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Water Stress induced Trait Association Studies on Yield and Drought Selection Indices in Rice (*Oryza sativa* L.)

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ABSTRACT: Drought stress is considered the most serious of all biotic and abiotic stresses affecting rice, resulting in severe yield loss. Detailed understanding regarding the contribution of traits towards yield and identification of the most effective selection indices under diverse soil moisture levels can equip plant breeders in the selection of climate adaptive genotypes. Rice being a crop that is affected severely by water stress, defining specific combinations of drought selection indices for the selection of genotypes that can perform better under water-stressed and non-stressed conditions is mandatory to ensure stable yield. The present study elucidates the relationships between grain yield of contrasting rice genotypes with various drought selection indices for the selection of stress-tolerant and high-yielding genotypes under diverse regimes of water availability. Nine drought selection indices and three contrasting genotypes were used in the study. A comparative evaluation of the grain yield of the genotypes was done under non-stress and drought-stress environments. Drought selection indices were worked out, followed by correlation studies and principal component analysis (PCA). Drought selection indices namely MP, GMP, HM, STI, and YI were identified to be the suitable indicators with significant positive correlations that can be used in selection for high grain yield under both water-stressed and non-stressed conditions. In PCA analysis, two principal components *i.e.*, PC1 and PC2 accounted for 58.98% and 41.02% of the total variation in grain yield. Results from the biplot based on PCA were in line with the interpretations of correlation analysis. Genotypes with higher YSI and RSI values can be utilized to achieve better stability in yield across contrasting soil water conditions in rice.

Keywords: Water stress, Correlation, PCA, Biplot, Drought selection indices, Drought, Rice.

INTRODUCTION

Rice feeds more than half of the global population. Asia, where 60% of the earth's population lives, is the major producer and consumer of the world's rice. The increasing population, increasing demand for water, water crisis, failure to adapt to climate change, and the frequency of biotic and abiotic stresses will amplify the challenges of achieving future food requirements (Sandhu and Kumar 2017). Asian cultivated rice has been cultivated under diverse agroecological systems, including environments with contrasting water availability. Currently, about 42% of India's land area is facing drought, with 6% exceptionally dry *i.e*., nearly four times the spatial extent of drought compared to previous years (Gogoi and Tripathi 2019). Nevertheless, the quantitative and complex nature of the drought-tolerant traits has made it challenging to study drought responses and the selection of superior and adapted genotypes. Understanding the way plants respond to drought stress is one of the most important steps in the development of drought-tolerant varieties (Oladosu *et al*., 2019). Grain yield during drought is contributed by diverse physiological pathways controlling the uptake of water and nutrients, photosynthetic efficiency, and maintenance of osmotic balance. The variations in growth conditions such as soil water levels, and differences in light intensities have significant roles in determining sensitivity levels of genotypes under water stress (Parida *et al.,* 2021). For the selection of high-yielding and water-stress-tolerant genotypes, grain yield is considered an effective parameter. Still, a more efficient method may be based on the evaluation of the performance and adaptability of the genotypes under stress and non-stress conditions. Such a conclusive selection for yield and drought tolerance can be made by incorporating drought selection indices or combinations of these indices, proposed based on the relationship between grain yield under stress and non-stress conditions

(Sabouri *et al.,* 2022). Different stress selection indices have been proposed in different crops namely Tolerance (TOL), Mean Productivity (MP), Geometric Mean Productivity (GMP), Harmonic Mean (HM) in pearl millet, Stress Susceptibility Index (SSI) in spring wheat, Stress Tolerance Index (STI), Yield Index (YI) in winter cereals, Yield Stability Index (YSI) in soybeans and Relative Stress Index (RSI)in spring wheat for improving the efficiency of plant selection under stress environment. With this background, the present study was taken up to elucidate the relationships between crop yield of contrasting rice genotypes and various drought selection indices that are reported to be useful in the selection of tolerant, high-yielding genotypes under water stress environments. Detailed insights on crop yield under stress and non-stress conditions and such drought selection indices can through light on efficiency in the usage of specific indices under varying conditions and in the development of combinatorial drought selection indices for effective plant selection**.**

