51**	**13.56**	
	SEm±			**CD (P=0.05)**		**SEm±**			**CD (P=0.05)**			**SEm±**		**CD (P=0.05)**		**SEm±**			**CD (P=0.05)**	
I	1.1			4		0.044			0.15			1.81		6.3		0.057			0.20	
N	1.2			4		0.033			0.10			1.70		5.0		0.095			0.28	
N at I	2.4			7		0.067			0.20			3.41		9.9		0.190			NS	
I at N	2.4			5		0.073			0.17			3.46		7.9		0.175			NS	

Table 3. Grain yield, straw yield and harvest index (two year pooled data) of aerobic rice as influenced by irrigation regimes, nitrogen levels and their interaction under drip irrigation.

Treatments	Grain yield (kg ha^{-1})					Straw yield (kg ha^{-1})					Harvest index				
	1.25 Epan	1.50 Epan	1.75 Epan	2.00 Epan	Mean (N)	1.25 Epan	1.50 Epan	1.75 Epan	2.00 Epan	Mean (N)	1.25 Epan	1.50 Epan	1.75 Epan	2.00 Epan	Mean (N)
90 kg N ha^{-1}	3229	3376	3315	3256	**3294**	3778	3933	3862	3798	**3843**	0.46	0.46	0.46	0.46	**0.46**
120 kg N ha^{-1}	3522	3759	3911	3864	**3764**	4082	4317	4465	4421	**4321**	0.46	0.47	0.47	0.47	**0.47**
150 kg N ha^{-1}	3441	4090	4359	4468	**4089**	4002	4630	4873	5058	**4641**	0.46	0.47	0.47	0.47	**0.47**
180 kg N ha^{-1}	3330	4183	4651	4804	**4242**	3884	4722	5157	5349	**4778**	0.46	0.47	0.47	0.47	
Mean (I)	**3381**	**3852**	**4059**	**4098**		**3936**	**4401**	**4589**	**4656**		**0.46**	**0.47**	**0.47**	**0.47**	
		SEm±		**CD (P=0.05)**			**SEm±**		**CD (P=0.05)**			**SEm±**		**CD (P=0.05)**	
I		68.4		237			57.7		200			0.002		NS	
N		48.2		141			44.7		131			0.004		NS	
N at I		96.3		281			89.5		261			0.007		NS	
I at N		107.9		247			96.6		221			0.007		NS	

Scheduling drip irrigation at 2.0 Epan improved grain and straw yields by 6.4 % and 5.8 %, respectively over drip irrigation regime of 1.5 Epan. Higher grain yield at higher drip irrigation regimes was attributed to higher values of yield attributing characters *viz*., number of panicles, panicle weight, filled grains per panicle, and 1000 grain weight compared to other lower irrigation regimes because of availability of adequate soil moisture. Similar findings were reported by Duary and Pramanik (2019) and Natarajan et al. (2020). Lower yield in drip irrigation regime of 1.25 Epan might be due to water stress faced by the crop at the time of panicle development. The decrease in yield could also be attributed to decrease in root dry weight and volume due to lack of soil moisture (Mahajan et al., 2012). Increased straw yield under higher irrigation regimes could be attributed to increase in all growth parameters, including plant height, tiller density per unit area, and dry matter, as a result of favourable soil moisture conditions in the root zone. These findings agree with those of Rao et al. (2016), Jagadish et al. (2019) and Natarajan et al. (2020).

Application of nitrogen at 180 kg ha^{-1} resulted in maximum grain and straw yields which was however followed by 150, 120 and 90 kg N ha^{-1} in the order of descent with significant disparity between any two of the four nitrogen doses. Increasing nitrogen application from 90 kg N ha^{-1} to 120, 150 and 180 kg N ha^{-1} resulted in an average increase of 14.3, 24.1 and 28.8 per cent grain yield and 12.4, 20.8 and 24.3 per cent straw yield, respectively. Aerobic rice grown with 180 kg N ha^{-1} improved grain and straw yields by 3.7 and 3.0 %, respectively over 150 kg N ha^{-1}. Higher grain yield at higher nitrogen levels could be attributed to an increase in the number of panicles, the number of filled grains per panicle, and other yield attributes such as panicle weight. Nitrogen levels had a greater impact on grain yield than irrigation regimes, as evidenced by a greater increase in grain yield with higher nitrogen levels versus higher irrigation regimes. Higher nitrogen application allowed the rice plant to synthesize more chlorophyll and assimilate sufficient photosynthates through increased photosynthesis rate, resulting in increased vegetative growth, efficient sink formation and larger sink size, enhanced carbohydrate translocation from vegetative plant parts to grains, and ultimately higher grain yield of aerobic rice in these treatments. Similar results were reported by Nayak et al. (2015) and Natarajan et al. (2020). Increased straw yield with increased nitrogen level could be attributed to adequate nutrient supply, which improved growth parameters such as plant height, number of tillers, leaf area index and dry matter production, resulting in higher straw yield.

At any irrigation regime, each successive increment in the dose of nitrogen significantly interacted, resulting in increased grain and straw yields, except with the drip irrigation schedule of 1.25 Epan, wherein the increase was only up to 120 kg N ha^{-1}. Under moisture stress, adequate nitrogen supply can boost LAI and leaf photosynthesis, whereas excessive nitrogen inhibits photosynthesis. Low nitrogen uptake by moisture stressed aerobic rice plants may explain the lower responses to nitrogen rates in lower irrigation regimes (Belder et al., 2005). Xue et al. (2008) also reported similar finding of decrease in growth and yield of rice with increase in nitrogen fertilizer dose above optimum level at the lower water application. At higher nitrogen levels (150 kg and 180 kg N ha^{-1}), with increase in irrigation level there was an increase in grain and straw yield, whereas at lower nitrogen levels, the increase was observed only up to 1.5 Epan at 90 kg N ha^{-1}, and was up to 1.75 Epan at 120 kg N ha^{-1}, thereafter there was a decline which might be due to leaching of nitrogen at higher irrigation regimes. Among the different interaction combinations, the maximum grain and straw yields were recorded with the drip irrigation schedule of 2.0 Epan along with 180 kg N ha^{-1} followed by drip irrigation at 1.75 Epan along with 180 kg N ha^{-1} and drip irrigation at 2.0 Epan along with 150 kg N ha^{-1}. Drip irrigation regime of 2.0 Epan along with 180 kg N ha^{-1} improved grain and straw yields, by 7.5 and 5.8 %, respectively over scheduling drip irrigation at 2.0 Epan along with 150 kg N ha^{-1}. Better grain yield in these treatments might be due to better availability of moisture and nutrients at higher soil moisture and nitrogen levels, which resulted in increased crop growth and translocation of photosynthates from source to sink, producing higher productive tillers, panicle length, test weight and number of filled grains per panicle with lower chaffy percentage. Similar evidence was reported by Jagadish et al. (2019). Higher straw yield could be due to luxuriant vegetative growth in terms of plant height and number of tillers per plant with sufficient moisture and nutritional levels. These observations are

Table 4. Economics (two year pooled data) of aerobic rice as influenced by irrigation regimes, nitrogen levels and their interaction under drip irrigation.

Treatments	Cost of cultivation (Rs. ha^{-1})					Gross returns (Rs. ha^{-1})					Net returns (Rs. ha^{-1})					B:C ratio (Rs. ha^{-1})				
	1.25 Epan	1.50 Epan	1.75 Epan	2.00 Epan	Mean (N)	1.25 Epan	1.50 Epan	1.75 Epan	2.00 Epan	Mean (N)	1.25 Epan	1.50 Epan	1.75 Epan	2.00 Epan	Mean (N)	1.25 Epan	1.50 Epan	1.75 Epan	2.00 Epan	Mean (N)
90 kg N ha^{-1}	37475	38528	39580	40631	**39053**	70737	73911	72561	71288	**72124**	33262	35383	32981	30656	**33071**	1.89	1.92	1.83	1.75	**1.85**
120 kg N ha^{-1}	37835	38888	39940	40992	**39414**	77042	82099	85344	84345	**82208**	39207	43211	45404	43353	**42794**	2.04	2.11	2.14	2.06	**2.08**
150 kg N ha^{-1}	38195	39248	40300	41352	**39774**	75312	89130	94813	97368	**89156**	37117	49882	54513	56016	**49382**	1.97	2.27	2.35	2.35	**2.24**
180 kg N ha^{-1}	38555	39608	40660	41712	**40134**	72914	91128	101051	104441	**92384**	34358	51521	60391	62730	**52250**	1.89	2.30	2.48	2.50	**2.29**
Mean (I)	**38015**	**39068**	**40120**	**41171**		**74001**	**84067**	**88442**	**89360**		**35986**	**44999**	**48322**	**48189**		**1.95**	**2.15**	**2.20**	**2.17**	
		SEm±		**CD (P=0.05)**			**SEm±**		**CD (P=0.05)**			**SEm±**		**CD (P=0.05)**			**SEm±**		**CD (P=0.05)**	
I		-		-			1411		4884			1411		4884			0.035		0.12	
N		-		-			913		2664			913		2664			0.023		0.07	
N at I		-		-			1825		5328			1825		5328			0.045		0.13	
I at N		-		-			2119		4852			2119		4852			0.052		0.12	

consistent with the findings of Jagadish et al. (2019) and Karthika and Ramanathan (2019).

Harvest index

Harvest index of aerobic rice was not significantly influenced by drip irrigation regimes and nitrogen levels (Table 3). This could be attributed to a proportional rise in grain and straw yields as irrigation regimes and nitrogen levels are increased.

Effect of drip irrigation regimes and nitrogen levels on economics of aerobic rice

Cost of cultivation

Cost of cultivation increased with increase in irrigation regime and nitrogen levels. Among the irrigation regimes, cost of cultivation ranged from the lowest value of 38015 Rs. ha^{-1} in drip irrigation regime of 1.25 Epan to the highest value of 41171 Rs. ha^{-1} in drip irrigation regime of 2.0 Epan. With regard to nitrogen levels, cost of cultivation ranged from the lowest value of 39053 Rs. ha^{-1} in 90 kg N ha^{-1} to 40134 Rs. ha^{-1} in 180 kg N ha^{-1}. Among the interaction combinations, cost of cultivation ranged from the lowest value of 37475 Rs. ha^{-1} in drip irrigation regime of 1.25 Epan along with 90 kg N ha^{-1} to 41712 Rs. ha^{-1} in drip irrigation regime of 2.0 Epan along with 180 kg N ha^{-1} (Table 4).

Gross returns, net returns and B:C ratio

Different irrigation regimes and nitrogen levels as well as their interaction exhibited significant influence on gross returns, net returns and B:C ratio of aerobic rice. The higher gross returns were realized with the drip irrigation regime of 2.0 Epan which was however on par with 1.75 Epan and significantly superior to 1.5 Epan and 1.25 Epan. The higher net returns and B:C ratio were registered with drip irrigation regime of 1.75 Epan which was however comparable with drip irrigation at 2.0 Epan and 1.5 Epan and these treatments were significantly superior to 1.25 Epan. Drip irrigation regime of 1.75 Epan resulted in an average increase of 34.3 per cent net returns and 12.8 per cent B : C ratio, respectively over drip irrigation regime of 1.25 Epan.

Among the different nitrogen levels, application of 180 kg N ha^{-1} resulted in significantly higher gross returns, net returns and B:C ratio over lower doses. It was followed by 150, 120 kg N ha^{-1} and 90 kg N ha^{-1}. Increasing nitrogen application from 90 kg N ha^{-1} to 120, 150 and 180 kg N ha^{-1} resulted in an average increase of 29.4, 49.3 and 58.0 per cent net returns and 12.4, 21.1 and 23.8 per cent B : C ratio respectively. Aerobic rice grown with 180 kg N ha^{-1} resulted in 5.8 % higher net returns over 150 kg N ha^{-1}.

Among the different treatment combinations, the higher gross returns, net returns and B:C ratio were recorded with drip irrigation scheduled at 2.0 Epan along with 180 kg N ha^{-1} followed by 1.75 Epan along with 180 kg N ha^{-1} which were on par. Drip irrigation regime of 2.0 Epan along with 180 kg N ha^{-1} improved net returns and B:C ratio by 12.0 %and 6.4 %, respectively over scheduling drip irrigation at 2.0 Epan along with 150 kg N ha^{-1}.

Relatively higher moisture content increased the grain and straw yields in higher irrigation regimes, which was finally reflected in gross returns, net returns and B : C ratio. On the other hand, at drip irrigation schedule of 1.25 Epan wherein the crop was subjected to moisture stress, lower monetary returns were realized. Similar findings have been reported by Padmaja and Reddy (2018) and Natarajan et al. (2020). With regard to nitrogen levels, increase in nitrogen dose from 90 to 180 kg ha^{-1} resulted in an increase in gross returns, net returns and B : C ratio. This could be due to higher nitrogen levels resulting in higher yields, which could have resulted in remunerative returns. These results corroborate with the findings of Shukla et al. (2015). The higher monetary returns under drip irrigation at 1.75 Epan along with 180 kg N ha^{-1} and 2.0 Epan along with 180 kg N ha^{-1} might be due to increased grain and straw yields under favourable moisture conditions coupled with ample supply of nitrogen. The lower monetary returns were noticed with drip irrigation at 2.0 Epan along with 90 kg ha^{-1}, which might be due to reduced yields. Present investigations confirmed the results of Padmaja and Reddy (2018).

CONCLUSION

Aerobic rice cultivation with drip irrigation provides feasible alternative to traditional rice system. Based on the outcome of the investigation, it could be inferred that drip irrigation at 2.0 Epan resulted in higher growth, yield and gross returns. However, drip irrigation at 1.75 Epan can be practiced considering higher B : C ratio. Application of 180 kg N ha^{-1} can be practiced as it results in superior growth, yield and higher monetary returns. Combination of scheduling drip irrigation at 1.75 Epan along with 180 kg N ha^{-1} can be recommended over 2.0 Epan along with 180 kg N ha^{-1} considering their parity in yield and monetary returns and low water requirement in case of 1.75 Epan along with 180 kg N ha^{-1}. However, under water scarce conditions, combination of 1.5 Epan along with 180 kg N ha^{-1} may be practiced for getting higher yield and monetary returns.

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Identification and characterization of drought tolerant rice genotypes using physiological and biochemical traits

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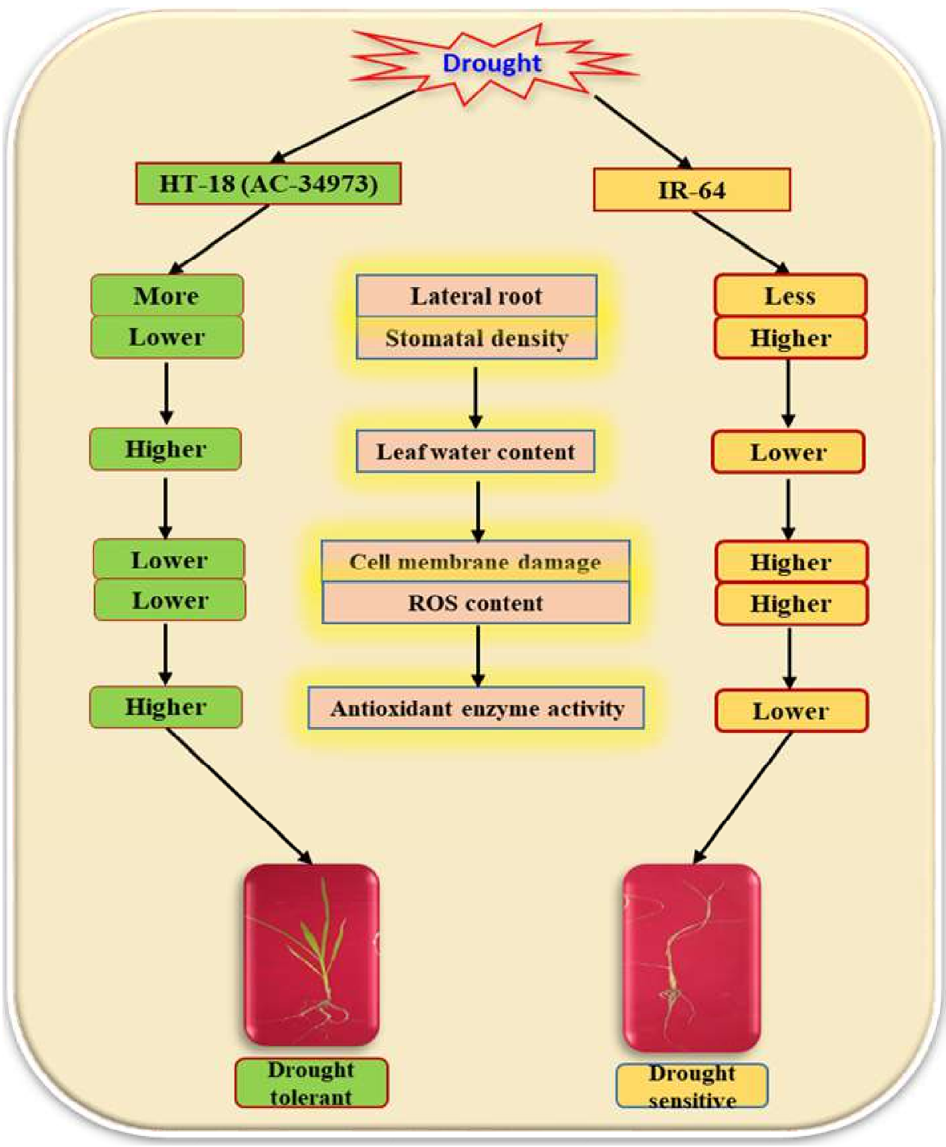

ABSTRACT

The present study was conducted to evaluate the performance of seven rice genotypes using morphological, physiological and biochemical parameters, under induced drought (water stress) conditions at seedling level using PEG6000 in Hoagland's medium. At the end of the stress period sampling was done to record the root and shoot lengths and various physiological parameters viz., total chlorophyll content, cell membrane stability index (MSI), relative water content were estimated. Proline and Malondialdehyde (MDA) content were also estimated as biochemical parameters. The results obtained from the study revealed the existence of significant variation in the seven genotypes studied for different physiological and biochemical parameters. Out of the seven genotypes studied, HT-18 (AC-34973) had performed better than the tolerant check CR-143-2-2 and showed better root and shoot growth, maintained higher total chlorophyll content (2.6 mg/gm FW), relative water content (61.3%) and membrane stability index (MSI) (52.9%), it has also shown higher proline content (20.52 ?moles/gm FW) and lesser MDA content (0.068) under stress. To assess the membrane integrity under osmotic stress, roots from all the genotypes grown in hydroponic culture with 20% PEG were stained with Evan's blue, where the stress effect is directly reflected on the intensity of Evans blue uptake by the cell. Because of more membrane damage, the roots of the susceptible genotype, IR-64, had taken up more stain than the roots of tolerant genotype HT-18. The present study has identified HT-18 as seedling level drought tolerant genotype.

