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Evaluation of drought resistance indices and grain yield in basmati and non-basmati rice under water stress at reproductive stage

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Abstract
Water stress is the most critical abiotic stress which under declines the rice yield in rainfed and drought prone environment. Majority of rice cultivated area in south Asia is under rainfed, where moisture stress at any of the critical growth stage such as tillering, panicle initiation, heading, grain filling etc. causes sharp decline in yield. Based on water stress resistance indices such as Stress tolerance level (STL), mean productivity (MP), geometric mean productivity (GMP), yield index (YI), yield stability index (YSI), Stress tolerant efficiency (STI), stress susceptibility index (SSI), and stress tolerance index (STE), were calculated grain yield per plant. Based on the water stress to resistant trait and their contribution to yield in diverse group of genotypes, SSI, STE, and YSI are the stress indices which can evaluate the stress resistance characters with precisions in a genotypes. The three genotype show high stability in grain yield under the stress i.e., N-22, Sharbati, and Kasturi respectively, appeared relatively more tolerance to water stress, with high yield performance in both stress and non-stress conditions.

Keywords: Water stress, drought tolerant efficiency, mean productivity, geometric mean productivity, stress tolerant index, and yield

Introduction
Rice is a major cereal crop grown under the well-irrigated cropping system of South and South-east Asia, with humidity 70-80 per cent and maximum temperatures near to critical threshold ranging between 33 ºC and 35 ºC (Nakagawa, *et al*., 2002) [24]. Water is a necessary for seed germination, seedling growth, vegetative period of crop, flowering at translocation of minerals and nutrition incorporate throughout the plants, from root to leaf and vice versa in the plants (Kijne, 2006) [17]. Water stress is a major limiting factor for crop production and estimated the 50% of the global rice production is affected by water deficit conditions (Wang *et al*., 2003) [35]. The unequal distribution of precipitation make rice grower to depend on irrigation. Plants are exposed to different type of abiotic (water stress, low and high temperature, salt concentration, etc.) biotic (virus, bacteria, fungi, insect etc.) and environmental as well as edaphic stresses that affects growth and development of plants and lead to change in the gene expression and metabolism. In Asian continent approximately 130 million ha of rice growing field are annually affected by water stress, therefore limited rice production worldwide (Rahimi, *et al*., 2013; Nahakpam, 2017) [29, 23]. India is the world's second largest producer of rice, and the largest exporter of basmati and non-basmati rice worldwide. In India, rice is cultivated on 43.79 million hectares with a production of 112.91 million tons of milled rice and yield of 2578 kg/hectare during 2017-2018 (Puppala, *et al*., 2021) [28]. It is grown in almost all the state of the country, but major rice producing states fall in the regions of middle and lower gangetic plains and the coastal peninsular lowland. Global climate change affects a variety of factors associated with water stress and extreme drought land area is likely to increase from 1-35% by the year 2100 (Miao, *et al*., 2015 and Puppala *et al*., 2021) [21, 28].
Selection of the different rice genotypes under the water stress conditions is one of key task of plant breeders for exploiting genetic variability to enhance stress tolerance ability in cultivar (Khan *et al*., 2014) [14]. Therefore, a major challenge faced by conventional breeding for stress tolerance is the identification of reliable screening methods and effective selection criteria to facilitate the detection of water stress tolerant plants. Numerous screening methods and selection criteria have been proposed by many researchers, but limited methods were reported for screening of water stress tolerant genotypes in rice crop.

Rosielle and Hamblin (1981) [33] defined stress tolerance (TOL) as the differences in yield between the well irrigated and water stress environments and mean productivity (MP) as the average yield of these two environments. They reported a positive correlation between mean productivity (MP) and yield under stress environment (Ys), therefore selection based on MP could improve average yield under both water stress and irrigated environments. Several studies also showed a high and positive correlation between MP and Ys (Sanjeri, 1998; Ghagar Sepanlo *et al*., 2000; Nouri *et al.*, 2011) [32, 9, 26]. Several screening methods and selection criteria have been proposed by many researchers like stress susceptibility index (SSI) (Fischer and Maurer, 1978) [5], stress tolerance index (STI) (Fernandez, 1992) [4], Geometric mean productivity (GMP) (Ramirez and Kelly, 1998) [31] and yield index (Gavuzzi, *et al*., 1997) [8] another index which is often used by breeders interested in relative performance. For instance, SSI, STI and GMP were establish to be the most efficient methods for selecting water stress tolerant and high yielding genotypes of rice (Adhikari *et al*., 2019; Garg *et al* 2017) [1, 6], maize (Khodarahmpour *et al*., 2011) [16] and wheat (Khan *et al.*, 2014) [14]. A positive and significant correlation of GMP and grain yield under both controlled and water stress environment, suggested that this index is more applicable and efficient for selection of parent material in producing rice hybrids tolerant to water stress & high temperatures and high yielding under both environments. GMP in combination with SSI was found a desirable criterion for selecting improved drought resistant common bean genotype (Ramirez and Kelly, 1998) [31] in another study**,** Moghaddam and Hadizadeh (2000) [22] found STI more applicable than SSI for selection of various genotypes tolerant to stress. Combination of different stress indices was observed in different crops.