MATERIAL AND METHODS

The rice genotypes namely Kinandang patong, Manu Ratna and Jyothi were used in the present study. Kindandang patong is a medium-duration tropical japonica cultivar while Manu Ratna and Jyothi are two short and medium-duration indica cultivars. Breeder seeds of the genotypes were collected from ICAR-National Bureau of Plant Genetic Resources, New Delhi; Agricultural Research Station, Mannuthy, Kerala and Rice Research Station, Moncompu, Kerala respectively. The experiment was conducted in a rainout shelter facility available in the Department of Seed Science and Technology, College of Agriculture, Vellayani, Kerala Agricultural University during the rabi season in the year 2022. The statistical design used for the study was RCBD with five replications for each genotype maintained separately understress and non-stress conditions. The soil type of the experimental area is clay soil maintained at ambient pH of 5 to 5.5 by following liming before transplanting. Under both the conditions same management practices were followed until the crop reached flowering. Water stress was induced in one set of genotypes at the flowering stage by completely withholding the irrigation for a period of 10 days while a 4-5cm water level was maintained for the control. After stress treatment, watering was done regularly throughout the growing period. At maturity, the crop yield of the genotypes was recorded on an individual plant basis, both under water stress and non-stress conditions. Grains were dried and grain yield per plant was documented.

Stress tolerance selection indices such as Tolerance (Rosielle and Hamblin 1981), Mean Productivity (Rosielle and Hamblin, 1981), Geometric Mean Productivity (Fernandez, 1992), Harmonic Mean (Bidinger *et al.,* 1987), Stress Susceptibility Index (Fischer and Maurer, 1978), Stress Tolerance Index (Fernandez, 1992), Yield Index (Gavuzzi *et al.,* 1997), Yield Stability Index (Bouslama and Schapaugh 1984) and Relative Stress Index (Fischer and Wood 1979) were worked out based on the mathematical methods available in the respective publications. The indices were computed based on plant yield under water stress and non-stress conditions.

Two way-Analysis of variance (ANOVA) of grain yield were computed to study the response under drought and non-drought conditions. Karl Pearson's coefficient of correlation and principal component analysis of the nine drought selection indices along with grain yield under water stress and non-stress conditions of the three genotypes were carried out using R version 4 2.2 package and iPASTIC software (Pour-Aboughadareh *et al.,* 2020)

RESULTS AND DISCUSSION

Crop yield is considered the deciding factor in the selection of a superior genotype in an era where the achievement of food security for the existing population itself is beyond reach. The yield of a plant is a complex character that involves the contribution from most of the plant traits involving complex gene regulation and expression levels. The present study relates the difference in grain yield obtained under water stress and non-stress conditions with the available nine drought selection indices to identify the most effective criteria for the selection of high-yielding and stress-tolerant genotypes in the crop improvement programs.

The results of two-way ANOVA proved a negative and significant ($p<0.05$) difference in grain yield per plant under water stress and non-stress treatments. This negative impact of water stress was observed in all three genotypes used in the study of which the most severe reduction in yield was observed for Jyothi (28.7%), followed by Manu Ratna (17%) and Kinandang patong (11.6%) as shown in Fig. 1. Such yield reductions due to reproductive stage drought stress is widely reported in rice (Yang *et al.,* 2019; Manikanda *et al.,* 2022). The grain yield of Jyothi and Manu Ratna were on par with each other during well-watered conditions but due to drought imposition yield of Jyothi reduced substantially and became on par with that of Kinandang patong (Table 1). Though Kinandang patong showed minimal yield reduction compared to the other two genotypes, it could not surpass the yield of Jyothi and Manu Ratna under stress. Similar reports on water stress tolerance of Kinandang patong is already reported by Uga *et al.* (2015); Aghaei *et al.* (2017). This dilemma in yield and drought adaptability levels during plant selection can be resolved by incorporating various drought selection indices.