Key words: *Drought, vegetative stage, MDA, MSI, proline, rice*

INTRODUCTION

Drought is the most devastating stress affecting crop production worldwide. Climate change is expected to increase the occurrence and severity of droughts, posing ever more serious constraints to global rice production (Wassmann et al., 2009). Drought can come at any phase of the rice crop in any year in rainfed areas. Modern rice cultivars are particularly prone to drought stress at the seedling, vegetative, and reproductive stages, and even minor drought stress can result in a large yield drop (O'Toole, 1982; Torres and Henry, 2016). Drought has an impact on establishment of crop and seedling survival rates at the seedling stage. Drought lowers leaf production and tillering during the vegetative stage, affecting the number of panicles per plant and a loss of output. Drought reduces the quantity of grains per panicle, increases grain sterility, and reduces grain weight at the reproductive stage (Pantuwan et al., 2002).

Drought stress at the reproductive stage is known to induce a large yield drop (Hsiao, 1973), although vegetative stage drought was previously thought to have a very little influence on grain yield in rice (Boonjung and Fukai, 1996). It should be highlighted, however, that these conclusions are based on the impacts of drought stress on the rice plant, not on the type of drought stress that occurs most commonly in farmers' fields. Because of the late arrival of monsoon rains or extended gaps between first rains, vegetative-stage dryness has become a key factor in lowering rice output in shallow rainfed areas in recent years (Bunnag and Pongthai, 2013). In shallow rainfed parts of South and Southeast Asia, notably in eastern India, the frequency and intensity of vegetative-stage drought stress has risen in recent years. Farmers fail to amass enough water in the field early in the season to prepare land and begin transplanting due to lack of first rainfall. As a result, in years with lower early rainfall, significant portions of shallow rainfed ecosystems are left untransplanted. Slow development, decreased tillering, and in some cases mortality of early transplanted seedlings owing to vegetative-stage drought stress produce large output losses even when farmers are able to transplant.

Drought tolerance phenotyping at the seedling stage is a frequent practise in wheat, barley, triticale, maize, and rice (Moud and Maghsoudi, 2008; Gonzalez and Ayrbe, 2011; Grzesiak et al., 2012; Krishnamurthy et al., 2016). It is a quick, cost-effective, and dependable way to assess a plant's performance (Krishnamurthy et al., 2016). There are reports on the relationship between drought tolerance at the seedling stage and reproductive stage in rice and wheat, demonstrating the necessity of drought tolerance screening at the seedling stage (Singh et al., 1999; Dodig et al., 2015). Seedling survival, dry weight, root shoot ratio and root length, relative water content, and seed reserve mobilization are the features that have been employed for drought tolerance screening of germplasm (Soltani et al.,2006; Hameed et al., 2010).

Although some information on screening techniques is available (Verulkar and Verma, 2014), parameters for the level of drought stress to be induced have not been particularly specifically established for vegetative-stage drought stress screening. These guidelines will assist scientists in determining the best watering time for vegetative-stage drought stress screening trials. The discovery and development of rice varieties that are tolerant to vegetative-stage drought will be aided by developing methods for successful vegetative-stage drought stress screening. Only a few types have been identified as having great production potential as well as drought tolerance at both phases. Breeders can select lines that combine tolerance to vegetative- and reproductive-stage drought stress in high-yielding genetic backgrounds by selecting for yield and yield-associated traits at the vegetative and reproductive stages in standardized drought screens, in addition to high yield potential under well-watered conditions.

Rice (*Oryza sativa* L.) is the chief source of nutrition for more than half of the world's population (Singh et al., 2012). In underdeveloped nations, it accounts for 27% of dietary calories and 20% of dietary protein (Singh and Singh, 2007). It is grown in at least 114 poor nations, and it provides income and work to more than 100 million Asian households (Singh et al., 2015). Approximately 16.2 million hectares of India's total 20.7 million ha of rainfed rice area are in eastern India (Singh and Singh, 2000), with 6.3 million ha of highland and 7.3 million ha of lowland being very drought prone (Pandey and Bhandari, 2009). The eastern Indo-Gangetic Plain is one of the world's most important rice-producing regions, yet it is also one of the most drought-prone (Huke and Huke, 1997). Over-all losses to rice production in Chhattisgarh, Odisha and Jharkhand have been reported to be as high as 40% in severe drought years, totaling US$ 650 million (Pandey et al., 2005). In order to ease the growing food crisis, rice cultivars that can withstand drought stress at both the growth stages and deliver economic yields must be identified or developed. With this in mind, the current work used morpho-physiological and biochemical characterization under drought stress to discover drought resistant rice genotypes in the vegetative stage.

MATERIALS AND METHODS

Plant material

Seven diverse rice genotypes *viz*., CR-143-2-2 (tolerant check), Satyabhama, Sahbhagi Dhan, HT-18 (AC-34973), HT-72 (AC-35076), DBT-917 and IR-64 (susceptible check) were selected for the present study.

Growth conditions

Seeds of all the genotypes were surface sterilized in 0.5% bavistin for 15mins and then thoroughly washed in distilled water for 4-5 times, after washing seeds were soaked in distilled water for overnight for imbibition. Next day seeds were put for germination in sterile pertiplates containing blotting paper moistened with distilled water. 5 days after germination, seedlings were transferred to ½ strength Hoagland's solution in plastic trays for seedling establishment. 21 days after seedling growth, osmotic stress (drought) was imposed using 20% PEG 6000 in hydroponic system for 7 days. After the stress treatment leaf samples were collected for physiological and biochemical analysis along with the control (without PEG) samples.

Morpho-physiological and biochemical analysis to assess the stress effect

To measure the stress effect on genotypes, various morphological, physiological and biochemical traits were measured after imposing osmotic stress. Data was recorded for different physiological and morphological traits using standardized methods as described in literature and with the help of appropriate instruments.

Morphological traits

Root and shoot lengths

At the end of the stress period, root and shoot lengths (cm) were measured in both control and stressed seedlings to assess the impact of water stress on growth parameters.

Evan's blue staining for membrane integrity assay

The roots from all the genotypes which were grown in hydroponic culture with PEG solution were stained with Evan's blue to check the membrane integrity of root cells under osmotic stress. The cells when subjected to stress, loss of membrane stability enhances the uptake of the dye and results in accumulation of blue protoplasmic stain. The stress effect is directly reflected on the intensity of Evans blue uptake by the cell (Baker and Mock,1994).

Physiological traits

Relative water content (RWC)

Leaf RWC was measured by recording the turgid weight of 0.5 g fresh leaf sample by keeping in water for 4h, subsequently drying it in hot air oven till constant weight was achieved (Weatherly, 1950). A precision analytical balance (HR- 60) was used for all weight measurements. The relative water content of a leaf was calculated by using the formula given below,

$$RWC\ (\%) = FW - DW \ / \ TW - DW \quad x\ 100$$

Membrane stability index (MSI)

MSI was estimated as per protocol given by Sairam et al. (1997). For estimation of membrane stability index, 50 mg leaf material, in two sets, was taken in test tubes containing 10 ml of double distilled water. One set was heated at 40 ºC for 30 min in a water bath, and the electrical conductivity of the solution was recorded by using conductivity meter (CL-250) on a conductivity bridge (C1). Second set was boiled at 100 ºC on a boiling water bath for 10 min, and its conductivity was measured on a conductivity bridge (C2). Membrane stability index was calculated by using the formula,

$$MSI\ (\%) = [1 - (C1/C2)]\ x\ 100$$

Total chlorophyll (TC) content

Total chlorophyll content was estimated by extracting 0.05 g of leaf material in 10 ml dimethyl sulfoxide (DMSO) (Hiscox and Israelstam, 1979). The optical densities of the samples were recorded by using UV-VIS Spectrophotometer (UV-2600, SHIMADLU). Chlorophyll content was expressed as mg/g fresh weight and calculated using the formula,

$$TC = (20.2\ X\ OD_{645} + 8.02\ X\ OD_{663})\ X\ V\ /1000\ X\ W$$

OD_{645} = absorbance value at 645nm

OD_{663} = absorbance value at 663nm

W= weight of sample in mg

V = Volume of solvent used (ml)

Biochemical traits

Measurement of malondialdehyde accumulation by thiobarbituric acid reactive substances (TBARS) assay

Malondialdehyde (MDA) is a lipid peroxidation breakdown product that may be utilised as a lipid peroxidation indicator. The MDA content was measured using the thiobarbituric acid (TBA) reaction, which was modified slightly from Zhou Q. (2001). 0.5g of leaf tissue was collected and homogenised in 2 ml of 0.1 percent trichloroacetic acid (w/v) (TCA). After centrifuging the homogenate for 5 minutes at 10000 rpm, 1 ml of a solution comprising (4 percent (w/v) TCA+0.5 percent (w/v) TBA was added to 0.5 ml of supernatant. The mixture was heated to 95°C for 1 hour, then cooled to ambient temperature before being centrifuged for 5 minutes at 10000 rpm. The clear solution's absorbance was measured at 532 nm and the absorbance at 600 nm was subtracted to adjust for non-specific turbidity.

Proline estimation

Proline was estimated in both control and stressed samples seedlings. About 0.5gm plant material was ground in 10ml of 3% aqueous sulfosalicylic acid homogenized and filtrated via Whatman No.2 then about 2ml of extract was taken and to this 2ml acid - Ninhydrin + 2 ml acetic acid glacial was added and samples were heated at 100 °C for 1hrs later samples were allowed to cool on ice bath to stop the reaction. The reaction mixture was then extracted with 4ml toluene mixed vigorously using test tube stirrer for 15-20 seconds. Chromophore containing toluene was aspirated from aqueous phase, solution was warmed to room temperature and absorbance was recorded at 520nm with toluene as blank. Proline content was calculated using the formula,

$$\text{Proline Conc.}\ \left(\frac{\mu\text{moles}}{\text{gm FW}}\right) = \frac{\dfrac{\mu g\ \frac{\text{proline}}{\text{ml}}\ \text{x toluene in ml}}{115.5\ \frac{\mu g}{\mu\text{mole}}}}{\dfrac{\text{gram sample}}{5}}$$

Superoxide radical (O_2^-) content

The production of Superoxide radical (O_2^-) was determined by the oxygenated hydroxylamine method of Wang and Luo, 1990. The reaction mixture consisting of 0.5 ml potassium phosphate buffer (pH 7.8) and 0.5 ml of enzyme extract was incubated for 30 minutes at 25 °C. One millilitre of 3-aminobenzenesulfonic acid (58 mM) and an equal volume of 7 mM of 1-naphthyl amine was added to the reaction mixture and again incubated for 20 minutes. The absorbance was taken at 530 nm, and the amount of O_2^- production was calculated from the standard curve of $NaNO_2$.

Hydrogen peroxide (H_2O_2) content

Hydrogen peroxide (H_2O_2) was determined by the method of Alexieva et al., 2001. Fifty milligram of fresh leaf sample macerated with liquid nitrogen using pre-chilled mortar and pestle, and further homogenized with 10 ml of 0.1% TCA (w/v). The product was centrifuged for 15 minutes at 1000 rpm under 4°C. The supernatant was stored at -80°C refrigerator and used for enzyme activity assays. The reaction mixture consisted of 0.5 ml 100 mM potassium phosphate buffer, 2 ml KI (1M) (W/V), and 0.5 ml of leaf enzyme extract. The mixture was incubated for 1 hour at room temperature under dark conditions, and the absorbance was taken at 390 nm. The amount of H_2O_2 was calculated from the standard curve obtained from the known concentrations of H_2O_2.

ROS (Reactive Oxygen Species) scavenging enzymes activity

Fifty milligrams of fresh leave samples were homogenized with 3 ml of extraction buffer [100 mM potassium phosphate buffer (pH 7.8), 0.1 mM EDTA, and 1% Polyvinylpyrrolidone (w/v)] in an ice water bath. The homogenized material was centrifuged at 13000g for 10 minutes at 4°C. The supernatant was stored at -80°C refrigerator and used for enzyme activity assays. Activity of Super oxide dismutase (SOD) was determined by measuring the photochemical reduction of nitro-blue tetrazolium chloride (NBT) following the procedure of Giannopolitis and Ries, 1977. One unit of SOD was determined as the amount of enzyme causing 50% inhibition of NBT by photo-reduction at 560 nm absorbance.

Catalase activity was measured by the method described by Beers and Sizer, 1952. To 0.1 ml of enzyme extract, 0.9 ml of reaction mixture containing 0.1 ml of H_2O_2, 0.7 ml of 50 mM potassium phosphate buffer (pH 7.0), and 0.1 ml of EDTA was added. Rate of CAT activity was determined from the degradation of H_2O_2 per minute at 240 nm absorbance.

Statistical analysis

The means and standard error for expression values were calculated for three replicates using MS Excel.

RESULTS AND DISCUSSION

Rice requires water not just for growth and development, but also for increased harvests. Rice is thought to be poorly suited to low water circumstances as it was developed in semi-aquatic habitats. Rice droughts may occur in both irrigated and non-irrigated lowland systems, and they can impair the crop's early juvenile, reproductive, and grain development phases. The majority of drought research to date has focused on the effects of stress on panicle initiation and anthesis, as well as spikelet sterility. One of the key issues in rice research is identifying rice varieties and breeding lines with promising levels of drought resistance for use as donors in breeding and gene discovery. Drought stress at seedling level leads to significant reduction ($p<0.05$) in RWC, MSI, chlorophyll content, and significant increase ($p<0.05$) in lipid peroxidation and ROS scavenging enzymes.

Morphological analysis to assess the stress effect

To quantify the stress effect on genotypes at the end of the stress period, root and shoot lengths were measured with numerical scale. Under drought stress, root length is an essential feature of plant kinds, and

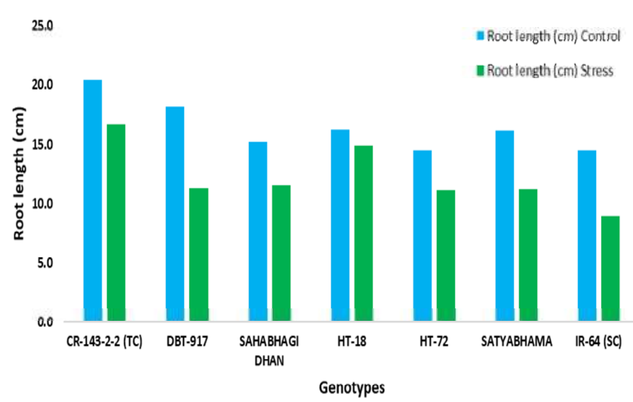

Fig. 1. Root length of different rice genotypes under control and osmotic stress

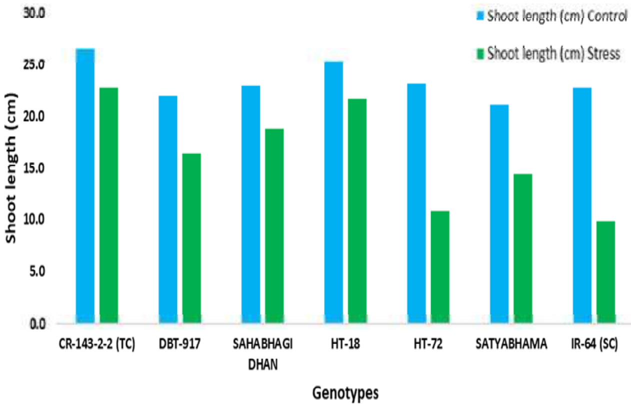

Fig. 2. Shoot length of different rice genotypes under control and osmotic stress.

roots play a key role in plant survival during drought times (Hoogenboom et al., 1987). Drought resilience is often better in varieties with longer root development. Under control conditions, the root lengths ranged between 14.5 to 20.5 cm whereas, under osmotic stress condition a significant variation in the root length was observed (Fig. 1). Tolerant check had 16.7 cm root length which was comparable with the genotype HT-18 with 14.9cm, and in other genotypes it ranged between 10-11.5 cm and susceptible check IR-64 had a root length of 8.9cm (Fig. 1). When it comes to the shoot length, HT-18 had shown 21.7cm as compared to tolerant check CR 143-2-2 with 22.8cm and others ranged between 10-16.4cm under stress situations and under control condition there was no significant variation observed, shoot length ranged between 22-26.4cm (Fig. 2). The results are in agreement with Sahoo et al. (2019) who found drought stress decreased both root and shoot lengths in 5 rice varieties. Similar kind of results were also observed by Khan et al., 2001 in maize genotypes.

