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RESEARCH

Yield Performance Evaluation of Thirty Spring Rice (*Oryza sativa* L.) Cultivars Under Terminal Drought Conditions Using Various Drought-Tolerant Indices

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Abstract

An experiment was conducted from February 19, 2022, to July 4, 2022, in the farmer's field of Itahari Sub-metropolitan city in Nepal under well water and drought conditions to screen thirty drought-tolerant spring rice (*Oryza sativa* L.) genotypes using various drought tolerant indices for its cultivation under rainfed and drought areas. Analysis of variance revealed that grain yield under both conditions were significantly different and yield under well-watered condition was higher than yield under drought condition. The greater value of tolerance index (TOL) was reported in Chaite-2 and IR-80991-B330-0-2 and the minimum value of TOL was reported in IRE16L1661 and IR16L1004. The lowest value of stress susceptibility index (SSI) was reported in IRE16L1661, the maximum value of yield susceptibility index (YSI) was reported in IRE16L1661, and the maximum values of mean productivity index (MP), geometrical mean productivity (GMP), and stress tolerance index (STI) were reported in IRE 1621661. Correlation analysis revealed that the high-yielding genotype under well-watered conditions also yielded higher under-stress conditions. For grain yield, analysis of variance and principal component analysis revealed that IRE 1621661 is suitable for both conditions and genotype IRE16L1661 is stable under drought conditions based on drought tolerance indices. Thus, these two genotypes can be recommended under drought stress in the inner plains of Nepal with appropriate agronomic practices.

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Statement of Sustainability: This study focuses on the role of water stress conditions in food security, as the yield of a crop is directly affected by how well it is irrigated, depending on the crop. Therefore, this study emphasizes SDG 1 (no poverty), 2 (zero hunger), and 13 (climate action). We focused on selecting genotypes that are suitable for both well-watered and water-stressed conditions to ensure that grain yield is not greatly affected by future climatic variability. Therefore, genotypes IRE 1621661 is suitable for both conditions and can be further studied under different environmental conditions under different packages of practices to ensure sustainability in production.

1. Introduction

Rice (*Oryza sativa* L.) is an important staple food, consumed by more than half of the world's population (Dawe et al., 2010). Rice is a cereal crop in the family Poaceae, belonging to the genus Oryza (Singh et al., 2018). Two species of rice, *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice) are known to be widely cultivated for their commercial value (Gadal et al., 2019). Asia produces the lion's share of the world's rice, which is mostly grown in tropical areas with abundant rainfall - about 90% of the rice consumed globally is produced there. In 2019, about 418.56 million tons of rice will be produced in East and Southeast Asia, accounting for about 55.4% of global rice production and 47.6% of the region's total cereal production (Lin et al., 2011). Rice contributes 15% of the protein and 21% of the carbohydrate consumed per capita by humans worldwide, and provides trace amounts of minerals, vitamins, and fiber (Dawe et al., 2002).

In Nepal, rice is divided into agro-ecological zones (terai, mid-hills, and mountains), growing seasons (spring, summer, rainy, and winter), and varieties (*O. indicia*, *O. japonica*, and *O. javanica*) (Adhikari and Haefele, 2014). In Nepal, rice is grown in three seasons: main season rice (Barkhe dhan), boro rice (winter season rice), and spring season rice (Chaite dhan). Irrigated and rainfed habitats account for 49% and 51% of Nepal's productive ecosystems, respectively (Ghimire and Mahat, 2019). Due to the availability of rainfall, main-season rice has a larger area than other rice; however, the yield is higher in the spring season (Rajapur, 2021). Despite having a larger yield than main season rice, spring rice production in Nepal is limited to a small region, this might be caused by lack of water availability during spring rice cultivation, resulting in drought. In Nepal, main-season rice accounts for 92 percent of the country's total rice supply, while spring rice, also known as Chaite rice, accounts for only 8 percent (MoLAD, 2021). Large annual and seasonal variations in rainfall cause significant fluctuations in total rice production, as a large proportion of the total rice area in Nepal is rainfed (about 65%). Due to rice's high susceptibility to water stress, which can result in either partial or total yield loss, drought can cause significant damage at any stage of crop growth and development (Adhikari et al., 2018).