The computed values of drought selection indices showed variation among the studied genotypes (Table 2). YSI and RSI were higher for Kinandang patong compared to other genotypes while Manu Ratna recorded the highest measures for MP, GMP, HM, STI, and YI. Measures of SSI and TOL were maximum for the genotype Jyothi. Among all drought selection indices MP, GMP, HM, and STI showed similar variation trends in all genotypes. A simultaneous increase in TOL and SSI was accompanied by a substantial reduction in YSI and RSI in all the genotypes. As the genotype Manu Ratna showed the highest measures for MP, GMP, HM, STI, and YI, it can be considered the most suitable and high-yielding genotype under water stressful and non-stressful conditions. Usage of MP, GMP, HM, STI, and YI was reported to be useful in the selection of superior barley cultivars suitable for multiple environments; in screening super sweet maize inbred lines for drought tolerance; and for identifying nitrogen deficiency tolerant wheat genotypes (Kang and Futakuchi 2019; Shahrokhi *et al.,* 2020; Ivić *et al.,* 2021). Similar usage of MP, GMP, HM, and STI for the selection of adapted and high-yielding genotypes under salinity stress has been reported in wheat (Pour-Aboughadareh *et al.,* 2020). STI, MP, and GMP were also used for the selection of rice genotypes for sodic and salinity stress resistance (Sabouri *et al.,* 2022).

Few deviated reports from the above findings are also available where higher values of GMP, STI, HM, and MP along with YSI estimates have been reported as selection criteria for identifying high-yielding and stable water logging tolerant wheat genotypes (Singh *et al.,* 2018), but YSI may not be recommended for selection for high yield and drought tolerance in rice. YSI will be higher for highly drought tolerant genotypes with low yield which will show comparatively stabilized yield than a high yielding genotype with substantial yield reduction, but still capable of maintaining moderate yield levels under drought. Along with YSI, YI, and RSI are also measures for genotypic stability under contrasting environments. In the present study, YSI and RSI were maximum for Kinandang patong rendering it the most stable genotype followed by Manu Ratna, while Jyothi recorded minimum index values for YSI, YI, and RSI. The tolerance (TOL) index was minimum for the genotype Kinandang patong (2.20) indicative of maximum stress tolerance while the Jyothi (6.51) was most sensitive to water stress. Similar findings were reported in wheat by Pour-Aboughadareh *et al.* (2020); Sabouri *et al.* (2022). When ranks were allotted based on drought selection indices, Kinandang patong had the high ranks for TOL, SSI, YSI, and RSI but the lowest rank for MP, GMP, HM, and STI. Manu Ratna obtained the best ranks for MP, GMP, HM, STI, and YI while Jyothi obtained the lowest ranks for TOL, SSI, YI, YSI, and RSI.

The study of the association between drought selection indices and grain yield under contrasting conditions can reveal the effectiveness of each indices or its combinations in the selection of genotypes suitable for diverse environments. Yield under stress is positively correlated to all section indices except for TOL, and SSI while yield under non-stress conditions showed a negative correlation only with YSI and RSI. Drought selection indices such as MP, GMP, HM, and STI had positive and significantly high correlations with grain yield under well-watered and water-scarce environments, while YI had a higher positive association with grain yield under water stress than that of grain yield under well-irrigated conditions (Fig. 2).

Use of the above combination of positively correlated drought selection indices have been implemented for selection for high yield under various stress tolerance like drought tolerance in canola (Malekshahi *et al.,* 2009), heat stress tolerance in wheat (Sareen *et al.,* 2012; Khan and Kabir 2014; Ivić *et al.,* 2021) and nutrient stress tolerance in maize hybrids (Lyra *et al.,* 2017). Correlation analysis revealed that under a water-stress environment, a moderately positive correlation exists between grain yield towards YSI and RSI estimates, while the correlation was negative towards SSI and TOL. So SSI and TOL indices can be used for the selection of genotypes that are high yielding only under well-irrigated conditions. On the contrary, genotypes with high YSI and RSI values are suitable only under water-scarce environment to get substantial yield. Thus, associations obtained among the indices are in agreement with the variation trends observed while computing the drought selection indices and the effectiveness of using the above indices is herein confirmed.