Evan's blue staining for membrane integrity assay

The roots from all the genotypes grown in hydroponic culture with 20% PEG were stained with Evan's blue to check the membrane integrity under osmotic stress. The roots of susceptible genotype, IR-64 had taken up more stain compared to HT-18 roots as a result of more membrane damage. The stress effect is directly reflected on the intensity of Evans blue uptake by the cell (Fig. 3). Similar results were reported by Preethi et al., 2020 in both wheat and rice genotypes subjected to drought stress.

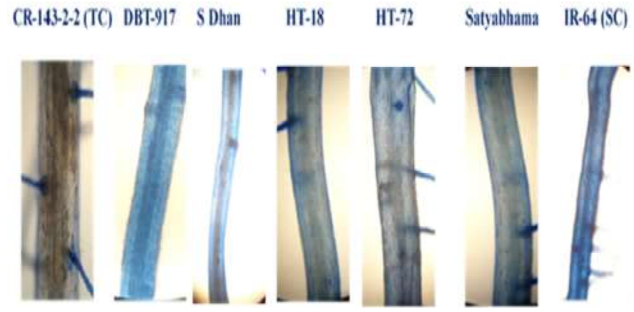

Fig. 3. Evan's blue staining for membrane integrity of rice genotypes under osmotic stress condition.

Physiological analysis to assess the stress effect

Relative Water Content (RWC)

The link between plants and water may be represented in a variety of ways, including the water potential of the leaf and relative water content (RWC) (Farooq et al., 2009). RWC is a key aspect of plant water relations and is regarded as the most comprehensive assessment of plant water status, representing fluctuations in water potential and turgor potential (Gupta et al., 2020). Between the stress and control conditions, there was a substantial variation in RWC among genotypes. In osmotic stress, the water deficit stress tolerant rice genotype HT-18 had a higher RWC of 73 percent, which is comparable to the tolerant check CR-143-RWC 22's of 73 percent, and the rest of the genotypes had RWCs ranging from 40-57.5 percent, compared to the susceptible genotype's RWC of 36.9 percent (Fig. 4). RWC of all genotypes ranged from 89 to 91 percent under control circumstances, with no significant

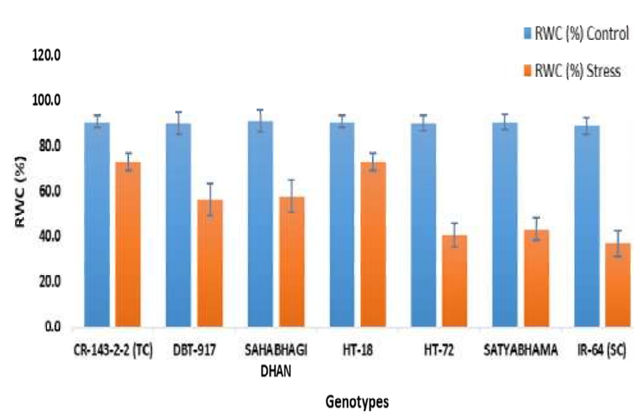

Fig. 4. Relative Water Content (RWC) of different rice genotypes under control and osmotic stress.

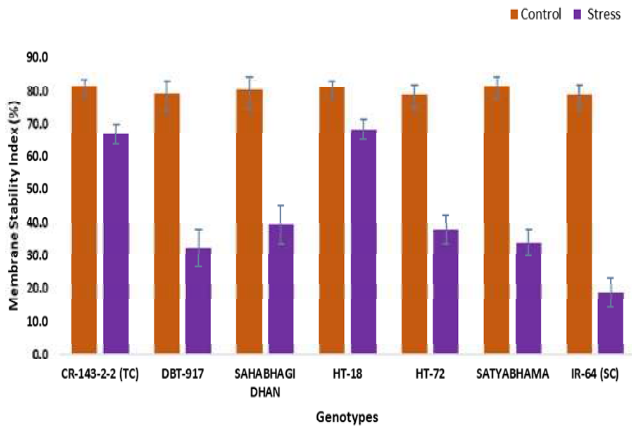

Fig. 5. Membrane Stability Index (MSI) of different rice genotypes under control and osmotic stress.

variance. Dien et al., 2019 found that genotypes with a lower drop in RWC have superior tissue tolerance potential under drought circumstances.

Membrane stability index (MSI)

Change in the membrane integrity is considered as a primary injury under stress. This is caused by osmotic effects of drought injury; leading to disorganization of cell membrane and leading to electrolyte leakage and is determined based on this parameter. The MSI was significantly higher in HT-18 *i.e.*, 68.2% as compared to other genotypes which ranged between 34-37% under stress, but under control condition all the genotypes performed same with MSI of 79-81.5% (Fig. 5). Bangar et al., 2019 reported that the ability of the genotype to maintain higher MSI is one of the acquired traits of tolerance under moisture stress condition.

Total chlorophyll content

The decrease in chlorophyll pigment is mainly due to chloroplast photo-oxidation, ultrastructure degradation and increment in chlorophyllase activity (Mafakheri et al., 2010; Kabiri et al., 2014). Higher genotypic differences in chlorophyll content were observed under stress condition and it ranged between 1.5 to 3.29 mg/gm FW. The tolerant check has shown total chlorophyll of 3.14 mg, HT-18 with 3.29 mg/gm FW and susceptible check IR-64 with 1.5 mg/gm FW. The total chlorophyll content observed under normal condition was 3.3 to 4.06 mg/gm FW (Fig. 6). Chutia and Borah, 2012 in there investigation, observed the significant decrease in the Chlorophyll-a and Chlorophyll-b and total chlorophyll content in the rice plants of unirrigated upland situations.

Biochemical analysis

Measurement of malondialdehyde accumulation by thiobarbituric acid reactive substances (TBARS) assay

The concentration of malondialdehyde (MDA) generated by the thiobarbituric acid (TBA) reaction in the drought stressed and control leaves of all genotypes was used to evaluate membrane lipid peroxidation. The production of MDA is an indicator of lipid peroxidation (Celik et al., 2017). There was significant reduction in membrane lipid peroxidation in HT-18 with MDA content of 0.055 compared to susceptible check IR-64 with MDA content of 0.139 (Fig. 7).

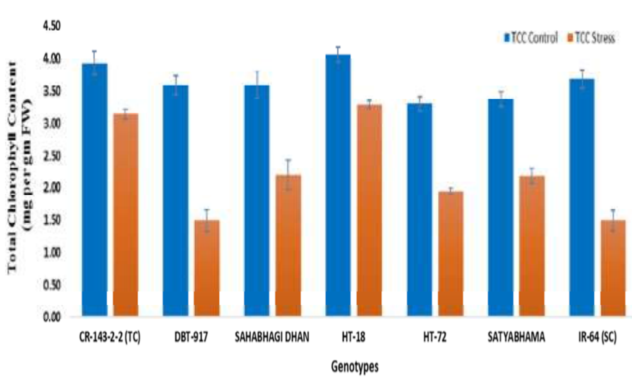

Fig. 6. Total Chlorophyll Content (TCC) of different rice genotypes under control and osmotic stress.

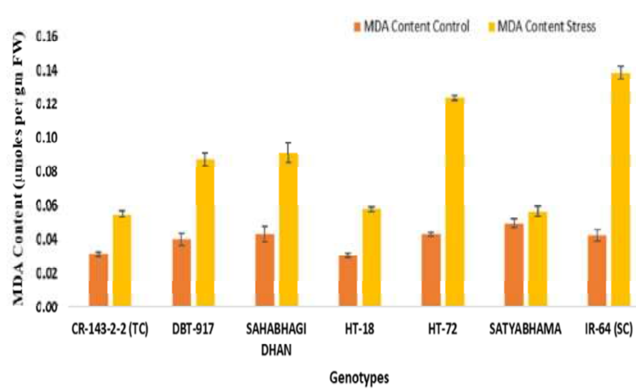

Fig. 7. Malondialdehyde (MDA) content of different rice genotypes under control and osmotic stress.

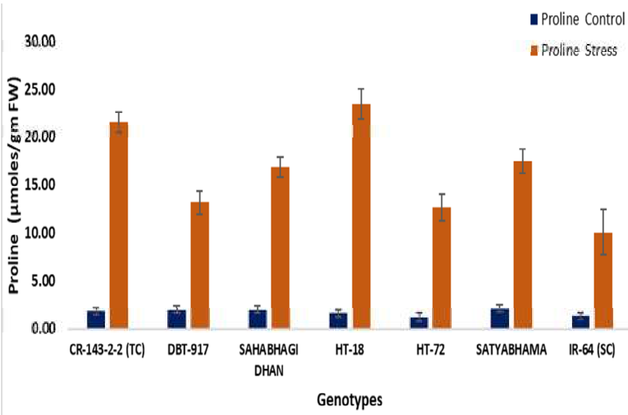

Fig. 8. Proline content of different rice genotypes under control and osmotic stress

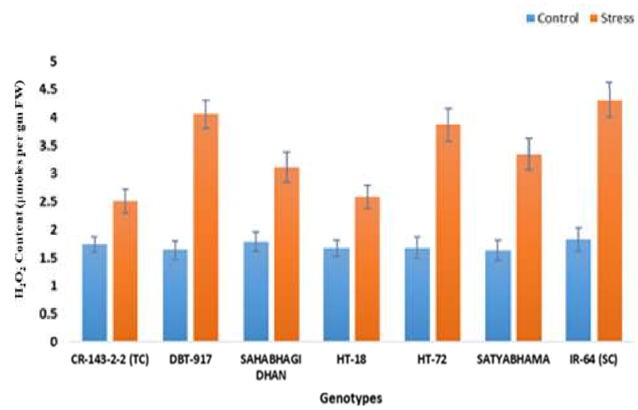

Fig. 9(B). Variation in Hydrogen Peroxide content (H_2O_2) in different rice genotypes under control and osmotic stress.

Proline estimation

Plants strive to maintain cell turgor during drought stress by accumulating organic and inorganic solutes that reduce the osmotic potential. Plants get osmotic adaptations through accumulating osmoprotectants such as proline, glycine betaine, and soluble sugar (Hayat et al., 2012). Compared to well-watered settings, proline accumulation rises in all rice cultivars during drought (Mishra et al., 2018). Between stress and control circumstances, there was a substantial variation in proline accumulation among genotypes. In osmotic stress condition, higher value of proline was observed in HT-18 with 23.45 moles/gm FW and in tolerant check it was 21.55 moles/gm FW, the susceptible genotype had 10.08 moles/gm FW (Fig. 8).

ROS content

Excessive production of ROS *i.e.*, O_2^- and H_2O_2 because of water loss causes oxidative damage and lipid peroxidation under drought conditions (Mittler, 2002). Drought stress significantly increased ($p<0.05$) O_2^- and H_2O_2 in all the genotypes. The value of O_2^- ranged between 0.0031-0.045 molg^{-1} fw under stress condition and HT-18 had shown similar O_2^- value (0.031 molg^{-1} fw) with that of tolerant check (CR143-2-2) (Fig. 9A). The values for H_2O_2 ranged between 2.51 to 4.31 mg/FW and HT-18 has showed lowest content of H_2O_2 (2.59 mg/FW) (Fig. 9B). Tolerant genotypes have antioxidant defense mechanisms to scavenge ROS production and mitigate oxidative damage (Gill and Tuteja, 2010). Similar kind of results were also obtained by Lu et al., 2010; Kumar et al., 2014; Dudziak et al.,

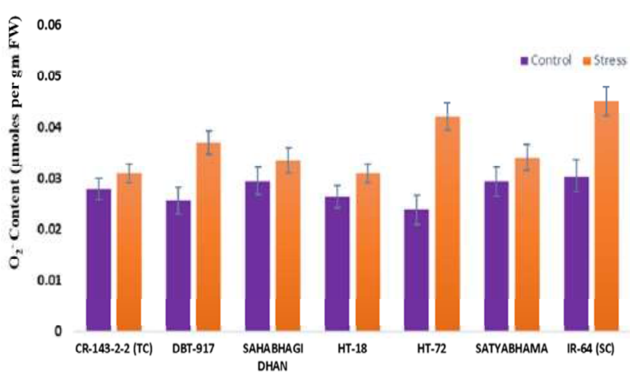

Fig. 9(A). Variation in super oxide radicle content (O_2^-) in different rice genotypes under control and osmotic stress.

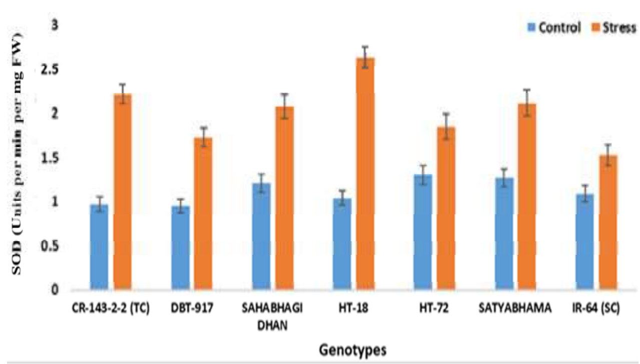

Fig. 10(A). Variation in Super Oxide Dismutase (SOD) enzyme activity in different rice genotypes under control and osmotic stress.

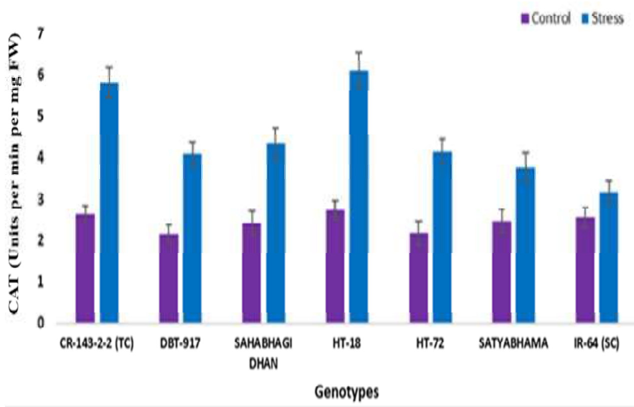

Fig. 10(B). Variation in Catalase (CAT) enzyme activity in different rice genotypes under control and osmotic stress.

2019.

ROS scavenging enzymes activity

Plants have an antioxidant defense mechanism to protect the cells from oxidative stress by producing antioxidant enzymes under DS conditions (Chutipaijit, 2016). Drought stress significantly increased ($p<0.05$) both SOD and Catalase activity in HT-18 genotype. (Fig. 10 A and B). Activity of both the enzymes SOD and CAT was increased in tolerant genotype HT-18 to mitigate the toxic effects of O_2^- and H_2O_2 respectively. Samota et al., 2017 reported the similar findings from their study.

CONCLUSION

Approximately 1100 to 1250 mm water is required for the proper cultivation of rice which is more than 50 percent of all the fresh water used in agriculture. With increase in population and the forecasted global food demand, cultivating rice by the conventional method is increasingly becoming uneconomical. So, priority must be given to save water and also sustaining productivity under water limited conditions. Therefore, the emphasis in this study was to improve the vegetative level drought tolerance of rice and to identify genotypes with better tolerance at cellular level for water deficit condition. The present study evaluated the performance of seven rice genotypes using morphological and physiological growth parameters, under induced drought conditions. All the genotypes which were studied, indicated the presence of exploitable genetic variation in terms of physiological and biochemical traits. Of the genotypes evaluated, HT-18 (AC-34973) was identified as seedling level drought tolerant genotype whose performance was better than CR-143-2-2 which is a tolerant check used in the present study.

Conflict of interest: The authors declare that they have no conflict of interest.

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Rice production in Telangana: growth, instability and decomposition analysis

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ABSTRACT

One of the objectives of the study is to assess the growth of rice sector in Telangana and growth rate is the measurable indicator for assessing the growth. The present study was conducted to assess the growth rates and instability in the area, production, and yield of rice in Telangana. Also, the relative contribution of area and yield to change in output was estimated by decomposition analysis. The study is based on secondary data for a period of 30 years i.e., 1990-91 to 2019-20. The secondary data were obtained from various publications of the Directorate of Economics and Statistics, Government of India and Directorate of Rice Development, Patna. For this study, the whole period (1990-91 to 2019-20) is divided into three sub-periods to have a period-wise examination of growth and instability patterns of the area, production, and productivity of rice and the sub-periods were as follows: period I (1990-91 to 1999-2000), period II (2000-01 to 2009-10) and period III (2010-2011 to 2019-20), and overall period (1990-91 to 2019-20). Compound Growth Rates were used to calculate the growth rates. The instability in area, production, and yield was measured with Cuddy Della Valle Index and Coppock's Instability. The study revealed that the growth rates for Telangana in the overall period were positive for the area, production, and yield (2.1%, 3.7%, and 1.5% respectively). The Cuddy Della Valle Index for the overall period registered higher, medium, and low instability for production (35.1), area (26.4), and yield (7.6) respectively. Coppock's Instability indices revealed that the degree of instability for area and production was higher during period III in comparison to periods I and II. One of the major reasons for this could be the increased area under rice in period III, because of the assured irrigation due to the completion of many major and minor irrigation projects and revival of tanks under Mission Kakatiya in Telangana. The decomposition analysis for the overall period (1990-91 to 2019-20) revealed that the area effect was highly responsible for the production variability (46.1 percent) in Telangana. The area effect in enhancing rice production increased over some time. Since the scope to further increase the area under rice cultivation is limited, the focus should be on the improvement of the yield to meet the future demand for rice.