Drought stress is one of the major issues due to climate change and the intensification of agricultural production. Rice is the major cereal crop of Nepal and ranks 3rd in the world. Despite being the major staple food crop of Nepal and having the largest area under cultivation, the average production and productivity still show a huge difference when compared to the neighboring countries of China and India. In rainfed systems, drought is the major limiting abiotic stress that reduces productivity by 13-35% (Kandel et al., 2022; Tiwari et al., 2019). The yield of rainfed rice is very low compared to favorable growing conditions (Kandel et al., 2022; Kumar et al., 2012; Pavithra and Vengadessan, 2020; Raman et al., 2012). The development and deployment of drought stress-tolerant rice genotypes specific to agroclimatic conditions have been recommended by several authors to enhance production and maintain food security (Amgai, 2020; Kandel et al., 2022; Majumder et al., 2016; Mau et al., 2019; Ouk et al., 2006; Tiwari et al., 2019).

Various drought tolerance indices are used to screen for drought-tolerant genotypes under normal and drought-stress conditions, and their success in selecting the stress-tolerant rice genotype has also been reported by Kandel et al. (2022). Rice is susceptible to water stress and can have very low to almost no economic yield. Moreover, drought stress is associated with heat waves (Hussain et al., 2019), which further enhances pollen sterility, resulting in husked grains. Thus, this experiment was conducted to screen the drought-tolerant rice genotypes based on the grain yield suitable for the spring season in the rainfed and drought-prone inner plains of Nepal.

2. Materials and Methods

2.1. Experimental Location

An experiment was conducted in a farmers' field in Itahari Sub metropolitan city (26°39′47″N 87°16′28″E) in the spring season when rainfall is highly scattered, and farmers depend on canals and pumps for cultivation. The study area is located at 110 m asl and experiences hot and humid summers and cold winters. The soil type present in the study area was clay loam soil. The details of agro-climatic data have been presented in Figure 1.

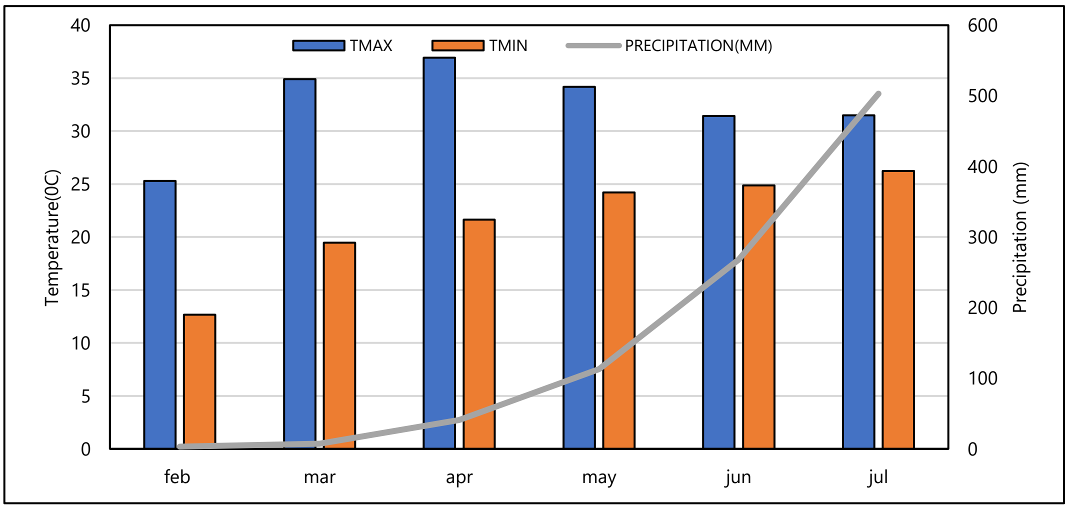

Figure 1. Agro-climatic parameters (TMAX: maximum temperature; TMIN: minimum temperature) of the experimental site.