Multivariate analysis methods such as principal component analysis (PCA) are used in the study for reducing the data to interpretable forms by dividing the variance of projections into independent principal components. Biplots developed through principal component analysis (PCA) were used for a detailed understanding of relationships between drought selection indices with grain yield under stress and non-stress environments. PCA based on correlation data indicated that the first two principal components namely PC1 and PC2 had eigenvalues 6.49 and 4.51 respectively, accounting for 58.98% and 41.02% (PC1 and PC2 respectively) of the total variation in grain yield. Individual contributions of all drought selection indices, grain yield under water stress, and the non-stress state towards the two principle components are given in Table 3. From the biplot of PCA (Fig. 3) it is clear that PC1 has a positive influence from grain yield (under drought and non-drought conditions) and all other drought selection indices except YSI and RSI. A similar grouping has been reported by Aminpanah *et al.* (2018); Shahrokhi *et al.* (2020). PC2 had a positive influence from all drought selection indices except SSI and TOL and also from yield under irrigated conditions. Under such circumstances, selection based on high values of PC1 can help in the selection of drought-tolerant genotypes with superior yield performance. The relative position of genotypes in the biplot also confirms that Manu Ratna can provide a high yield under water stress and non-stress conditions; Jyothi can give on par yield with Manu Ratna only under irrigated conditions, while Kinandang patong shows a lower yield but higher yield stability under water stress. Similar findings were made by Pour-Aboughadareh *et al.* (2020); Shahrokhi *et al.* (2020). Minor variations from outcomes of several reports and the present study can be due to the variations in genotypes studied, the extent of drought imparted, the stage of crop growth, and several other environmental factors.

Table 1: Two way-Analysis of variance (ANOVA) of grain yield per plant of three genotypes under water stress and non-stress conditions.

Genotype	Treatment	Yield per plant (g)
Manu Ratna	Drought	19.71 [b]
Jyothi		16.15 [c]
Kinandang patong		16.70 [c]
Manu Ratna	No Stress	23.76 [a]
Jyothi		22.66 [a]
Kinandang patong		18.90 [b]
LSD ($P \leq 0.05$)		
Genotype		1.120
Treatment		0.917
Genotype X treatment		1.590
SED		0.712
CV (%)		4.440

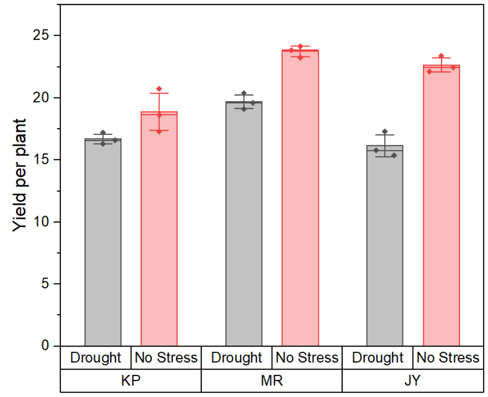

Fig. 1. Graphical representation of grain yield per plant of Kinandangpatong (KP), Manu Ratna (MR) and Jyothi (JY) under water stress and non-stress conditions.

Table 2: Crop selection indices values for the three rice genotypes *i.e.,* Kinandang patong, Manu Ratna and Jyothi computed based on yield under water stress and non-stress conditions.

Genotypes	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
Kinandang patong	2.200	17.800	17.766	17.732	0.596	0.666	0.953	0.884	1.098
Manu Ratna	4.050	21.735	21.640	21.546	0.873	0.988	1.125	0.830	1.031
Jyothi	6.510	19.405	19.130	18.859	1.471	0.772	0.922	0.713	0.886

Table 3: Contributions of drought selection indices, grain yield under water stress, and non-stress conditions towards the two principle components (PC1 and PC2).