Key words: *Rice, Telangana, growth rates and decomposition analysis*

INTRODUCTION

Rice is the staple food for more than half of the world's population and is grown in an area of about 162 million hectares worldwide, and 755 million tonnes of paddy is harvested each year. Of this, Asia accounted for 90% of the production and consumption and 86% of the area in 2019-20. (http://www.fao.org/faostat 2020). Rice provides up to 60 percent of the daily energy requirement and therefore is crucial for food and nutritional security (Nirmala et al., 2019)

India has the world's largest area of 44 million hectares under rice with the production of 118 million tonnes in 2019-20. India stands as the second-largest producer in the world which accounts for 23.5 percent of global rice production next only to China. India is both the world's second-largest producer and consumer of rice. Rice accounts for 41 percent of total food grain production occupying 35 percent of the food grain area of the country and continues to play a key role in the national food and livelihood security system (Nirmala et al., 2021). Telangana has a productivity of (3649 kg ha^{-1}) (Agricultural statistics at a glance 2020).

Rice production has increased significantly in Telangana; it continues to dominate as a major crop produced in the state and has seen a prominent increase in production in recent years. Rice is the predominant crop in Telangana, accounting for 50.3 percent (4.12 mha) of the total gross cropped area in 2020-21, up from 26.6 percent in 2014-15. In contrast, production accelerated by 29.9% from 19.3 million tons in 2019-20 to 25.1 million tons in 2020-21. It marked the state as one of the national leaders in paddy production.

Keeping this in view, the present paper is an attempt to examine the growth and instability in the area, production, and yield of rice crop in Telangana and also to assess the contribution of area, yield, and their interaction to growth in the production of rice.

MATERIALS AND METHODS

The present study is based on secondary data. Time-series data related to the area, production, and yield of rice in Telangana for the period of 30 years *i.e.*,1990-91 to 2019-20 have been collected from publications of the Directorate of Economics and Statistics, Govt. of India (https://eands.dacnet.nic. in/), Directorate of Rice Development, Patna, Bihar (https://drdpat.bih.nic.in//). For lucidity, the study period is divided into three sub-periods to have a period-wise examination of growth and instability patterns of the area, production, and productivity of rice and the sub-periods were as follows: period I (1990-91 to 1999-2000), period II (2000-01 to 2009-10) and period III (2010-2011 to 2019-20) and overall period (1990-91 to 2019-20).

Compound Annual Growth Rate (CAGR): Compound annual growth rate is calculated to study the growth pattern in the area, production, and productivity of rice in Telangana.

The growth rate was estimated using an exponential trend model.

$Y = ab^t$

Where, Y = area/ production / yield

a = intercept,

b = regression coefficient,

t = time in years

From the estimated function, the compound annual growth rate percentage (r %) can be expressed as

CAGR (r) = (Antilog of b - 1) x 100

Where,

r = Compound Annual Growth Rate (%)

Instability index

Instability means deviation from the "trend". In agriculture, instability is an inherent characteristic due to weather conditions, seasonal variation in area, yield, and production of crops from year to year. Instability analysis can be studied using three measures of instability *viz*., Coefficient of Variation, Cuddy-Della Valle index, and Coppock's index. The use of coefficient of variation as a measure to show the instability in any time series data has some limitation. If the time series data exhibit any trend, the variation measured by CV can be overestimated. Hence, present study applies the Cuddy Della Valle Index and Coppock instability index for measuring the instability. Cuddy Della Valle index attempts to de-trend the CV by using coefficient of determination. Coppock's instability index is a close approximation of the average year to-year percentage variation adjusted for trend and the advantage is that it measures the instability in relation to the trend in prices. Thus, two better measures *viz*., Coppock's instability index and Cuddy Della Valle index were used to capture instability in rice area, production and yield.

Cuddy- Della Valle Index (CDVI)

CDVI was originally developed by Cuddy and Valle (1978) for measuring the instability in time-series data that is characterized by trends. The estimable form of the equation is as follows:

$$\text{Cuddy-Della Valle Index (CDVI)} = C.V \times \sqrt{1 - R^2}$$

Where,

C.V. = Coefficient of Variation

R^2 = ESS/TSS *i.e.*, ratio of explained variation to total variation.

ESS = Variation explained by explanatory variable.

TSS = Total Variation

The present study includes the ranges of Cuddy- Della Valle Index suggested by Rakesh Sihmar (2014) are given as follows:

Low instability = between 0 to 15

Medium instability = > 15 to < 30

High instability = >30

Coppock's Instability Index (CII)

Coppock's instability index =

$$\text{Antilog } \sqrt{V\log - 1} \quad \text{x } 100$$

$$V\log = \frac{\Sigma \left[\log \frac{X_t + 1}{X_t} - m\right]^2}{N}$$

Where Xt = Area/production/yield of rice in year t

N = number of years minus one (*i.e.*, N = n^{-1})

m = Arithmetic means of the difference between the log of X_t and X_{t+1}, X_{t+2}, etc.

The CII analysis was used to measure percentage variation from year to year.

Decomposition analysis:

Decomposition analysis is used to measure the relative contribution of area and yield towards the total production changes of rice. This has been worked out using the formula recommended by Palanisami, Paramisivam, and Ranganathan (2002).

$$P_t - P_0 =$$

$$A_0 (Y_t - Y_0) + Y_0 (A_t - A_0) + (A_t - A_0) (Y_t - Y_0)$$

$$P = A_0 \; Y_t + Y_0 \; A_t + \; A \; \; Y$$

Production = Yield effect + Area effect + Interaction effect

Where,

P, A, and Y represent production, area, and yield.

'0' represents the base period and 't' represent current period.

Thus, the total change in production can be decomposed into three components *viz*., yield effect, area effect, and the interaction effect due to change in yield and area.

RESULTS AND DISCUSSION

Telangana is the rice bowl of South India. The area under rice has increased from 1.3 million hectares to 3.2 million hectares during the period 1990-20. Similarly, the yield has increased from 2.4 t ha^{-1} to 3.7 t ha^{-1} during the above mentioned period.

The data presented in Table 1 depicts the area, production, and yield of rice in Telangana during the period 1990-91 to 2019-20. It was observed that the

Table 1. Area, production and yield of rice in Telangana from 1990-91 to 2019-20.

S. no.	Year	Area (Million hectares)	Production (Million Tonnes)	Yield (Tonnes ha^{-1})
1	1990-91	1.3	3.2	2.4
2	1991-92	1.3	2.9	2.2
3	1992-93	1.1	2.3	2.1
4	1993-94	1.0	2.3	2.3
5	1994-95	1.1	2.7	2.5
6	1995-96	1.1	2.6	2.4
7	1996-97	1.3	3.1	2.4
8	1997-98	0.8	1.7	2.2
9	1998-99	1.5	4.2	2.7
10	1999-00	1.2	3.0	2.4
11	2000-01	1.5	4.4	2.8
12	2001-02	1.3	3.6	2.7
13	2002-03	1.0	2.0	2.1
14	2003-04	1.0	2.9	2.8
15	2004-05	0.9	2.2	2.5
16	2005-06	1.5	4.4	3
17	2006-07	1.5	4.3	2.8
18	2007-08	1.4	4.4	3.1
19	2008-09	1.7	5.4	3.1
20	2009-10	1.1	3.3	2.9
21	2010-11	2.0	6.5	3.3
22	2011-12	1.8	5.1	2.9
23	2012-13	1.4	4.6	3.2
24	2013-14	2.0	6.6	3.3
25	2014-15	1.4	4.5	3.2
26	2015-16	1.0	3.0	2.9
27	2016-17	1.7	5.2	3
28	2017-18	2.0	6.3	3.1
29	2018-19	1.9	6.7	3.4
30	2019-20	3.2	11.9	3.7

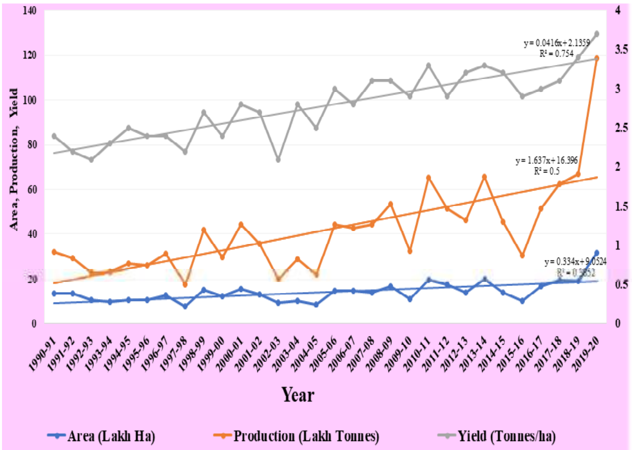

Fig. 1. Trends in area, production, and yield of rice in Telangana from 1990-91 to 2019-20.

production of rice in Telangana has increased from 3.2 million tonnes in 1990-91 to 11.9 million tonnes in 2019-20. The increase in production was approximately 3.7 times whereas the area of rice has increased from 1.3 million hectares in 1990-91 to 3.2 million hectares in 2019-20. Similarly, yield also has increased throughout the study period *i.e.*, 2.4 tonnes ha^{-1} in 1991 to 3.7 tonnes/ha in 2019-20. It is observed from the data that from the year 2015-16 to 2019-20 there is an even increase in the area, production, and yield of rice. The increase in the area can be attributed to assured irrigation due to the completion of many major and minor irrigation projects and the revival of tanks under 'Mission Kakatiya' in Telangana. With assured irrigation more land was brought under rice cultivation in the last five years. Enhancement in the production of rice in Telangana can be attributed to irrigation facilities, favourable rainfall, investment support provided by the government through the 'Rythu bandhu' scheme, quality seed and good management practices followed by the farmers.

Compound annual growth rates

The district-wise compound annual growth rates of area, production, and yield of rice in Telangana for three periods and the overall study period have been examined and are presented in Table 2. Analysis across districts revealed that the compound annual growth rates of area, production, and yield are fluctuating throughout the three periods.

During the period I, the highest growth rate was recorded in Adilabad for production (4.6) and yield (4.8). The growth rate for the area was highest in the Khammam district. However, it was observed from the results that in period I both positive and negative growth rates were found across districts for the area, production, and yield. Due to better irrigation facilities and good drainage system, where water is aerated quickly in the fields, the growth rate of Karimnagar was positive and significant at 1 percent level for yield (3.5***).

During period II, Nalgonda registered the highest growth rate in area and production (7.0* and 9.4* respectively) and Nizamabad has the highest growth rate in yield (5.0*) which was found positive and significant at 10 percent level. The highest decline

Table 2. CAGR of area, production and yield of Rice in Telangana from 1990-91 to 2019-20.

District	Particular	Period I	Period II	Period III	Overall period
Adilabad	Area	-0.2	-3.5	7.9*	1.7**
	Production	4.6	-1.8	10.2*	4.5***
	Yield	4.8	3.1	4***	2.7***
Karimnagar	Area	-0.3	1.6	5.2	3.3***
	Production	3.3	3	6.4	4.7***
	Yield	3.5***	1.3	1.1	1.4***
Khammam	Area	0.9	0.5	0.1	0.4
	Production	1.7	2.7	2.8	1.9***
	Yield	0.8	2.2	2.6**	1.5***
Mahabubnagar	Area	0.2	1.5	2	2.4***
	Production	-0.1	3.3	3.2	3.9***
	Yield	-0.3	1.8	1.1	1.4***
Medak	Area	-1.1	-0.5	-5.2*	0.5
	Production	0.4	1.7	-4.3	3***
	Yield	1.5	2.3	0.9	2.5**
Nalgonda	Area	-1.2	7*	6.9*	2.4***
	Production	-1.4	9.4*	8.1*	3.3***
	Yield	-0.2	2.3*	1.1	0.9***
Nizamabad	Area	0.3	0.7	4.2	2.8***
	Production	1.5	5.7	4.8	5.4***
	Yield	1.2	5*	0.6	2.5***
Rangareddy	Area	-1.6	-4.2*	1.6	-0.3
	Production	-1.8	-2.9	4.9	0.6
	Yield	-0.3	1.4	3.3***	0.9***
Warangal	Area	0.4	-0.5	4.5	2.8***
	Production	0.4	-0.1	5.9	4.4***
	Yield	0.02	0.4	1.4	1.6***
Telangana	Area	-0.2	1.5	3.5	2.1***
	Production	0.8	3.7	4.7	3.7***
	Yield	1	2.1*	1.1	1.5***

***Significant at 1% level, **Significant at 5% level, * Significant at 10% level in growth was observed for the production of the Rangareddy and Adilabad districts in comparison to the period I. The compound growth rate of area (4.2*) in Rangareddy district was negative and statistically significant at 10 percent level. This may be due to the diversion of rice area to other commercial crops and non-agricultural purposes.

During period III, Adilabad recorded positive and significant growth rates for the area (7.9*), production (10.2*) at 10 percent level while for yield (4***) significant at 1 percent level of significance. In this period almost all districts registered a positive growth rate for the area, production and yield except Medak which has shown a negative but significant growth rate at a 10 percent level of significance for the area (-5.2*) and a negative and non-significant growth rate for production (-4.3) The yield growth rate of Khammam was positive and statistically significant at 5 percent level of significance, while the growth rate of area (6.9*) and production of Nalgonda was positive and statistically significant at 10 percent level of significance.

During the overall period the compound growth rates of area, production and yield were positive and statistically significant (except Khammam and Medak which were positive but statistically not significant) in almost all districts except the area of Rangareddy (-0.3) which was found to be negative and statistically non-significant. The highest growth rate for production was recorded in Nizamabad (5.4***) followed by Karimnagar (4.7***), Adilabad (4.5***), and Warangal (4.4***) which were positive and statistically significant at 1 percent level. The highest growth for the area was found in Karimnagar (3.3***) followed by Warangal (2.8***) and Nizamabad (2.8***) which were also significant at 1 percent level. The highest growth rate for yield was found in Adilabad followed by the Nizamabad district and were significant at 1 percent level of significance.

Examining Telangana as a whole, the period I growth rates for the area, produc,tion and yield of rice was -0.2, 0.8, and 1.0 percent respectively. During the period I yield growth was the main source of production. In period II all three components were positive and yield (2.1*) was found significant at 10 percent level of significance. In period II, period- III the growth rates of area, production, and yield of Telangana reveal positive and higher growth than in period-I. This could be due to increased irrigation facilities in the state. During period III, the growth rates of area (3.5), production (4.7), and yield (1.1) were positive but statistically non-significant. The yield peaked till period II and after it has shown declined growth in period III. In the overall period compound growth rate for the area (2.1***), production (3.7***), and yield (1.5***) of Telangana registered positive and significant growth at the 1 percent level of significance. The compound growth rates of area, production, and yield of rice in Telangana were positive in all the periods except in the area during Period I.

Instability index

The level of instability cannot be detected by focusing solely on growth rates. Growth rates will simply explain

Table 3. Cuddy- Della Valle Index for area, production, and yield of rice.

District	Particular	Period I	Period II	Period III	Overall period
Adilabad	Area	19.4	21.3	40.0	36.8
	Production	40.5	33.1	49.6	54.7
	Yield	29.0	17.8	10.9	19.6
Karimnagar	Area	25.2	35.6	34.3	35.7
	Production	29.6	41.0	38.4	42.2
	Yield	8.1	11.1	6.0	8.4
Khammam	Area	13.7	23.4	25.9	20.4
	Production	20.2	28.9	30.7	26.8
	Yield	9.5	13.9	8.5	10.5
Mahabubnagar	Area	33.2	22.4	30.9	28.3
	Production	46.2	28.7	43.0	39.9
	Yield	17.3	10.0	11.4	12.5
Medak	Area	18.2	22.2	21.6	23.4
	Production	28.6	30.4	28.9	33.7
	Yield	13.4	12.5	10.5	11.7
Nalgonda	Area	17.4	27.0	31.0	32.2
	Production	20.2	29.9	33.8	37.3
	Yield	6.3	8.4	6.0	7.1
Nizamabad	Area	19.7	30.1	33.9	34.7
	Production	30.8	38.6	39.9	46.2
	Yield	13.2	16.4	11.8	13.9
Rangareddy	Area	21.2	20.3	25.0	24.5
	Production	21.6	26.0	30.8	29.5
	Yield	5.1	9.4	6.6	8.7
Warangal	Area	29.9	23.0	26.7	27.1
	Production	37.9	29.9	30.9	34.0
	Yield	16.7	10.8	8.6	11.4
Telangana	Area	19.8	22.8	29.1	26.4
	Production	24.4	29.2	36.3	35.1
	Yield	6.5	9.7	7.2	7.6

the rate of growth over time, whereas instability will determine whether the growth performance for the variable under study was stable or unstable over time. In this study, the level of instability in the area, production, and yield of rice was determined by using Cuddy-Della Valle Index and Coppock's Instability Index.

Cuddy Della Valle Index

It is evident in Table 3 that during the period I, the highest instability for area and production has been found in the Mahbubnagar district while Adilabad registered high instability in yield. Low instability for the area (13.7) was recorded in Khammam while production (20.2) recorded low instability in Khammam and Nalgonda districts. Medium instability in the area and production has been found in most districts. The area has been found low and medium unstable in all districts whereas in the case of production, instability varies from low to high and yield has been found less unstable in the majority of districts. The instability of Telangana for the area, production and yield was found to be medium(19.8),, medium(24.4) and low(6.5) respectively.

During period II, high instability for the area and production was recorded in Karimnagar (35.6 & 41.0 respectively) followed by Nizamabad (30.1 & 38.6 respectively). Low instability for yield was registered in Nalgonda (8.4) district followed by Rangareddy (9.4), Mahbubnagar(10.0), and Karimnagar (11.1) respectively. The instability varies from 20.3 to 35.6 percent, 26.6 to 41.0 percent for the area and production respectively which are in medium to the highly unstable range, and 8.4 to 17.8 percent for yield which is low to medium unstable in period II. The instability of Telangana for the area (22.8) and production (29.2) was found to be medium unstable and yield (9.7) has shown low instability.