Therefore, to ease the selection or development of rice variety for water stress conditions, a thorough understanding of the different stress indices characters that govern the yield of rice, is a prerequisite. In the present study, we tried to assess the various morphological, physiological and biochemical changes taking place in selected rice genotypes under water stress and irrigated control conditions.

Materials and Methods

A total of 12 genotypes used under this study, consisting two check variety Nagina-22 and IR-64 were tested under the both well irrigated (control) and water stress (treatments) environments with three replication in rainout shelters at experimental field, Department of Agriculture Biotechnology, College of Agriculture SVPUA&T, Modipurum, Meerut (U.P.) during Kharif session 2020 and 2021. The field experiment was conducted in Randomized Block Design (RBD). There were two conditions, well irrigated and water stress. The controlled experiment was measured to be a favorable condition so that plots were watered at planting, tillering, panicle initiation, anthesis and grain filling stages, but water stress experiment were not irrigated at time of panicle initiation. Grain yield (gm) per plant for each genotypes at two environment were recorded (Yp non-stress-irrigated and Ys water stress), and subjected to calculate drought selection indices. The water stress tolerance indices were calculated using the following formulas:

1. Stress Tolerance Level

STL = Yp-Ys (Rosielle and Hamblin 1981) [33]

2. Mean Productivity

MP = Yp + Ys / 2 (Hossain *et al*., 1990) [11]

3. Geometric Mean Productivity

GMP = $\sqrt{Yp \times Ys}$ (Fernandez. 1992) [4]

4. Yield Index

YI = Ys/$\overline{\text{Ys}}$ (Gavuzzi *et al*.,. 1997) [8]

5. Yield Stability Index

YSI = Ys/Yp (Bouslama and Schapaugh, 1984) [2]

6. Stress Tolerance Index

STI= (Ys) (Yp)/ $(\overline{\text{Yp}})^2$ (Fernandez, 1992) [4]

7. Stress Susceptibility Index

SSI $= \frac{1-Ys/Yp}{1-\overline{Ys}/\overline{Yp}}$ (Fischer and Maurer 1978) [5]

Where,
Y_s is the yield of genotypes under water stress condition,
Yp is the yield of genotypes under well irrigated environment,
$\overline{Ys}$ and $\overline{Yp}$ are the mean yields of all genotypes under water stress and control environmental conditions, respectively, and 1− ($\overline{Ys}$ / $\overline{Yp}$) is the stress intensity.

8. Stress Tolerance efficiency

$STE = \frac{Yield\ of\ Stress}{Yield\ of\ control} \times 10$ (Fischer and wood, 1981) [36]

Statistical analyses

The data obtained were analyzed using statistical software OP STAT, and Statistical Tool XLSTAT used for Life science Research and preparation of and Agglomerative Hierarchical Clustering based on average taxonomic distance for Yp, Ys and eight resistance indices.

Result and Discussion

Drought Indices

Different drought indices probably measure similar aspect of drought tolerance/resistance. Results obtained on mean yields of all genotypes evaluated under stress and irrigated conditions illustrated in Mean Table 1.

Table 1: Mean performance of twelve genotype of rice for eight water stress tolerance indices characters under control (Yp) and water stress (Ys) environment