2.2. Design of Experiment, Treatment Details, and Agronomic Practices

The experiment was conducted in an alpha lattice design with 30 treatments (genotypes) and two replications. There were six blocks per replication and each block had five genotypes. The thirty genotypes (seeds) used in this study were provided by Regional Agriculture Research Station (RARS), Tarahara. All the genotypes are under evaluation phase except Chaite-4, Chaite-5, Sukkha-4, Sukkha-6, Sukkha-3, and Hardinath-1 which are released varieties for spring and main season cultivation (Kandel et al., 2022; Adhikari et al., 2019). Sowing was done in a dry bed (1 × 1 m) on February 19, 2022, and 20-day-old seedlings were transplanted in the main field (3 × 3 m) on March 11, 2022, and harvesting was done from June 26 to July 4, 2022. A spacing of 20 × 20 cm was maintained during transplanting and the water level was maintained at 5 cm in both environmental conditions (irrigated and non-irrigated). The distance between plots was 50 cm and between blocks was 1 m. One month after transplanting, the water level was reduced and one of the environments was subjected to terminal drought stress, taking care that no moisture from rainfall or artificial means reached the drought field. After one month, the drought field was water-stressed - no additional irrigation was provided and it was subjected to terminal stress (Kandel et al., 2022). The distance between the drought field and the well-watered field was 12 m to ensure that there was no movement of subsurface water between the environments. Agronomic practices were followed as suggested by (Kandel et al., 2022; Tiwari et al., 2019).

2.3. Data Collection and statistical analysis

Grain yield data were collected for the whole plot and weighed using a digital scale, and moisture content was recorded in the field using a hand-held moisture meter (Wile 55). Grain yield was converted to moisture content at 12.5% in kg/ha according to Kandel et al. (2022). From the data of both environmental conditions entered in Ms-Excel 2016, drought tolerance indices were calculated and processed for further analysis. Correlation analysis was performed using SPSS v.25 (IBM Corp., Armonk, NY, USA) and biplot analysis was performed using Minitab. Analysis of variance with the environment was done using R-studio v.4.0.1 (R Core Team LLP, Boston Massachusetts, USA). The drought tolerant indices (Table 1) used in the study have been used by several researchers to select the appropriate genotype under both conditions (Kandel et al., 2022; Kumar et al., 2012; Muthuramu and Ragavan, 2020; Poudel et al., 2021; Garg and Bhattacharya, 2017). The drought tolerance indices used in the study are as follows:

Table 1. Description of the drought tolerance indices used in the study.

Index	Formula	Description
Tolerance index (TOL)	TOL = Yp -Ys	TOL= Tolerance index, Y_p = yield under well-watered conditions, and Y_s = yield under drought conditions A higher value of TOL indicates, the susceptibility of a given cultivar (Rosielle and Hamblin, 1981)
Mean productivity index (MP)	MP = (Yp +Ys)/2	The average performance of genotypes under both conditions (Adhikari et al., 2019; Kandel et al., 2022)
Geometrical mean productivity (GMP)	GMP= (Yp *Ys)1/2	When breeding goals are focused on comparing performance in favorable and unfavorable environments while taking variability in drought intensity and years into consideration, GMP is more effective and valuable (Adhikari et al., 2019).
Stress tolerance index (STI)	STI = Yp × Ys/ (average Yp)2	Used to quantify genotypes performing well under contrasting environmental conditions viz. optimal *vs*. stress-induced (Adhikari et al., 2019)
Yield stability index (YSI)	YSI = Ys/ Yp	If the result is near 1, it means that genotypes are more stable under stress than they are under non-stress (Bouslama and Schapaugh, 1984; Adhikari et al., 2019)
Stress susceptibility index (SSI)	SSI= [1- (Ys/Yp)]/[1-(average Ys/ average Yp)]	Fisher and Maurer (1978): The stress susceptibility index (SSI), developed by Fisher and Maurer in 1978, measures the yield drop induced by favorable vs. unfavorable environmental conditions. proposed stress susceptibility index (SSI), which assesses the reduction in yield caused by unfavorable vs favorable environments,

3. Results and Discussion

3.1. Performance of Grain Yield and Drought Tolerant Indices

Grain yield is significantly ($P \leq 0.001$) influenced by genotype, environment, and genotype × environment interactions, which accounted for 93.68%, 4.02%, and 2.30% of the observed variation, respectively, according to the analysis of variance results. In addition, yield under ideal (well-watered) and drought conditions, as well as all drought-tolerant metrics, varied significantly (P≤0.05). Grain yield under ideal conditions ranged from 4472.5 to 2969.5 kg/ha, with a mean yield of 3555.35 kg/ha (Table 2). Under ideal conditions, genotype IRE 1621661 was the best performer, followed by Chaiate-2 and Chaite-1, while IR-192077-21-21-3-B (2969.5 kg/ha) was the worst performer. Under drought conditions, genotype IRE 1621661 (3099.5 kg/ha) had the highest grain production, followed by IR- 12907721-36-8-B (2888.5 kg/ha) and IR-129077-11-12-7-B (2750 kg/ha). Yield under ideal and drought conditions was used to determine drought tolerance indices (Muthuramu and Ragavan, 2020). To reduce the trade-off between water and grain yield, genotype selection is also influenced by the performance of a genotype under optimum conditions. Under water stress conditions, the grain yield of drought-tolerant genotypes is higher than that of drought-susceptible genotypes (Garg and Bhattacharya, 2017).