In period III the high instability index for the area registered in Adilabad (40.0) followed by Karimnagar, Nalgonda and Nizamabad while production is highly unstable in Adilabad (49.6), followed by Mahbubnagar (43.0), Nizamabad (39.9) and Karimnagar (38.4) respectively. Yield has shown low instability in Karimnagar and Nalgonda (6.0). The area has shown medium to high instability (21.6 to 40.0%), production showed a similar pattern of medium to highly unstable (28.9 to 49.6%) and yield varies from 6.0 to 11.8% which is less unstable. The instability of Telangana for the area, production, and yield are 29.1, 36.3, and 7.2 respectively.

Table 4. Coppocks Instability Index for the area, production, and yield of rice.

District	Particular	Period I	Period II	Period III	Overall period
Adilabad	Area	45.86	47.63	54.96	51.26
	Production	60.08	53.85	60.23	65.69
	Yield	51.79	45.20	45.89	52.38
Karimnagar	Area	47.77	56.05	53.46	57.75
	Production	49.97	62.45	56.14	65.18
	Yield	42.09	41.51	39.28	42.83
Khammam	Area	42.20	46.90	46.50	45.20
	Production	44.92	52.29	48.43	50.24
	Yield	40.45	43.55	41.26	43.77
Mahabubnagar	Area	50.16	46.10	48.90	51.66
	Production	56.16	49.86	53.67	60.17
	Yield	43.01	41.00	41.12	44.00
Medak	Area	44.14	45.56	47.99	46.39
	Production	47.75	51.01	50.42	55.44
	Yield	42.08	42.53	40.81	47.16
Nalgonda	Area	43.35	53.10	53.17	53.17
	Production	44.58	57.67	55.30	57.55
	Yield	39.09	41.08	39.32	40.89
Nizamabad	Area	44.58	50.18	54.05	54.93
	Production	50.46	58.55	60.53	68.99
	Yield	42.06	46.59	41.75	48.10
Rangareddy	Area	44.91	45.78	47.96	46.81
	Production	45.20	47.79	51.51	48.68
	Yield	38.65	40.87	41.33	41.34
Warangal	Area	50.79	46.21	49.25	53.20
	Production	52.90	50.37	51.54	60.96
	Yield	43.75	41.07	40.45	44.41
Telangana	Area	44.66	46.31	49.17	49.64
	Production	46.56	50.86	52.33	56.48
	Yield	39.40	41.45	39.68	42.87

During the overall period, high instability for the area (36.8) and production (54.7) was found in the Adilabad district. The instability for area varies from 20.4 to 36.8%, for production varies from 29.5 to 54.7% and for yield varies 7.1 to 19.6%. Telangana registered higher, medium, and low instability for production (35.1), area (26.4), and yield (7.6) respectively.

Coppock's Instability Index

The results of Coppock's instability analysis of the area, production, and yield of rice are presented in Table 4 and are discussed period wise including the overall period. The instability analysis revealed that in the period I higher instability for the area was observed in Warangal (50.79) whereas production and yield were highly instable in the Adilabad district (60.08 and 51.79 respectively). The lowest Instability was shown in Khammam district for the area (42.20), whereas for production low instability was found in Nalgonda (44.58) followed by Khammam (44.92) and for yield, the district observed was Rangareddy (38.65). In period II, the Karimnagar district showed the highest instability for the area (56.05) and production (62.45) respectively. Highest instability for yield was registered in the Nizamabad district (46.59). Low instability for the area was registered in Khammam district (45.56) followed by Rangareddy (45.78). Similarly, the Rangareddy district recorded low instability in production (4.79) and yield (40.87) respectively.

In period III Adilabad district registered a high level of instability for area and yield (54.96 &45.89 respectively) followed by Nizamabad (54.05 & 41.75 respectively) whereas high instability for production was found in Nizamabad district followed by Adilabad. A low level of instability was recorded by Khammam district for the area (46.50), production (48,.43) and for yield low instability registered in Karimnagar (39.28) followed by Nalgonda (39.32).

In the overall period, Karimnagar has shown higher instability for the area component (57.75). In the case of production and yield components, the highest instability was found in Nizamabad (68.99) and Adilabad (52.38) respectively. The low level of instability registered in Khammam, Rangareddy and Nalgonda for the area (45.20), production (48.68), and yield (40.89) respectively.

The instability analysis for the Telangana state revealed that the production component was highly instable for all study periods followed by the area component. The yield component has shown high instability in the overall period compared to other

Table 5. Decomposition analysis in area, production, and yield of rice in Telangana (1990-91 to 2019-2020).

District	Particular	Period I	Period II	Period III	Overall period
Adilabad	Area effect	-4.2	257.1	71.2	30.3
	yield effect	106.5	-204.9	16.1	31.5
	Interaction effect	-2.3	47.8	12.7	38.2
Karimnagar	Area effect	-28.8	47.9	81.0	51.6
	yield effect	137.5	46.6	12.4	19.5
	Interaction effect	-8.7	5.5	6.6	28.9
Khammam	Area effect	30.2	33.0	30.9	26.6
	yield effect	67.0	60.2	63.5	58.3
	Interaction effect	2.8	6.9	5.5	15.1
Mahabubnagar	Area effect	40.8	38.1	61.0	53.1
	yield effect	63.8	56.2	31.4	26.4
	interaction effect	-4.6	5.8	7.6	20.5
Medak	Area effect	-274.7	-21.7	131.3	-10.2
	yield effect	415.6	125.3	-41.4	118.9
	interaction effect	-40.9	-3.6	10.1	-8.7
Nalgonda	Area effect	101.7	66.8	84.8	66.2
	yield effect	-1.8	21.5	8.7	16.0
	interaction effect	0.2	11.7	6.5	17.8
Nizamabad	Area effect	-15.2	-3.9	83.0	42.3
	yield effect	116.7	105.6	12.1	24.6
	interaction effect	-1.5	-1.7	4.9	33.2
Rangareddy	Area effect	94.5	128.0	36.6	2.5
	yield effect	6.3	-38.4	54.1	96.5
	interaction effect	-0.8	10.4	9.3	0.9
Warangal	Area effect	9.7	6.2	77.3	54.0
	yield effect	89.2	93.4	16.5	20.5
	interaction effect	1.2	0.4	6.2	25.5
Telangana	Area effect	-79.8	34.1	71.0	46.1
	yield effect	188.2	59.7	21.2	28.5
	interaction effect	-8.5	6.3	7.8	25.4

periods. The Instability indices revealed that the degree of instability for area and production was higher during period III (49.17 and 52.33 respectively) in comparison to period I (44.66 and 46.56 respectively) and II (46.31 and 50.86 respectively). In the overall period production registered the highest instability (56.48) followed by area and yield with instability indices of 49.64 and 42.87 respectively.

Decomposition analysis

Decomposition analysis is used to study the contribution of area, yield, and their interaction effects on the variability of production. The source of production growth was decomposed into three effects *i.e*., area, yield, and interaction effect. Examining Table 5, results revealed that in the period I yield effect was found to be a positive and major contributor to production of rice in almost all districts except for Nalgonda which has a negative yield effect (-1.8) and Rangareddy though showed positive yield effect (6.3) area is the major contributor of production of rice in both the districts. It is evident from the study that during period-I area effect contributing to the increase in rice production is highest in Nalgonda (101.7 percent) followed by Rangareddy (94.5percent), whereas the change in production due to yield effect was recorded highest in Medak (415.6 percent) followed by Karimnagar (137.5 percent). The contribution of interaction effect was observed highest in Adilabad (44 percent) followed by Nizamabad (33 percent). In contrast to the high positive yield effect, Medak has shown a high negative area effect (-274.7 percent) on the production of rice.

In period II area effect was found to be positive in almost all districts except for Medak which is negative whereas interestingly yield effect was found to be positive and a major contributor to the production of rice in the Medak district (125.3). The contribution of area (257.1) to the production of rice was found high in the Adilabad district, in contrast, the yield effect was found to be negative(-204.9). The interaction and yield effect were also found positive in almost all districts.

It is evident from table 5 that in period III, the area, yield and interaction effect was found to be positive in all districts except the Medak which has a negative yield effect. The area effect was more responsible for production in period III in most of the districts and was shown a higher area effect (131) by the Medak district. The yield was a major source of production in Khammam (63.5) in comparison to other districts.

In the overall period area, yield and interaction effect were found to be positive as observed in period III except Medak in which yield (118.9) was a positive and high profound contributor to the production but area (-10.2) and interaction effect (-8.7) were found to be the negative source of production of rice. The area effect was found high in the Nalgonda district (66.2). In this study period, the yield was the main source of production.

Examining the results of area, yield and their relative contribution to production in Telangana it was found that in the overall period, the area effect of Telangana was highly responsible for the production variability *i.e*., 46.1 percent, and the yield and interaction effect accounts for 28.5 percent and 25.4 percent production variability, respectively. Study shows that in Telangana during the period I and II the yield effect (188.2 and 59.7 respectively) was the major source of rice production while interestingly the area effect (71.0) was dominating for rice production during period III than the yield effect.

CONCLUSION

The study revealed that the growth rates for Telangana in the overall period were positive for the area, production, and yield (2.1%, 3.7%, and 1.5% respectively). The Cuddy Della Valle Index for the overall period registered higher, medium, and low instability for production (35.1), area (26.4), and yield (7.6) respectively. Coppock's Instability indices revealed that the degree of instability for area and production was higher during period III in comparison to the periods I and II. One of the major reasons for this could be the increased area under rice in period III, because of the assured irrigation due to completion of many major and minor irrigation projects and revival of tanks under Mission Kakatiya in Telangana. Also, annual rainfall has significantly exceeded normal levels in the last two years and has recorded rainfall of 1033 mm in 2019-20 and 1078 mm in 2020-21. This, combined with the government's investment in irrigation infrastructure, has driven increased agricultural output. (Socio-economic outlook 2021, DES, Govt. of Telangana). The decomposition analysis for overall period (1990-91 to 2019-20) revealed that the area effect was highly responsible for the production variability (46.1 percent) in Telangana. The area effect in enhancing the rice production increased over a period of time. Since the scope to increase the area under rice cultivation is limited, the focus should be on the improvement of the yield to meet the future demand for rice.

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Genotype × environment interaction in rice using measures of stability from AMMI model

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ABSTRACT

The present research was conducted to study the stability analysis and comparison between different stability measures from AMMI model in nine rice genotypes. The experiment was conducted in rabi/dry season during 2010-11 in randomized complete block design with three replications at experimental farm of NRRI research station. Eleven stability measures of AMMI model have been used in this study. Spearman's rank correlation was used to measure the relationship between measures of stability from AMMI model. Genotypic and environment effects are significant at 1% whereas their GE interaction is significant at 5%. WITA12 genotype was found to be the most stable while Lalat was found to be the least stable using seven models AMMI Stability Index, AMMI based stability parameter, Sum Across Environments of Absolute Value of GEI Model, Annicchiarico's D Parameter values, Stability Measure based on Fitted AMMI Model, Modified AMMI Stability Index and Absolute Value of the Relative Contribution of IPCs to the Interaction. Annada was most stable and Naveen was least stable using three models Zhang's D Parameter value, Averages of the Squared Eigenvector Values and Simultaneous Selection Index for Yield and Stability. IR64 was the most stable using Sums of the Absolute Value of the IPC Scores Model. Sums of the Absolute Value of the IPC Scores positively and significantly correlated with AMMI Stability Value, Averages of the Squared Eigenvector Values, Modified AMMI Stability Value but not correlated with Sum Across Environments of GEI Model. Modified AMMI Stability Value positive and significantly correlated with Averages of the Squared Eigenvector Values while negatively correlated with Sum Across Environments of GEI Model. Averages of the Squared Eigenvector Values significantly and positively correlated with AMMI Stability Value but negatively correlated with Sum Across Environments of GEI Model.

Key words: *Rice, AMMI model, stability, genotype × environment interaction, heatmap*

INTRODUCTION

Rice is the world's most important food crop grown for more than 6000 years in South Asia. India has the world's largest area and is the second highest producer of rice. In Odisha, about 3.94 million hectare area was used for rice cultivation during 2019-20. Odisha ranked fifth in rice production with the production of 8.36 million tonnes in 2019-20. (DES (GOI), 2020). Rice farming is the backbone of agriculture in Asia as over 90% of the world's rice is produced and consumed in this region.

Different rice genotypes perform differently in different environments. Even the same genotype performs differently in multi-environmental conditions. The performance of any genotype is the result of the genotypic effect (G) of the cultivar, the environment (E) effect in which the genotype is grown, and the interaction between genotypic and environmental effects (GEI). Interaction between these two explanatory variables gives insight for identifying genotypes suitable for specific environments. The knowledge of GEI is of great importance in developing improved varieties/hybrids. When genotypes are tested over a series of environments/locations, the relative ranking of these genotypes for any given attribute is rarely the same at each environment/location. Such changes in order, ranking and relative values among the genotypes over several environments are due to the phenomenon of G × E interaction.

The additive main effect and multiplicative interaction (AMMI) method combines analysis of variance and principal components analysis into a unified approach (Gauch, 1988). Gauch and Zobel (1988) showed that, AMMI model can be used to analyze multi-location trials. Some methods are based on the AMMI model, *e.g.,* Averages of the Squared Eigenvector Values (EV) (Zobel, 1994), Sum Across Environments of GEI Model (AMGE) (Sneller et al., 1997), Annicchiarico's D Parameter value (Da) (Annicchiarico, 1997), Sums of the Absolute Value of the IPC Scores (SIPC) (Sneller et al., 1997), Zhang's D Parameter value (Dz) (Zhanget al., 1998), Stability Measure Based on Fitted AMMI Model (FA) (Raju, 2002), Simultaneous selection indices (Ii) (Rao and Prabhakaran, 2005), AMMI Based Stability Parameter value (ASTAB) (Rao and Prabhakaran, 2005), Sum Across Environments of Absolute Value of GEI Model (AVAMGE) (Zali et al., 2012), Modified AMMI Stability Value (MASV) (Zali et al., 2012), The Absolute Value of the Relative Contribution of IPCs to the Interaction (Za) (Zaliet al., 2012), AMMI Stability Index (ASI) (Jambhulkar et al., 2015; Jambhulkar et al., 2017).

A biplot was constructed using first two principal components. For better description of the interaction, both first and second PC scores of genotypes and environments are considered for plotting. Biplot formulation of interaction will be successful only when significant proportion of GEI is concentrated in the first or first two PC axes. When the stability difference among different genotypes becomes very close, it will be difficult to differentiate the genotypes with respect to stability. Because of the limitation of biplot concerning stability conclusion, attempt has been made to use different AMMI models for comprehensive study of stability measures. Hence, the objective of the study is to identify the G × E interaction of rice genotypes using different AMMI stability models and to identify the stable genotype; and to compare different stability method.

MATERIAL AND METHODS

The study was carried during 2010-11 at the research farm of ICAR-National Rice Research Institute, Cuttack. The experiment was carried-out in a Randomized Complete Block Design (RCBD) with three replications. Nine rice genotypes were used *viz.*, Annada, Satabdi, Naveen, WITA12, Lalat, MTU1010, IR64, Vandana and Ratna. These genotypes were denotes as genotype 1, genotype 2, genotype 3, genotype 4, genotype 5, genotype 6, genotype 7, genotype 8 and genotype 9 respectively. The rice genotypes were sown during three different dates *i.e.*,15th November 2010, 15th December 2010 and 15th January 2011 during the year 2010-11.

Measures of stability from AMMI Model

AMMI model

The Additive Main effect and Multiplicative Interaction (AMMI) method proposed by Gauch (1992) is a statistical tool which leads to identification of stable genotypes with their adaptation behavior in an easy manner. In this method main effects are initially accounted for a regular analysis of variance and then the interaction is analyzed through principal component analysis.

$$Y_{ijk} = \mu + G_i + E_j + \quad \lambda_k \alpha_{ik} \gamma_{jk} + e_{ijk}$$

where, Y_{ij} is the observed mean yield of the i^{th} genotype in j^{th} environment.   is the general mean. G_i and E_j is the effects of genotype and environment respectively. 2_k is the singular value of the k^{th} axis in the PCA. $_{ik}$ is the eigenvector of the i^{th} genotype for the k^{th} axis. $_{jk}$ is the eigenvector of the j^{th} environment for the k^{th} axis. Here, n is the number of principal components in the model. e_{ijk} is the average of the corresponding random errors

Various AMMI models were derived from AMMI analysis as explained below:

Sum Across Environments of GEI Model (AMGE) (Sneller et al., 1997)

AMGE considered all significant interaction principal components (IPCs) in the AMMI model for calculation. The Model AMGE is computed as follows:

$$AMGE = \Sigma^{E}_{j-1} \Sigma^{N'}_{n=1} \lambda_n \gamma_{in} \delta_{jn}$$

where, N' is the number of significant IPCs (number of IPC that were retained in the AMMI model via F tests);2_n is the singular value for n^{th} IPC and correspondingly $2\ _n$ is its eigen value; $_{in}$ is the eigenvector value for i^{th} genotype; and $_{jn}$ is the eigenvector value for the j^{th} environment.

AMMI Stability Index (ASI) (Jambhulkar et al., 2015)

First two interaction principal components (IPCs) have been used for ASI calculation. Simultaneous Selection Index for Yield and Stability (SSI) is also calculated using the value of ASI. ASI is computed as follows:

$$ASI = \sqrt{PC_1^2 \text{ x } \theta_1^2 \quad + \quad PC_2^2 \text{ x } \theta_2^2}$$

where, PC1 and PC2 are the scores of 1st and 2nd IPCs respectively; and $_1$ and $_2$ are percentage sum of squares explained by the 1st and 2nd principal component interaction effect respectively.