Genotypes	Yp	YS	STL	MP	GMP	YI	YSI	STI	SSI	STE
Ranbir Basmati	18.05	12.48	5.57	15.26	15.01	0.89	0.69	0.54	0.98	69.12
Kasturi	21.24	15.84	5.40	18.54	18.34	1.13	0.75	0.80	0.81	74.60
Basmati Csr-30	19.44	13.76	5.68	16.60	16.36	0.98	0.71	0.64	0.93	70.79
Pusa Basmati-1	20.55	12.12	8.43	16.34	15.78	0.86	0.59	0.59	1.31	58.98
Vallabh Basmati-24	20.83	14.75	6.08	17.79	17.53	1.05	0.71	0.73	0.93	70.82
Punjab Basmati-4	19.41	14.34	5.07	16.88	16.68	1.02	0.74	0.66	0.83	73.87
Pant Basmati-1	22.49	15.13	7.36	18.81	18.45	1.08	0.67	0.81	1.04	67.26
Pusa Basmati-1121	23.42	16.26	7.17	19.84	19.51	1.16	0.69	0.91	0.98	69.41
Vallabh Basmati-23	20.12	11.68	8.44	15.90	15.33	0.83	0.58	0.56	1.34	58.04
Sharbati	21.16	15.83	5.32	18.49	18.30	1.13	0.75	0.80	0.80	74.84
Ir-64	21.11	11.92	9.19	16.52	15.86	0.85	0.56	0.60	1.39	56.48
Nagina-22	18.01	14.64	3.36	16.32	16.24	1.04	0.81	0.63	0.60	81.33
Mean	20.49	14.06	6.42	17.27	16.95	1.00	0.69	0.69	0.99	68.79
Std. Deviation	±1.614	±1.646	±1.706	±1.389	±1.440	±0.117	±0.076	±0.118	±0.241	±7.552
Max	23.42	16.26	9.19	19.84	19.51	1.16	0.81	0.91	1.39	81.33
Min	18.01	11.68	3.36	15.26	15.01	0.83	0.56	0.54	0.60	56.48

Yp and Ys are the mean value of grain yield per plant produced under the control and water stress environment.

Stress tolerance level (STL)

The mean values for stress tolerance level (STL) ranged from 3.36 in Nagina-22 to 9.19 in IR-64. The average value recorded for these traits were 6.42. The genotypes with low values of stress tolerance level (STL) indices are more stable in two different environments and suitable for the screening of breeding materials for water stress tolerance. Significant variability were found amongst the genotypes for tolerance (STL) to water stress Punjab Basmati-4, Sharbati, Kasturi and Basmati-CSR-30 exhibited the lower STL values and indicating the suitable for water stress environment (Table-1). Whereas rice Genotypes IR-64, Vallabh Basmati -23, Pant basmati-1 and Pusa Basmati-1 showed higher tolerance values representing susceptibility for the water stress conditions. Similar results were recorded by several workers for Selections based on these indices (Pantuwan *et al*., 2002, Ouk *et al*., 2006 and Sio-Se Mardeh *et al*., 2006). [34, 27, 20]

Mean Productivity (MP)

The values of mean productivity (MP) ranged from 15.26 in Ranbir Basmati to 19.84 in Pusa Basmati-1121. The average value recorded for these traits were 17.27. The genotypes with high values of MP are more stable in both controlled and environments water stress for suitable the screening of breeding materials for development of tolerance varieties. Significant variability were found amongst the genotypes for productivity (MP) to water stress, namely Pant Basmati-1, Kasturi, and Sharbati exhibited the higher MP values and indicating the suitable for water stress environment (Table-1). Whereas rice Genotypes Vallabh Basmati -23, Nagina-22 and Pusa Basmati-1 lower stress tolerance values represent not suitability for the water stress conditions. Similar results were recorded by several workers for Selections based on these indices (Pantuwan *et al*., 2002, Ouk *et al*., 2006 and Sio-Se Mardeh *et al*., 2006) [34, 27, 20].

Geometric Mean Productivity (GMP)

The values of geometric mean productivity (GMP) ranged from 15.01 in Ranbir Basmati to 19.51 in Pusa Basmati-1121. The average value recorded for geometric mean productivity was 16.95. The genotypes with high values of geometric mean productivity indices are more suitable for the selection of genotypes and helpful to development of water stress tolerant verities. Significant variability were found amongst the genotypes for geometric mean productivity to water stress, namely Pusa Basmati-1121, Pant Basmati-1, Kasturi, and Sharbati exhibited the higher GMP values and indicating the suitable for water stress environment (Table-1). Whereas rice Genotypes Ranbir Basmati, Vallabh Basmati -23, and Pusa Basmati-1 lower geometric mean productivity values represent not suitability for the water stress conditions. Similar results were recorded by several workers for Selections based on these indices (Pantuwan *et al*., 2002, Ouk *et al*., 2006 and Sio-Se Mardeh *et al*., 2006) [34, 27, 20].