Table 2. Mean Performance of thirty rice genotypes using various drought tolerant indices.

Name Code	Genotype	Yield (Optimum)	Yield (Drought)	TOL	YSI	MP	GMP	SSI	STI
1	Chaite-1	4011	2641.5	1369.5	0.66	3326.25	3254.89	1.02	0.83
2	Chaite-2	4051.5	2402	1649.5	0.59	3226.75	3117.92	1.22	0.77
3	HARDINATH-1	3839.5	2570.5	1269	0.67	3205	3141.139	0.99	0.78
4	IR- 12907721-36-8-B	3844	2888.5	955.5	0.75	3366.25	3332.16	0.74	0.87
5	IR10L192	3636.5	2420	1216.5	0.66	3028.25	2963.89	1.02	0.77
6	IR-10L192	3141.5	2073	1068.5	0.67	2607.25	2551.36	1.02	0.55
7	IR-1-19-2-1-1-1-186515	3679.5	2524	1155.5	0.68	3101.75	3043.26	0.95	0.76
8	IR129077-11-12—7-B	3641	2750	891	0.75	3195.5	3163.61	0.73	0.79
9	IR129077123-1-1-55-8-B-83	3544.5	2572	972.5	0.72	3058.25	3018.90	0.82	0.72
10	IR-129077-21-42-5-B	3822	2181	1641	0.57	3001.5	2887	1.28	0.66
11	IR129077-21-7-8-B	3722.5	2580	1142.5	0.69	3151.25	3099.03	0.91	0.76
12	IR1611795	3673	2505.5	1167.5	0.67	3089.25	3021.63	0.99	0.75
13	IR1621004	3505.5	2215	1290.5	0.63	2860.25	2786.22	1.10	0.61
14	IR1621226	3638	2375.5	1262.5	0.66	3006.75	2937.68	1.04	0.68
15	IR16L1004	3179	2399	780	0.75	2789	2761.04	0.73	0.60
16	IR16L1226	3370	2511.5	858.5	0.74	2940.75	2908.70	0.77	0.68
17	IR16L1411	3032.5	2200	832.5	0.72	2616.25	2582.89	0.82	0.53
18	IR17A1723	3249.5	1604.5	1645	0.49	2427	2282.28	1.51	0.42
19	IR17L1317	3894.5	2694.5	1200	0.69	3294.5	3239.03	0.92	0.83
20	IR-192077-21-21-3-B	**2969.5**	1969.5	1000	0.66	2469.5	2418.05	1.00	0.46
21	IR-80991-B330-0-1	3534.5	2207.5	1327	0.62	2871	2791.85	1.12	0.62
22	IR-80991-B330-0-2	3782	2384	1398	0.63	3083	3002.72	1.10	0.71
23	IR96321-1447651-B-1-1-2	3292	2036	1256	0.61	2664	2588.79	1.14	0.53
24	IRE 1621661	4472.5	3099.5	1373	0.69	3786	3722.97	0.92	1.20
25	IRE16L1661	3358	2628.5	729.5	0.78	2993.25	2970.35	0.65	0.70
26	NR2184	3461.5	2266.5	1195	0.65	2864	2800.88	1.03	0.62
27	Sukkha-3	3506	2200	1306	0.61	2853	2771.33	1.14	0.62
28	Sukkha-4	3240	1889	1351	0.58	2564.5	2473.68	1.25	0.49
29	Sukkha-6	3556.5	2332.5	1224	0.65	2944.5	2878.99	1.03	0.66
30	SVIN-312	3013	1827	1186	0.60	2420	2345.27	1.179	0.44
	Grand Mean	**3555.36**	**2364.93**	**1190.43**	**0.66**	**2960.15**	**2895.24**	**1.01**	**0.68**
	CV%	7	13.9	9.3	7.2	9.7	10.4	14.2	20.8
	F-test	**	**	**	**	*	**	**	*

*: Denotes level of significance at P-value≤0.05; **: denotes Level of significance at P-value ≤ 0.01, CV: coefficient of variation; TOL: tolerance index; YSI: yield susceptibility index; MP: mean productivity; GMP: geometric mean productivity; SSI: stress susceptibility index: STI: stress tolerance index.