AMMI Based Stability Parameter value (ASTAB) (Rao and Prabhakaran, 2005)

ASTAB considered all significant interaction principal components (IPCs) in the AMMI model and is computed as follows;

$$ASTAB = \Sigma_{n=1}^{N'} \lambda_n \gamma_{in}^2$$

where, N' is the number of significant IPCs (number of IPC that were retained in the AMMI model via F tests); 2_n is the singular value for nth IPC and correspondingly 2_n is its eigen value; and $_{in}$ is the eigenvector value for ith genotype.

Sum across environments of absolute value of GEI model (AVAMGE) (Zali et al., 2012)

AVAMGE is computed as follows:

$$AVAMGE = \Sigma_{j=1}^{E} \Sigma_{n=1}^{N'} \mid \lambda_n \gamma_{in} \delta_{jn} \mid$$

where, N' is the number of significant IPCs (number of IPC that were retained in the AMMI model via F tests); $_n$ is the singular value for nth IPC and correspondingly $_n$ is its eigen value; $_{in}$ is the eigenvector value for ith genotype; and $_{jn}$ is the eigenvector value for the jth environment.

Annicchiarico's D Parameter value (Da) (Annicchiarico, 1997)

D_a is computed as follows:

$$D_a = \sqrt{\sum_{n=1}^{N'} \lambda_n \gamma_{in} \quad ^2}$$

where, N' is the number of significant IPCs (number of IPC that were retained in the AMMI model via F tests); $_n$ is the singular value for nth IPC and correspondingly $_n$ is its eigen value; and $_{in}$ is the eigenvector value for ith genotype.

Zhang's D Parameter value (Dz) (Zhang, 1998)

Dzis computed as follows:

$$D_z = \sqrt{\sum_{n=1}^{N'} \gamma_{in}^2}$$

where, N' is the number of significant IPCs (number of IPC that were retained in the AMMI model via F tests); and $_{in}$ is the eigenvector value for ith genotype.

Averages of the Squared Eigenvector Values (EV) (Zobel, 1994)

EV is computed as follows:

$$EV = \Sigma_{n=1}^{N'} \frac{\ _{in}^2}{N'}$$

where, N' is the number of significant IPCs (number of IPC that were retained in the AMMI model via F tests); and $_{in}$ is the eigenvector value for ith genotype.

Stability measure based on Fitted AMMI model (FA) (Raju, 2002)

FA is computed as follows:

$$FA = \Sigma_{n=1}^{N'} \lambda_n^2 \gamma_{in}^2$$

where, N' is the number of significant IPCs (number of IPC that were retained in the AMMI model via F tests); $_n$ is the singular value for nth IPC and correspondingly $_n$ is its eigen value; and $_{in}$ is the eigenvector value for ith genotype.

When N' is replaced by 1 (only first IPC axis is considered for computation), then the parameter FP can be estimated (Zali et al., 2012).

$$FP = \lambda_1^2 \gamma_{i1}^2$$

When N' is replaced by 2 (only first two IPC axes are considered for computation), then the parameter B can be estimated (Zali et al., 2012).

$$B = \Sigma_{n=1}^{2} \lambda_1^2 \lambda_{i1}^2$$

When N' is replaced by N (All the IPC axes are considered for computation), then the parameter estimated is equivalent to Wricke's ecovalence (W_{AMMI}) (Wricke, 1962; Zali et al., 2012).

$$W_{AMMI} = \Sigma_{n=1}^{N'} \lambda_1^2 \gamma_{i1}^2$$

Modified AMMI Stability Value (MASV) (Zali et al., 2012)

A parameter is a modified formula of AMMI Stability Value (ASV) (Purchase et al.,2000). The MASV is computed as follows:

$$MASV = \sqrt{\Sigma_{n=1}^{N'-1} \left(\frac{SSIPC_n}{SSIPC_{n+1}} \times PC_n\right)^2 + PC_{N''}^2}$$

where, $SSIPC_1$, $SSIPC_2$,….., $SSIPC_n$ are the sum of squares of the 1st, 2nd, ..., and nth IPC; and PC1, PC2,…., PCn are the scores of 1st, 2nd, ..., and nth IPC. In this modified AMMI stability parameter, all significant IPCs were used.

Sums of the Absolute Value of the IPC Scores (SIPC) (Sneller et al., 1997)

SIPC considered all significant interaction principal components (IPCs) in the AMMI model. SIPC is computed as follows:

$$SPIC = \Sigma_{n=1}^{N'} | \lambda_n^{0.5} \gamma_{in} |$$

or

$$SPIC = \Sigma_{n=1}^{N'} | PC_n |$$

where, N' is the number of significant IPCs (number of IPC that were retained in the AMMI model via F tests). $_n$ is the singular value for nth IPC and correspondingly $_n$ is its eigen value; $_{in}$ is the eigenvector value for ith genotype; and PC1, PC2,…., PCn are the scores of 1st ,2nd, ..., and nth IPC. The closer the SIPC scores are to zero, the more stable the genotypes are across test environments.

Simultaneous selection indices (*Ii*) (Rao and Prabhakaran, 2005)

The most stable genotype need not necessarily be the highest yielding genotype. Hence, simultaneous selection indices (SSIs) have been proposed for the selection of stable as well as high yielding genotypes. A family of simultaneous selection indices (*Ii*) was proposed by Rao and Prabhakaran (2005) similar to those proposed by Bajpai and Prabhakaran (2000) by incorporating the AMMI Based Stability Parameter (ASTAB) and Yield as components. These indices consist of yield component, measured as the ratio of the average performance of the ith genotype to the overall mean performance of the genotypes under test and a stability component, measured as the ratio of stability information ($1/ASTAB$) of the ith genotype to the mean stability information of the genotypes under test. In the ammistability methodology, the expression has been implemented for all the stability parameters (*SP*) including ASTAB.

$$I_i = \frac{\bar{Y}_i}{Y_{..}} + \alpha \frac{\frac{1}{SP_i}}{\frac{1}{T}\Sigma_{i=1}^{T} \frac{1}{SP_i}}$$

where SPi is the stability measure of the ith genotype under AMMI procedure; Y_i is mean performance of ith genotype; Y_i is the overall mean; T is the number of genotypes under test and is the ratio of the weights given to the stability components (w2) and yield (w1) with a restriction that w1 + w2 = 1.

The SSI proposed by Farshadfar (2008) is called the Genotype stability index (GSI) or Yield stability index (YSI) and is computed by summation of the ranks of the stability index/parameter and the ranks of the mean yields.

$$GSI = YSI = R_{SP} + R_Y$$

where, R_{SP} is the stability parameter/index rank of the genotype and R_Y is the mean yield rank of the genotype.

The Absolute Value of the Relative Contribution of IPCs to the Interaction (Za) by Zali et al. (2012) is computed as follows:

$$Z_a = \Sigma_{n=1}^{N'} | {}_n\gamma_{in} |$$

where, N' is the number of significant IPCAs (number of IPC that were retained in the AMMI model via F tests); $_{in}$ is the eigenvector value for ith genotype; and $_n$ is the percentage sum of squares explained by the nth principal component interaction effect.

Spearman's coefficient of rank correlation (r_s) was used to statistically compare the stability indices used in the present study. Spearman's rank correlation coefficient (r_s) can be described as:

$$r_s = 1 - \frac{6\Sigma d_i^2}{n - 1\ n\ n + 1}$$

Where n is the number of observations and di is the difference of the ranking. The stability measures from AMMI analysis were compared using their ranks for each genotype via calculating Spearman's rank correlation. 'Ammistability' package of R software (Ajay et al., 2018) has been used for the analysis.

RESULTS AND DISCUSSION

Estimation of stability of rice genotypes

The analysis of variance for nine rice genotypes is presented in Table 1. The result shows that environment and genotypic effects are significant at 1% whereas GE interaction is significant at 5%. The result of IPCA has been shown in Table 2. The interaction was explained by first two principal components. PC1 and PC2 explained 79.1% and 20.9% variation respectively for the IPCA. Hence, first two PCs are sufficient to explain 100% variability in the data.

The AMMI model showed that there was a more complex GE interaction which could not facilitate graphical visualization of the genotypes in low dimensions and so it is essential to use an alternative procedure to interpretation of GEI using AMMI parameters.

Table 1. Analysis of variance of nine rice genotypes.

Source	df	MS	F-value
Environment	2	6.760	66.130**
Replication	6	0.102	0.716
Genotype	8	5.643	39.567**
Env×Gen	16	0.336	2.362*
Residuals	48	0.142	

*Significant at 5% probability level, **Significant at 1% probability level

Table 2. Interaction Principle Components analysis along with the variation explained by them.

IPCs	Percent	df	MS	F-value
PC1	79.1	9	0.474	3.32*
PC2	20.9	7	0.161	1.13*

IPCs- Interactive principle components. *Significant at 5% probability level.

The AMMI model used in the present research showed a more complex interaction which required a maximum of two PC axes to account for considerable amount of GEI variation. The mean yield of the genotypes along with eigenvectors has been presented in Table 3. In Table 3, mean yields and interaction principle component (IPC) value of individual genotypes are given which is to be used for further stability calculation. Genotype MTU1010 and Vandana has the highest and lowest mean yield respectively.

AMMI stability measures

Using AMGE model, Lalat has lowest AMGE value having rank 1 and Naveen shows highest AMGE value having rank 9; hence Lalat is the most stable while Naveen is least stable based on AMGE model. Annada yields highest grain yield (5.277t/ha) with rank 1 and Vandada yield lowest grain yield (2.777t/ha) with rank 9. These two ranks have been combined for calculation of SSI. WITA12 ranks first with the SSI value 6 and Annada ranks last with SSI value 14. So, WITA12 is more stable and Annada is least stable based on SSI criterion.

WITA12 and IR64 are more stable genotypes according to AMMI stability index parameter and Lalat is the most unstable genotype. MTU1010 and Vandana are the highest and lowest yielders with yield 5.278(t/ha) and 2.778(t/ha) respectively. According to SSI, WITA12 shows lowest SSI value (0.051) and Lalat shows the highest SSI value(0.529). So, WITA12 is the most stable and Lalat is the least stable genotypes using SSI model. WITA12 is more stable according to

Table 3. Mean yield and interaction principle component scores of genotypes and locations.

S. no.	Type	Mean yield (t/ha)	PC1	PC2
1	Genotype 1	3.811	-0.172	-0.106
2	Genotype 2	4.056	0.474	0.178
3	Genotype 3	4.567	-0.473	-0.387
4	Genotype 4	5.222	0.001	-0.243
5	Genotype 5	4.056	0.669	0.023
6	Genotype 6	5.278	-0.282	0.363
7	Genotype 7	4.111	-0.065	0.156
8	Genotype 8	2.778	0.217	-0.311
9	Genotype 9	4.956	-0.368	0.327
10	Location 1	4.804	-0.775	0.316
11	Location 2	4.337	0.005	-0.639
12	Location 3	3.804	0.769	0.323

this parameter with lowest ASTAB value and Lalat is the least stable genotype with highest ASTAB value. WITA12 shows lowest SSI value and Lalat shows highest SSI value. So WITA12 is the most stable and Lalat is least stable genotype with SSI ranking among the nine genotypes. Based on AVAMGE model, WITA12 shows the lowest AVAMGE value (0.001) and ranked first. Similarly Lalat has the worst ranking with AVAMGE value 0.869, but both of the genotype have above average mean yield i.e. 5.222t/ha and 4.056t/ha respectively. The most stable and least stable genotypes according to SSI ranking are WITA12 and Lalat with SSI value 3 and 15.5 respectively. WITA12 is the most stable and Lalat is the least stable genotype based on AVAMGE model. The mean yield values of genotypes MTU1010, WITA12, Ratna, Naveen, IR64, Satabdi, Lalat, Annada and Vandana ranked from 1st to 9th. Using SSI model WITA12 has the lowest value (3) and Lalat has the highest value (15.5). Hence, WITA12 and Annada are the most stable and most unstable genotypes respectively using SSI criterion. Based on Zhang's D parameter value model, Annada shows lowest (0.001) and Naveen shows highest Dz values (0.433). So Annada is most stable and Naveen is least stable genotype among the nine genotypes. WITA12 and Lalat are the top and bottom ranker in SSI ranking indicating the most stable and least stable genotypes in this model. MTU1010 and IR64 have same SSI ranking as they have same SSI value after adding the ranking of Dz and respective mean yield ranking. Genotypes Naveen and Vandana ranked same with the SSI parameter (7.5). Annada, IR64 and WITA12 are the most stable and genotypes Ratna, Lalat and Naveen are the least stable based on EV model. The genotype WITA12, MTU1010 and IR64 are the most stable and Lalat, Naveen and Vandana are the least stable genotypes using SSI criteria. Genotypes WITA12, IR64 and Annada are most stable genotypes and genotypes Lalat and Satabdi are the most unstable ones based on FA model. Using MASV model, genotypes WITA12, IR64 and Annada are more stable genotypes and Lalat is the least stable which is same in many of the other AMMI stability models. WITA12 shows lowest and Lalat shows highest SSI value. Hence, WITA12 and Lalat are the most stable and least stable genotypes using SSI criterion. Genotype IR64, WITA12 and Annada are the most stable genotypes according to SIPC model and Vandana is the most unstable genotype. Lalat shows highest SSI value (13.5) and WITA12 shows lowest SSI value (4). So Lalat and WITA12 are the least stable and most stable genotypes respectively. Based on Za model, WITA12 is the most stable genotype with the lowest Za value (0.065) and Lalat is the least stable genotype with the highest Za value (0.490). Using SSI criteria, Lalat is the least stable genotype with high SSI value (15.5) and WITA12 and MTU1010 are the most stable genotypes with lower SSI values.

Comparison of AMMI stability models

Rank of different stability parameters has been presented in Table 4. Genotype WITA12 was found to be most stable while Lalat was found to be least stable

Table 4. Rank of mean yield and different stability models for nine genotypes.

Genotypes	Name	R(Y)	AMGE	ASI	ASTAB	AVAMGE	DA	DZ	EV	FA	MASV	SIPC	Za
1	Annada	8	6	3	3	3	3	1	1	3	3	3	3
2	Satabdi	6.5	2	7	8	8	8	5	5	8	7	6	7
3	Naveen	4	9	8	7	7	7	9	9	7	8	9	8
4	WITA12	2	4	1	1	1	1	3	3	1	1	2	1
5	Lalat	6.5	1	9	9	9	9	8	8	9	9	7	9
6	MTU1010	1	7	5	5	5	5	6	6	5	5	5	5
7	IR64	5	5	2	2	2	2	2	2	2	2	1	2
8	Vandana	9	3	4	4	4	4	4	4	4	4	4	4
9	Ratna	3	8	6	6	6	6	7	7	6	6	8	6

Sum Across Environments of GEI Model (AMGE), AMMI stability index (ASI), AMMI based stability parameter (ASTAB), Sum Across Environments of Absolute Value of GEI Model (AVAMGE), Annicchiarico's D Parameter values (Da), Zhang's D Parameter value (Dz), Averages of the Squared Eigenvector Values (EV), Stability Measure Based on Fitted AMMI Model (FA), Modified AMMI Stability value (MASV), Sums of the Absolute Value of the IPC Scores (SIPC), Absolute Value of the Relative Contribution of IPCs to the Interaction (Za), Rank of mean yield R(Y).

using seven models AMMI Stability Index, AMMI based stability parameter, Sum Across Environments of Absolute Value of GEI Model, Annicchiarico's D Parameter values, Stability Measure based on Fitted AMMI Model, Modified AMMI Stability Index and Absolute Value of the Relative Contribution of IPCs to the Interaction. Annada was most stable and Naveen was least stable using three models Zhang's D Parameter value, Averages of the Squared Eigenvector Values and Simultaneous Selection Index for Yield and Stability. IR64 was most stable using Sums of the Absolute Value of the IPC Scores Model. Lalat is most stable using Sum Across Environments of GEI Model.

Table 5 showed that WITA12 is the most stable and Lalat is the most unstable with ranking of 11 SSI indices *i.e.*, AMMI stability index (ASI), AMMI based stability parameter (ASTAB), Sum Across Environments of Absolute Value of GEI Model (AVAMGE), Annicchiarico's D Parameter values (Da), Zhang's D Parameter value (Dz), Averages of the Squared Eigenvector Values (EV), Stability Measure Based on Fitted AMMI Model (FA), Modified AMMI Stability value (MASV), Sums of the Absolute Value of the IPC Scores (SIPC), Absolute Value of the Relative Contribution of IPCs to the Interaction (Za). In AMGE_SSI ranking WITA12 is the most stable but the most unstable genotype is Annada among the nine rice genotypes.

The heatmap of Fig. 1 and Fig. 2 shows ranks of different AMMI stability models along with mean yield and simultaneous selection indices along with mean yield of nine genotypes respectively. The dark green colour in the heatmap shows more stable genotype with rank 1, while light green colour shows the least stable genotype with rank 9. Stability of genotypes decreases with decrease in colour intensity in the heatmaps.

In Figure 1, the genotypes 4 (WITA12) and 7 (IR64) have the darkest coloration indicating higher stability in most of the parameter ranking systems. Similarly genotypes 3 (Naveen) and 5 (Lalat) have the lighter coloration in most of the ranking parameters indicating least stable genotypes among the nine genotypes. Again genotypes 1 (Annada) and 8 (Vandana) are the medium dark colour graph indicating stable genotypes after genotypes 4 (WITA12) and 7 (IR64). Fig. 2 indicates that genotypes 4 (WITA12), 7 (IR64) and 6 (MTU1010) have the darker green coloration in the ranking system indicating the most stable genotypes among the nine genotypes. Similarly genotypes 5 (Lalat) and 2 (Satabdi) have the lighter coloration graph indicating the least stable genotypes in the SSI rankings.