Factors	PC1	PC2
Yp	26.84408	5.360994
Ys	54.29513	39.28587
TOL	10.57593	89.2883
MP	51.64163	0.227865
GMP	84.26649	1.71911
HM	26.16311	1.264221
SSI	4.827387	95.05764
STI	89.63575	2.695035
YI	57.42272	41.54888
YSI	4.186642	82.44053
RSI	4.516498	88.93583

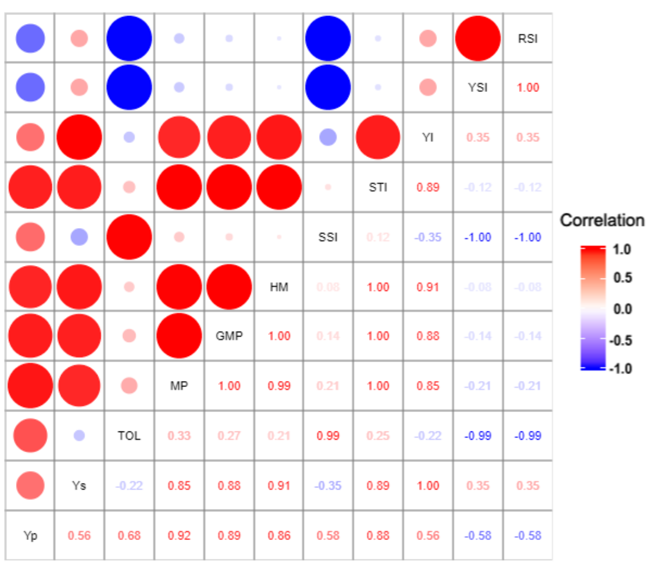

Fig. 2. Intensity of correlation and correlation coefficients between grain yield per plant under non-stress (Yp) and water stress condition (Ys) along with nine selection indices values for the three rice genotypes (Kinandang patong, Manu Ratna and Jyothi).

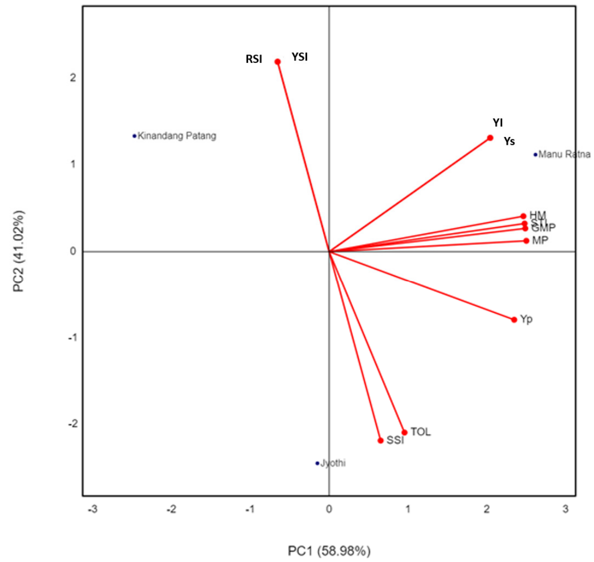

Fig. 3. Graphical representation of biplot from principal component analysis of drought tolerance indices based on grain yield of three rice genotypes (Kinandang patong, Manu Ratna and Jyothi).

CONCLUSIONS

Drought is an important abiotic stress which affects all plant growth processes and yields in rice. The present study on drought section indices helps in deciphering a combinatorial approach in the selection of superior genotypes under drought and well-irrigated environments. Character association studies conducted in the present study revealed that out of the nine drought selection indices, high measures of MP, GMP, HM, STI, and YI values for a genotype are indicative of higher yield and drought resistance. Rice genotypes with higher YSI and RSI values show better stability in yield across contrasting soil water regimes. Multivariate analytical methods prove their accuracy in handling and comparison of yield (under stresses and non-stress) and stress selection indices of diverse rice genotypes and provide a holistic selection approach in rice. Similar studies focusing on superior performance under diverse conditions can provide theoretical support and a material basis for future variety screening and selection in rice breeding.

FUTURE SCOPE

The future of any stress resistance breeding programs lies in the efficiency of screening and selection of genotypes. Selection efficiency of stress selection indices needs to be worked out for selection against various biotic and abiotic stress in major food crops like rice. The development of composite selection indices with higher accuracy instead of a combinatorial approach that involves multiple drought selection indices can make plant selection much more time-saving and effective. The establishment of such advanced statistical models and associated computation software can contribute to the high throughput selection of large and diverse plant populations. Such advances may play a pivotal role in crop improvement programs aimed at maintaining high yields in important food crops like rice, along with the maintenance of wider adaptability to diverse climatic regimes.

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Conflict of Interest. None.

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