Yield Index (YI)

The yield index value ranged from 0.83 in Vallabh Basmati-23 to 1.16 in Pusa Basmati-1121. The average value of yield index recorded was 1.00. The genotype with high values of Yield index (YI) found suitable for drought condition. The genotype had >1.00 value considered tolerant while, the genotypes having <1.00 value denoted as susceptible one (Table-1). The genotypes Kasturi, Sharbati, Vallabh Basmati-23, and Nagina-22 showing higher values as in case of STI cross testing the genotypes suitable for water stress prone area. Similarly lower values of YI were noted in the genotypes exhibited susceptibility to moisture stress and all other genotypes were intermediate and very similar result in previous literature (Garg & Bhattacharya, 2017; Khan *et al*., 2014) [6, 14].

Yield Stability Index (YSI)

The yield stress index ranged from 0.56 in IR-64 to 0.81 in Nagina-22. The average value recorded for these traits were 0.69. The genotypes with high YSI values can be regarded as stable genotypes under stress and non-stress conditions (Table -1). Significant differences were found amongst the genotypes for YSI and as in case of YSI the genotype Nagina-22, Kasturi and closely followed Sharbati, Punjab Basmati-4 had the highest YSI exhibited stability to stress while, lower values exhibited to suceptability under water stress and all other genotypes were intermediate in nature. Similar findings on these indices were carried out by many authors (Garrity and O'Toole 1995, Pantuwan *et al*., 2002, Ouk *et al*., 2006, Sio-Se Mardeh *et al*., 2006, Kumar *et al*., 2008 and Raman *et al*., 2012) [7, 34 27, 20, 18, 31].

Stress tolerance index (STI)

The mean values for stress tolerance index ranged from 0.54 in Ranbir Basmati to 0.91 in Pusa Basmati-1121. The average value recorded for stress tolerance was 0.69. Stress tolerance index varied significantly and genotype with high values indicated the tolerance to drought condition. Genotypes Pant Basmati-1, Kasturi, Sharbati, with high STI values indicating the resistance towards the water stress environment (Table 1). Earlier researchers show the similar results (Garg & Bhattacharya, 2017; Khan *et al*., 2014) [6, 14].

Stress susceptibility index (SSI)

Ys and Yp are the mean yield of genotypes under water stress and controlled environment conditions and the genotypes with lowest value of SSI are more resistant to water stress environment conditions. The mean values for stress susceptibility index ranged from 0.60 in Nagina-22 to 1.39 in IR-64. The average value recorded for these traits were 0.99. Result indicated that the genotype Nagina-22 had the lowest SSI followed by Sharbati and Kasturi, Punjab Basmati-4 exhibited resistance to water stress while, genotypes IR 64 followed by Vallabh Basmati-23 and Pusa basmati-1, Pant Basmati-1 exhibited susceptibility and all other genotypes were intermediate in nature. The similar findings were also observed in rice by Khan *et al.,* 2014; Chattopadhyay *et al.*, 2021[3, 14].

8 Stress Tolerant Efficiency (STE)

The mean values of Stress tolerant efficiency (STE) ranged from 56.48 in IR 64 to 81.33 in Nagina-22. The average value recorded for these traits were 68.79. The genotypes with high values of STE indices are more suitable for water stress in environments and make to ease the screening the genotype for water stress tolerance. Significant variability were found amongst the genotypes for tolerance to water stress, Sharbati, Kasturi, and Punjab Basmati-4 exhibited the higher STE values and indicating the suitable for water stress environment (Table-1). Whereas rice Genotypes IR-64, Vallabh Basmati-23, Pusa basmati-1 and Pant Basmati-1 lower value of STE and representing non suitability for the water stress conditions. Fischer and Wood (1981) [36] estimated Stress tolerance efficiency (STE) as a measure of Stress resistance mechanisms that determines the consistency of evaluated genotypes in response to water stress of different severity, timing and duration and thus may be helpful in identifying genotypes that possess Stress tolerance capability in rain-fed lowland ecosystem of rice. More of less similar results were recorded by several workers for Selections based on these indices (Pantuwan *et al*., 2002, Ouk *et al*., 2006 and Sio-Se Mardeh *et al*., 2006; Raman *et al*., 2012). [34, 27, 20, 31].

Conclusion

Water stress at reproductive growth stage significantly reduced yield in all rice genotypes. The degree of difference responses of genotypes to imposed water stress condition indicated the drought tolerance ability of some of the rice genotypes. Study indicated that selection based on water stress indices will result in the identification of genotypes with significantly higher performance under moderate to severe drought on the cost of slightly lower yield under normal irrigated condition. Based on drought tolerance indices, such as, SSI, YSI and STE, one of the promising high yield stability genotypes, namely, Sharbati and Kasturi appeared relatively more tolerance to water stress, with high stability of yield performance in both stress and non-stress conditions along with well-known drought tolerant Nagina-22 genotype.

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