Correlation among AMMI stability models

Spearman's rank correlation was computed for each pair of mean yield and measures of stability from AMMI model (Table 6). The table indicates positive and significant correlation (at 1%) among different stability parameters except with Sum Across Environments of

Table 5. Simultaneous Selection Indices Ranks of nine genotypes.

Genotype	AMGE_ SSI	ASI_SSI	ASTAB_ SSI	AVAMG E_SSI	Da_ SSI	Dz_ SSI	EV_SSI	FA_SSI	MASV_ SSI	SIPC_ SSI	Za_ SSI	SP_ SSI
1 (Annada)	9	5	5.5	5.5	5.5	4	4	5.5	5	4.5	5	4
2 (Satabdi)	4	8	8	8	8	6	6	8	8	6	8	6
3 (Naveen)	8	6	5.5	5.5	5.5	7.5	7.5	5.5	6	7.5	6	7.5
4 (WITA12)	1	1	1	1	1	1	1	1	1	1	1	1
5 (Lalat)	2	9	9	9	9	9	9	9	9	9	9	9
6(MTU1010)	3	2	2	2	2	2.5	2.5	2	2	2.5	2	2.5
7 (IR64)	5	3	3	3	3	2.5	2.5	3	3	2.5	3	2.5
8 (Vandana)	7	7	7	7	7	7.5	7.5	7	7	7.5	7	7.5
9 (Ratna)	6	4	4	4	4	5	5	4	4	4.5	4	5

Sum Across Environments of GEI Model (AMGE), AMMI stability index (ASI), AMMI based stability parameter (ASTAB), Sum Across Environments of Absolute Value of GEI Model (AVAMGE), Annicchiarico's D Parameter values (Da), Zhang's D Parameter value (Dz), Averages of the Squared Eigenvector Values (EV), Stability Measure Based on Fitted AMMI Model (FA), Modified AMMI Stability value (MASV), Sums of the Absolute Value of the IPC Scores (SIPC), Absolute Value of the Relative Contribution of IPCs to the Interaction (Za), Stability Parameter (SP), Simultaneous Selection Index for Yield and Stability (SSI).

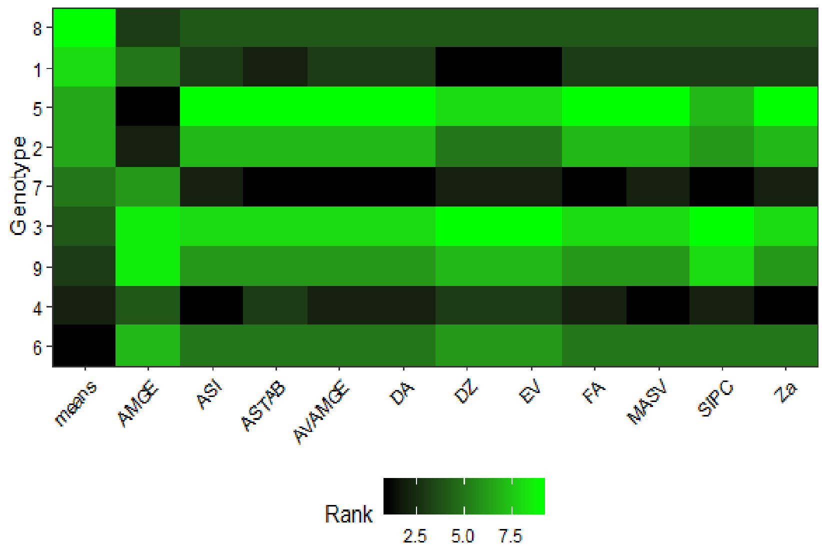

Fig. 1. Heatmapof AMMI stability parameters and mean yield of nine genotypes

GEI Model (AMGE). The AMGE parameter is negatively correlated with all other ten parameter estimates *viz*., the value of correlation is negative and insignificant with AMMI stability index (ASI), AMMI based stability parameter (ASTAB), Sum Across Environments of Absolute Value of GEI Model(AVAMGE), Annicchiarico's D Parameter values (Da), Zhang's D Parameter value (Dz), Averages of the Squared Eigenvector Values (EV), Stability Measure Based on Fitted AMMI Model (FA), Modified AMMI Stability value (MASV), Sums of the Absolute Value of the IPC Scores (SIPC), Absolute Value of the Relative Contribution of IPCs to the Interaction (Za). Zali et al. (2012) also observed that AMGE is negatively correlated with EV, SIPC, DZ, DA, MASV, AVAMGE and FA. The correlation of all other stability parameters is positive and significant. Zali et al. (2012) also observed that SIPC, Za, DA, DZ, AVAMGE were positively correlated with each other.

Table 6. Correlation among stability parameters.

Variables	AMGE	ASI	ASTAB	AVAMGE	DA	DZ	EV	FA	MASV	SIPC	Za
AMGE											
ASI	-0.48										
ASTAB	-0.36	0.97*									
AVAMGE	-0.32	0.97*	0.98*								
DA	-0.41	0.99*	0.99*	0.99*							
DZ	-0.13	0.80*	0.93*	0.95*	0.92*						
EV	-0.11	0.87*	0.95*	0.95*	0.93*	0.99*					
FA	-0.50	0.98*	0.98*	0.95*	0.98*	0.86*	0.88*				
MASV	-0.48	1.00*	0.97*	0.97*	0.99*	0.85*	0.87*	0.98*			
SIPC	-0.04	0.85*	0.90*	0.94*	0.91*	0.97*	0.96*	0.82*	0.85*		
Za	-0.32	0.98*	0.97*	0.99*	0.98*	0.92*	0.93*	0.95*	0.98*	0.94*	

*Significant at 1% probability level

Sum Across Environments of GEI Model (AMGE), AMMI stability index (ASI), AMMI based stability parameter (ASTAB), Sum Across Environments of Absolute Value of GEI Model (AVAMGE), Annicchiarico's D Parameter values (Da), Zhang's D Parameter value (Dz), Averages of the Squared Eigenvector Values (EV), Stability Measure Based on Fitted AMMI Model (FA), Modified AMMI Stability value (MASV), Sums of the Absolute Value of the IPC Scores (SIPC), Absolute Value of the Relative Contribution of IPCs to the Interaction (Za).

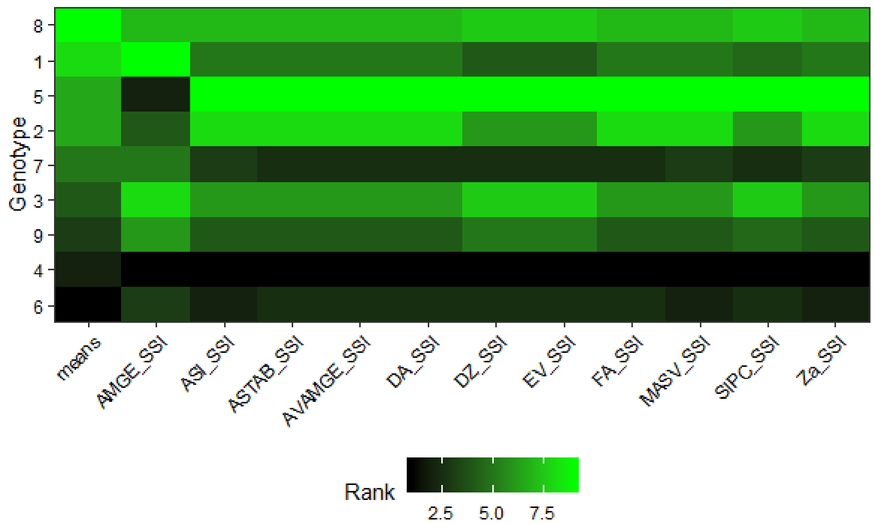

Fig. 2. Heatmap of simultaneous selection indices and mean yield of nine genotypes.

Table 7 shows the correlation between SSI of AMMI stability parameters. All the variables are significantly and highly correlated among each other except Sum Across Environments of GEI (AMGE). ASTAB has very high correlation (>0.90) with other models. AVAMGE is perfect positively correlated with DA and FA models. Similarly, ASI is perfectly and positively correlated with MASV and Za. AVAMGE has higher correlation (>0.90) with rest of the AMMI models. DA is perfectly correlated with FA and has high correlation (>0.90) with other AMMI models. DZ is perfectly correlated with EV and has higher correlation (>0.90) with other models. EV has very high correlation (>0.90) with other models. Similarly FA and SIPC have higher correlation (>0.90) with other models. MASV has perfect correlation with Za. Similarly result was observed by Verma and Singh (2020) were SIPC, ASTAB, EV were positively correlated with among each other.

Table 7. Correlation among simultaneous selection indices.

Variables	AMGE	ASI	ASTAB	AVAMGE	DA	DZ	EV	FA	MASV	SIPC	Za
AMGE											
ASI	0.32										
ASTAB	0.19	0.98*									
AVAMGE	0.27	0.99*	0.99*								
DA	0.27	0.99*	0.99*	1.00*							
DZ	0.30	0.95*	0.96*	0.95*	0.95*						
EV	0.30	0.95*	0.96*	0.95*	0.95*	1.00*					
FA	0.27	0.99*	0.99*	1.00*	1.00*	0.95*	0.95*				
MASV	0.32	1.00*	0.98*	0.99*	0.99*	0.95*	0.95*	0.99*			
SIPC	0.45	0.95*	0.95*	0.96*	0.96*	0.95*	0.95*	0.96*	0.95*		
Za	0.32	1.00*	0.98*	0.99*	0.99*	0.95*	0.95*	0.99*	1.00*	0.95*	

*Significant at 1 % probability level

Sum Across Environments of GEI Model (AMGE), AMMI stability index (ASI), AMMI based stability parameter (ASTAB), Sum Across Environments of Absolute Value of GEI Model (AVAMGE), Annicchiarico's D Parameter values (Da), Zhang's D Parameter value (Dz), Averages of the Squared Eigenvector Values (EV), Stability Measure Based on Fitted AMMI Model (FA), Modified AMMI Stability value (MASV), Sums of the Absolute Value of the IPC Scores (SIPC), Absolute Value of the Relative Contribution of IPCs to the Interaction (Za), Simultaneous Selection Index for Yield and Stability (SSI).

CONCLUSION

Conventional methods like ANOVA, regression analysis and PCA are often not efficient in analyzing the complex data. AMMI analysis combines ANOVA and PCA in a single model and helps in visual interpretation of complex multi-environment data. AMMI confirms the significant variation among the genotypes and environments and also for the GEI for all the characters under study. In the present study first two PCs are sufficient to explain the GEI variability in the data. The stable genotypes are different for different models. It can be observed that ranks of genotypes also vary with Simultaneous Selection Indices ranking. Lalat is more stable using AMGE model. In ASV and MASV the ranking of genotypes are the same. WITA12 was found to be most stable while Lalat was found to be least stable using seven models AMMI Stability Index, AMMI based stability parameter, Sum Across Environments of Absolute Value of GEI Model, Annicchiarico's D Parameter values, Stability Measure based on Fitted AMMI Model, Modified AMMI Stability Index and Absolute Value of the Relative Contribution of IPCs to the Interaction. WITA12 is the most stable and Lalat is the most unstable with all SSI indices ranking except AMGE_SSI.

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SHORT COMMUNICATION

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Growth and yield of some promising Egyptian rice genotypes under foliar application of different stimulating compounds

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ABSTRACT

The Effects of foliar application of different stimulating compounds on the growth and yield of three promising Egyptian rice genotypes were studied in a field experiments at the Experimental Farm of Rice Research and Training Center (RRTC), Egypt, during consecutive rice seasons 2018 and 2019. Three rice Egyptian genotypes (Sakha108, GZ9399, and GZ10154) were tested under different stimulating compounds like Ascobine (13% citric acid, 25% ascorbic acid plus 62% organic materials), humic acid (65% humic acid +10% K_2O), Amino acid (27.38 % mixed amino acid + 9% micronutrients + 2% magnesium), vulvic acid (50% Vulvic acid + 20% organic acid), N:P:K::20:20:20 and potassium sulphate (50% K_2O) The growth characteristics like number of tillers, chlorophyll content, leaf area and dry matter accumulation at 30 and 45 days after transplanting were determined . Number of panicles m^{-2}, panicle length, panicle weight, 1000-grain weight, number of filled grains per panicle, number of unfilled grains per panicle, grain yield and straw yield were studied at harvest. There were significant variations among the studied genotypes in terms of the studied characteristics like (chlorophyll content and grain yield). The foliar application of stimulating compounds significantly increased growth, yield and yield components of the studied rice genotypes. There were significant differences among the response of the studied genotypes to the application of the stimulating compounds. Application of amino acid to Sakha108 recorded the highest grain yield.

Key words: *Rice genotypes, amino acids, ascobine and grain yield*

INTRODUCTION

Rice demand is increasing year after year at the international and the national levels due to population growth. On the other hand, the available natural resources such as land and water are limited. The optimum way to overcome this problem is using new technologies to increase rice production per unit area. (Fageria et al., 2009) reported that to achieve more economic yield of different crops, essential plant nutrients are applied to as soil or foliar application. Soil application method is more common and most effective for nutrients. But, foliar fertilization requires fewer amounts than soil application so foliar application is more economic and effective.

Amino acids are organic molecules that contain nitrogen, carbon, hydrogen, and oxygen, and have an organic side-chain in their structure, a characteristic that distinguishes the different amino acids (Buchanan et al., 2000). The main amino acids synthesized by plants are the glutamate, glutamine, and aspartate, and from these other amino acids may be formed (Teixeira et al., 2017). Liu and Lee 2012 reported that traditional models of nutrient cycling assume that organic N matter must be decomposed by soil microorganisms to release inorganic N, before that N becomes available for plant uptake. But, there are growing evidences that plant can absorb organic N directly. Earlier studies of nutrient absorption demonstrated that higher plants could take up amino acids directly. They also reported that amino acids play an important role in enzyme regulation, nitrate uptake, N assimilation and yield of higher crops. Gharib et al., 2001 determined the effect of some stimulating compound applications and nitrogen fertilizer levels on growth and yield characteristics of Egyptian hybrid rice. The stimulating compounds were ascorbic acid, ascobin (13% citric cida, 25% ascorbic acid plus 62% organic materials), hammer (86% humate potassium), pepton (85% amino acid + 12% organic nitrogen + 3% K_2O) and water as a control. Foliar application of stimulating compounds significantly increase plant height, dry matter accumulation, number of tillers per hill, number of panicles per hill, panicle weight, number of filled grains per panicle, number of unfilled grains per panicle, 1000-grain weight, grain and straw yields. Fahramand et al., 2014 indicated that humic acids are heterogeneous, which include in the same macromolecule, hydrophilic acidic functional groups and hydrophobic groups. A distinction on the effects of humic acids should be made between indirect and direct effects on plants growth. Under water stress, foliar fertilization with humic molecules increased leaf water retention and the photosynthetic and antioxidant metabolism. Humic acid increase root length, root number and root branching. This research was conducted to investigate the response of three Egyptian rice genotypes to different stimulating compounds under the Egyptian condition.

The Experiment was carried out at the Experimental Farm of Rice Research and Training Center (RRTC), Egypt, during consecutive rice seasons 2018 and 2019. Three rice genotypes (Sakha108, GZ9399 and GZ10154) were tested under different stimulating compounds (amino acids - NPK 20:20:20 - ascobin - vulvic acids - humic acids - potassium sulphate - control). Stimulating compounds were applied tow times at 20 and 40 days after transplanting (DAT). Amino acid (27.38% mixed amino acids + 9% micronutrients + 2% magnesium) and humic acid (65% humic acid + 10% K_2O) were applied at the rate of 1 g L^{-1}. Vulvic acid (50% vulvic acid + 20% organic acid) was applied at the rate of 1 ml L^{-1}. NPK (20-20-20) and potassium sulphate (50% K_2O) were applied at the rate of 2%. Sakha108 is a newly released variety while GZ9399 and GZ10154 are promising genotypes. Split plot design with four replications was used. The three rice genotypes were arranged in the main plots, while the seven stimulating compounds were arranged in sub plots.

Soil samples were collected from the experimental site at depth of 0 to 25 cm from soil surface before cultivation to study the soil mechanical and chemical properties of the experimental site according to Piper (1950). The mechanical and chemical analyses of the soil are presented in Table 1.

Clean seeds of each genotype were soaked in water for 48 hours then incubated for 24 hours to enhance the germination. The pre-germinated seeds were carefully sown in the nursery bed. After 25 from nursery sowing, seedlings were pulled, transferred and transplanted on 2nd and 4th of June for 2018 and 2019 respectively. Three to four seedlings per hill were used at hill spacing of 0.2 × 0.2 m. The plot size was 12 m^2 (3 x 4 m). The water depth was maintained at 5 cm after transplanting up to 10 days before harvesting. Insects, diseases, and weeds were controlled to avert any crop damage. Ten days before harvest; the plots were drained to facilitate harvesting.

The growth and yield characteristics were determined according to Standard Evaluation System

Table 1. Soil mechanical and chemical properties of the experimental site.

Soil characteristics	Season	
	2018	2019
Soil texture (%)	Clayey	Clayey
clay %	57.00	55.00
Sand %	12.00	12.00
Silt %	31.00	33.00
pH (1: 2.5 water suspension)	8.15	8.12
EC (dSm^{-1})	2.06	2.04
Organic matter		
Available P mg Kg^{-1}	1.46	1.39
Available NH_4 mg Kg^{-1}	15.45	14.12
Available NO_3 mg Kg^{-1}	13.51	13.63
Available K mg Kg^{-1}	10.40	10.88
Cations (meq L^{-1})	346	357
Ca^{++}	7.30	6.10
Mg^{++}	2.60	1.50
Na^{+}	12.20	13.30
K^{+}	0.52	0.53
Anions (meq L^{-1})		
HCO_{3-}	5.62	5.03
Cl_{-}	14.20	14.10
SO_{4--}	2.80	2.30
CO_{3--}	0.00	0.00

for Rice, IRRI 2002. The growth characteristics include number of tillers, chlorophyll content SPAD, leaf area and dry matter accumulation at 30 and 45 days after transplanting. Number of panicles m^{-2}, panicle length, panicle weight, 1000-grain weight, number of filled grains per panicle, number of unfilled spikelets per panicle, grain yield t ha^{-1} and straw yield t ha^{-1} were studied at harvest.

Statistical analysis: The collected data were subjected to statistical analysis and were tested at 5% level of significance to interpret the differences among the treatments.

Number of tillers per m^2

The rice genotypes exhibited marked differences in the number of tillers per unit area irrespective of the date of sampling as shown in Table 2. The genotype Sakha108 recorded the highest values of tillers per m^2 at 30 and 45 days after transplanting (DAT). Foliar application of different stimulating compounds increased significantly the number of tillers per m^2 at 30 and 45 DAT. Amino acids foliar application recorded the highest values compared to other compounds followed by NPK 20:20:20. This might be due to that foliar application of amino acids and NPK accelerate the absorption of the amino acids and nutrients that penetrate the cuticle of the leaf or the stomata and then enter the cells. Hence, crop response occurs in short time (Fageria et al., 2009). (Hasewaga et al., 2000) reported that foliar spray of nutrients increased the photosynthesis and tiller number of rice. There were significant differences due to the interaction between rice genotypes and stimulating compounds at 30 and 45 DAT. Application of different stimulating compounds generally increased the tillering ability of the three rice genotypes. Sakha 108 recorded the highest values of tillers per m^2 under the foliar application of amino acids at 30 and 45 DAT followed by GZ9399 combined with amino acids foliar application. Similar results were recorded in both the seasons.

Chlorophyll content

Statistical analysis documented that there were significant differences among the rice genotypes in terms of chlorophyll content (SPAD value) at 30 and 45 DAT (Table 2). Higher chlorophyll content was recorded in GZ9399 at 30 DAT compared to other genotypes. AT 45 DAT, Sakha108 and GZ10154 surpassed GZ9399. These variations in chlorophyll content might be due to genotypic characteristics. Amino acid application recorded the highest values of chlorophyll content at 30 and 45 DAT followed by NPK 20-20-20. While control treatment (tap water spray) recorded the lowest values of chlorophyll content at 30 and 45 DAT. (Sadak et al., 2014) indicated that the ameliorative effect of

Table 2. Number of tiller m^{-2} and chlorophyll content of three rice genotypes under different stimulating compounds at 30 and 45 days after transplanting DAT in 2018 and 2019 seasons.

Treatment	Number of tiller m^{-2}				Chlorophyll content			
	30 DAT		45 DAT		30 DAT		45 DAT	
	2017	2018	2017	2018	2017	2018	2017	2018
Genotype:								
Sakha108	423.33a	416.0a	418.7a	412.6a	40.87b	40.78b	38.77a	38.84a
GZ9399	413.77b	402.4b	408.0b	401.0b	41.43a	41.14a	39.62a	39.75a
GZ10154	369.82c	341.8c	363.6c	357.5c	40.50c	40.51c	37.21b	37.75b
F test	*	*	*	*	*	*	*	
Stimulating compound:								
Amino acid	453.86a	442.9a	447.2a	436.6a	42.36a	42.15a	40.61a	41.16a
NPK 20:20:20	430.77b	398.6b	425.2b	416.1b	41.33b	41.31b	39.50b	39.83b
Ascobin	415.13c	396.8b	410.4c	403.2c	41.11c	40.96c	39.03c	39.23c
Vulvic acid	401.88d	377.8c	397.2d	391.4d	41.01d	40.91d	38.70c	38.93c
Humic acid	392.26e	375.5c	388.1e	381.8e	40.63e	40.30e	38.26d	38.40d
Potassium sulphate	369.68 f	367.3c	365.5f	363.7f	40.25f	40.20f	37.65e	37.88e
Control	352.56g	348.0d	343.7g	339.7g	39.85g	39.85g	36.00f	36.03f
F test	*	*	*	*	*	*	*	*
Interactions A x B	**	**	**	**	**	**	**	**

amino acids might be linked to the observable increase in photosynthetic pigments as well as, leaf number consequently the efficiency of the photosynthetic apparatus was increased due to amino acid treatments. (Venkateshprasath et al., 2017) reported that humic acid foliar spray might have improved the chlorophyll content, increased the CO_2 assimilation in plants. Genotype X stimulating compound interaction was significant for chlorophyll content at 30 and 45 DAT. Thus, genotypic performance may be specific under different stimulating compounds application. Foliar application of amino acids to GZ9399 rice genotype recorded the highest content of chlorophyll compared to other combinations.

Leaf area index (LAI)

Leaf area index varied significantly among the tested rice genotypes in the both seasons (Table 3). GZ9399 recorded the highest values of LAI followed by Sakha108. These variations are probably due to the differences in genotypic performance. The differences among stimulating compounds treatments with respect to the leaf area index at 30 and 45 DAT were found significant for the both seasons. The highest leaf area index was obtained from the treatment of amino acids, while the lowest values were obtained from the control. The interaction between genotype and stimulating compound for LAI were significant, indicating that the stimulating compounds application caused different responses in LAI in different genotypes. The highest values of LAI were obtained when amino acids were applied to GZ9399.

Dry matter accumulation

Distinct genotypic variation was observed in dry matter accumulation at 30 and 45 DAT in the both seasons (Table 3). Sakha108 had the greatest dry matter accumulation at 30 and 45 DAT. Difference in dry matter accumulation among the three rice genotypes may be due the differences in the genetic background of those genotypes. Considering the effect of stimulating compounds on the dry matter accumulation at 30 and 45 DAT, it is clear that all stimulating compounds caused significant increases. Thus, dry matter accumulation was maximum under amino acids treatment. Sadak et al., 2014 found that amino acids may play an important role in plant metabolism and protein assimilation which is necessary for cell formation and consequently increase in fresh and dry matter of bean. Hasewaga et al., 2000, found that foliar spray of nutrients increased dry matter accumulation of rice. The interaction effect was found significant for dry matter accumulation at 30 and 45 DAT. The combination of Sakha 108 with the foliar application of amino acids resulted in highest dry matter accumulation at 30 and 45 DAT.

Table 3. Leaf area index and dry matter accumulation g m^{-2} of three rice genotypes under different stimulating compounds at 30 and 45 days after transplanting DAT in 2018 and 2019 seasons.

Treatment	Leaf area index				Dry matter accumulation (g m^{-2})			
	30 DAT		45 DAT		30 DAT		45 DAT	
	2017	2018	2017	2018	2017	2018	2017	2018
Genotype:								
Sakha108	5.47 b	5.28 b	5.64 b	5.48 b	423.14a	392.07a	528.19a	485.17a
GZ9399	5.87 a	5.70 a	5.93 a	5.77 a	383.83b	373.85b	492.58b	448.95b
GZ10154	4.71 c	4.52 c	5.42 c	5.26 c	373.68c	360.21c	464.91c	401.41c
F test	*	*	*	*	*	*	*	*
Stimulating compound:								
Amino acid	6.03 a	5.86 a	7.15 a	6.99 a	454.08a	426.58a	637.36a	578.58a
NPK 20:20:20	5.74 b	5.58 b	6.30 b	6.14 b	433.58b	412.08b	536.08b	492.41b
Ascobin	5.60 c	5.39 c	6.07 c	5.91 c	404.38c	395.08c	512.21c	465.89c
Vulvic acid	5.38 d	5.17 d	5.90 d	5.74 d	383.66d	375.16d	476.61d	428.58d
Humic acid	5.15 e	4.95 e	5.34 e	5.18 e	379.94d	361.33e	466.20e	409.08e
Potassium sulphate	5.00 f	4.80 f	4.63 f	4.47 f	357.08e	338.58f	434.39f	383.38f
Control	4.56 g	4.42 g	4.26 g	4.10 g	342.00f	318.83g	410.73g	358.33g
F test	*	*	*	*	*	*	*	*
Interactions A x B	**	**	**	**	**	**	**	**

Number of panicles per m^2

Rice genotypes were significantly different in number of panicles per m^2 at harvest (Table 4). Sakha108 recorded the greatest number of panicles per m2 followed by GZ9399. Number of panicles per unit area had significant positive association with stimulating compounds application, and an increase in number of panicles per m^2 occurred with stimulating compounds application. Amino acid foliar application recorded the greatest number of panicles per m^2 followed by NPK treatment. Saha et al., 2013 indicated that the increase in rice number of tillers hill^{-1} was perhaps due to the addition of stimulating compounds which promote nitrogen supply which is essential for vegetative growth. Genotype x stimulating compound interaction was significant for number of panicles per m^2. Foliar application of amino acid to Sakha 108 recorded the highest values of number of panicles per m2.

Panicle length

There were significant genotypic differences in panicle length in both seasons (Table 4). Sakha108 produced the longest panicles followed by GZ9399 without any significant differences between them. Application of stimulating compounds significantly increased panicle length except potassium sulphate and humic acid in the first season and potassium sulphate only in the second season. Saha et al., 2013 reported that the loss of nitrogen is less in presence of stimulating compound which helps in vegetative growth such as panicle length of rice plant. The interaction effect between studied factors was significant in both seasons (Table 4). It is evident that application the combinations of amino acids to the three genotypes or application of NPK or ascobin to Sakha 108 and GZ9399 or application of vulvic acids to GZ9399 significantly increased the panicle length at harvest over the other combinations.

Panicle weight

Panicle weight was significantly varied among the three genotypes (Table 4). Sakha108 produced the heaviest panicles followed by GZ9399 without any significant differences between both of them. Panicle weight was significantly increased by stimulating compounds application compared with the control treatment. Foliar application of amino acid recorded the heaviest panicles followed by NPK and ascobin. The interaction between genotype and stimulating compound was significant in both seasons. In the first season, foliar application of amino acid, NPK or ascobin to Sakha 108 or GZ9399 recorded the heaviest panicles. In the second season, amino acid foliar application to Sakha 108 or to GZ9399 recorded the highest values of panicle weight.

1000-grain weight

Marked differences in 1000-grain weight were noted among the tested rice genotypes. GZ10154 produced the heaviest 1000-grain followed by Sakha108. 1000-

Table 4. No. of panicles m^{-2}, panicle length cm, panicle weight g and 1000-grain weight g of three rice genotypes under different stimulating compounds at 30 and 45 days after transplanting DAT in 2018 and 2019 seasons

Treatment	No. of panicles m^{-2}		Panicle length (cm)		Panicle weight (g)		1000-grain weight (g)	
	2017	2018	2017	2018	2017	2018	2017	2018
Genotype:								
Sakha108	407.0a	400.89a	20.99 a	20.58 a	3.99 a	3.80 a	23.28b	23.22b
GZ9399	373.0b	388.07b	21.25 a	20.85 a	4.02 a	3.86 a	21.92c	21.86c
GZ10154	350.6c	354.94c	20.18 b	19.92 b	3.58 b	3.41 b	25.94a	25.82a
F test	*	*	*	*	*	*	*	*
Stimulating compound:								
Amino acid	417.8a	427.17a	22.38 a	21.98 a	4.20 a	4.01 a	24.39a	24.26a
NPK 20:20:20	403.9b	407.00b	21.76ab	21.39 ab	4.02 b	3.82 b	24.16ab	24.06ab
Ascobin	384.5c	397.49c	21.36ac	20.87 bc	3.95 bc	3.84 b	23.74bc	23.71bc
Vulvic acid	373.4d	381.58d	20.80bd	20.41 bd	3.83 cd	3.73 c	23.38bc	23.57bd
Humic acid	368.9e	376.32e	20.33 ce	20.01 cd	3.77 cd	3.62 d	23.56bc	23.45cd
Potassium sulphate	351.4f	354.09f	19.86 de	19.61 de	3.72 de	3.56 d	23.38c	23.28cd
Control	338.3g	325.44g	19.16 e	18.91 e	3.57 e	3.26 e	23.17c	23.11d
F test	*	*	*	*	*	*	**	**
Interactions A x B	**	**	**	**	**	**	**	**

grain weight was influenced significantly by stimulating compounds application. An increase in 1000-grain occurred with all stimulating compounds foliar application except potassium sulphate. Among the stimulating compounds, amino acid and NPK foliar application recorded the highest values of 1000-grain weight in the both seasons. The interaction between the both studied factors was significant in the two seasons. The plants of GZ10154 sprayed with amino acid, NPK and ascobin recorded the heaviest 1000-grain weight compared to other combinations.

Number of filled grains per panicle

According to data in Table 5, there were significant differences in number of filled grains per panicle among rice genotypes in both seasons. GZ9399 produced more number of filled grains per panicle than the other genotypes. Stimulating compounds foliar application had significant effects on number of filled grains per panicle. All stimulating compounds foliar application increased significantly number of filled grains per panicle over control except potassium sulphate in second season only. Amino acid foliar application produced the highest values of number of filled grains per panicle followed by NPK. Hasewaga et al., 2000 reported that foliar spray of nutrients increased number of fertile spikelets in the panicle of rice. Number of filled grains per panicle responded significantly to the interaction effect between genotype and stimulating compound in the two seasons. Foliar application of amino acid to rice genotype GZ9399 produced more number of filled grains per panicle than other combinations.

Number of unfilled spikelets per panicle

Number of unfilled spikelets per panicle varied significantly among the rice genotypes (Table 5). Number of unfilled spikelets per panicle was highest in GZ10154 and lowest in GZ9399. Stimulating compounds application had had significant and negative effects on number of unfilled spikelets per panicle. Number of unfilled spikelets per panicle of the three rice genotypes decreased with the application of different stimulating compounds. Regarding the interaction effect, there were significant variation in number of unfilled spikelets per panicle due to the interactive effect of genotypes and stimulating compounds foliar application.

Grain yield

Rice yield showed significant variations among the genotypes (Table 5). The differences in grain yield among the genotypes are attributable to the differences in growth and yield attributes. Sakha108 produced more yield than GZ9399 and GZ10154. Grain yield were significantly increased by stimulating compounds application. The increase in grain yield was highest under the application of amino acids compared with the other treatments. Amino acid is used to increase

Table 5. Number of filled grains panicle^{-1}, number of unfilled spikelets panicle^{-1}, grain yield t ha^{-1} and straw yield t ha^{-1} of three rice genotypes under different stimulating compounds at 30 and 45 days after transplanting DAT in 2018 and 2019 seasons.

Treatment	Number of filled grains panicle^{-1}		Number of unfilled spikelets panicle^{-1}		Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
	2017	2018	2017	2018	2017	2018	2017	2018
Genotype:								
Sakha108	124.76 b	123.71 b	3.50 b	3.40 b	11.60a	11.14a	14.48 a	13.81 a
GZ9399	135.20 a	131.76 a	2.37 c	2.18 c	10.56b	10.12b	11.71 b	10.87 b
GZ10154	112.37 c	110.93 c	4.43 a	4.16 a	10.34b	9.89b	11.56 b	10.46 b
F test	*	*	*	*	*	*	*	*
Stimulating compound:								
Amino acid	139.03 a	137.17 a	2.07 d	1.96 d	11.87a	11.27a	14.18a	12.99a
NPK 20:20:20	123.27 b	129.74 b	2.23 d	2.13 d	11.59b	11.04b	14.13a	12.61a
Ascobin	126.72 c	124.03 c	2.77 d	2.67 d	11.33c	10.81c	13.48ab	12.38a
Vulvic acid	123.40 d	119.11 d	3.07 cd	2.84 cd	10.77d	10.33d	12.46bc	12.15ab
Humic acid	119.87 e	118.19 d	3.95 bc	3.75 bc	10.60d	10.22d	11.53cd	10.91bc
Potassium sulphate	115.80 f	114.23 e	4.33 b	4.13 b	10.05e	9.68e	11.46cd	10.75c
Control	111.67 g	112.44 e	5.61 a	5.26 a	9.63f	9.32f	10.83 d	10.21c
F test	*	*	*	*	**	**	**	**
Interactions A x B	**	**	**	**	**	**	**	**

the overall production and quality of a crop. It plays fundamental role in the synthesis of photo-assimilates and can directly or indirectly influence the physiological activities of a crop (Liu and Lee, 2012). Genotype X stimulating compound interaction for grain yield was significant indicating that the stimulating compounds caused different responses in grain yield of the studied genotype (Table 5). Application of amino acid to Sakha108 recorded the highest grain yield. Fageria et al., 2009 indicated that the yield response of field crops to foliar fertilization of macro and micronutrients is highly variable.

Straw yield

Straw yield differed significantly among the studied rice genotypes. The highest values of straw yield were recorded by Sakha101. Straw yield increased progressively with foliar application of stimulating compounds. Kundu and Sarkar, 2009 indicated that foliar application helps in effective absorption of nutrients at critical growth stages and resulted in enhanced physiological activity leading to better growth. The interaction effect between rice genotype and stimulating compound on straw yield appeared to be considerable (Table 5). The significant increase in straw yield was associated mainly with the increase in growth characteristics such as plant height and dry matter production.

From the study, it can be concluded that, application of different stimulating compounds significantly increased the growth and yield of the tested rice genotypes. GZ9399 surpassed the other genotypes in terms of growth and yield.

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