The higher value of TOL was reported in Chaite-2 and IR17A1723. The lowest value of TOL was reported in IRE16L1661 and IR16L1004. The higher stress tolerance of a particular variety is indicated by the lower value of TOL (Adhikari et al., 2019). The lower SSI value indicates higher yield stability as reported in IRE16L1661. Maximum YSI was reported in IRE16L1661 and minimum in IR17A1723. Adhikari et al. (2019), reported that genotypes with lower SSI have high drought tolerance capacity. Kandel et al. (2022) also reported that stress-tolerant cultivars had lower TOL; SSI and TOL are important drought-tolerant indices as they favor the selection of high-performing (high-yielding) genotypes under drought-stress conditions. In addition, MP, GMP, and STI are used to identify the genotype that produces a high yield under both conditions. Maximum MP, GMP, and STI were reported in IRE 1621661. The genotypes with high levels of STI and MP index and low levels of SSI are considered drought-tolerant genotypes. The importance of STI in the selection of stable and resistant genotypes has also been reported by (Kandel et al., 2022).

3.2. Correlation and Principal Component Analysis

The correlation between Yp, Ys, and drought tolerance indices was calculated to evaluate the most appropriate drought tolerance criterion. The correlation between Yp and Ys was positive and had a significant effect on the genotypes (Table 3). This implies that genotypes with high yields in non-stressed conditions can anticipate better yields in drought conditions. Thus, the selection of drought-tolerant genotypes based on the performance of genotypes under normal conditions is not beneficial. There was a negative and insignificant correlation between TOL and Ys, whereas SSI was negatively and significantly correlated with Ys. In addition, Ys had a significant and positive correlation with YSI.

Table 3. Correlation analysis between yield under optimum and drought conditions, and various stress tolerance indices

Parameters	Yield (Optimum)	Yield (Drought)	TOL	YSI	MP	GMP	SSI	STI
Yield (Optimum)	1							
Yield (Drought)	0.737**	1						
TOL	0.425*	-0.299	1					
YSI	0.050	0.709**	-0.878**	1				
MP	0.936**	0.928**	0.078	0.398*	1			
GMP	0.903**	0.955**	-0.003	.0471**	0.997**	1		
SSI	-0.050	-0.709**	0.878**	-1.000**	-0.398*	-0.471**	1	
STI	0.907**	0.948**	0.011	0.452*	0.995**	0.997**	-0.452*	1

*: Denotes level of significance at P-value≤0.05; **: denotes level of significance at P-value ≤ 0.01; TOL: tolerance index; YSI: yield susceptibility index; MP: mean productivity; GMP: geometric mean productivity; SSI: stress susceptibility index: STI: stress tolerance index.

The first two principal components showed cumulative variation greater than 99% with an eigenvalue greater than 1. The first and second components contributed 65% and 34.5% of the variation, respectively. Principal component analysis was performed for drought tolerance indices and genotype response. PC1 was positively correlated with all traits except SSI and TOL (Figure 2). PC2 has a negative relationship with all traits except YSI and yield under drought. Similar results were reported by Kandel et al. (2022). These drought indices Yp, Ys, SSI, MP, GM, and STI can be called drought stress tolerance components. Genotypes with a higher value of PC1 and a low value of PC2 are high-yielding genotypes under both conditions i.e., genotypes IR- 12907721-36-8-B, IR17L1317, and IRE1621661 (Figure 2). While genotypes with a high value of PC2 and a low value of PC1 are low-yielding genotypes under stress conditions i.e., SVIN-312, IR-192077-21-21-3-B, and IR10L192 which had relatively low performance under both conditions. Kamrani et al. (2018) and Puri et al. (2020) reported similar results while evaluating durum wheat and spring wheat genotypes for heat stress tolerance, respectively. A positive and significant correlation between STI, GMP, and MP with Yp and Ys has also been previously reported by other researchers (Abdolshahi et al., 2013; Carvalho et al., 2022; Hussain et al., 2021; Pavithra and Vengadessan, 2020; Garg and Bhattacharya, 2017; Ullah and Shakeel, 2019), which further supports our findings. Therefore, genotype selection considering MP, GMP, and STI would determine the genotype with high yield potential.

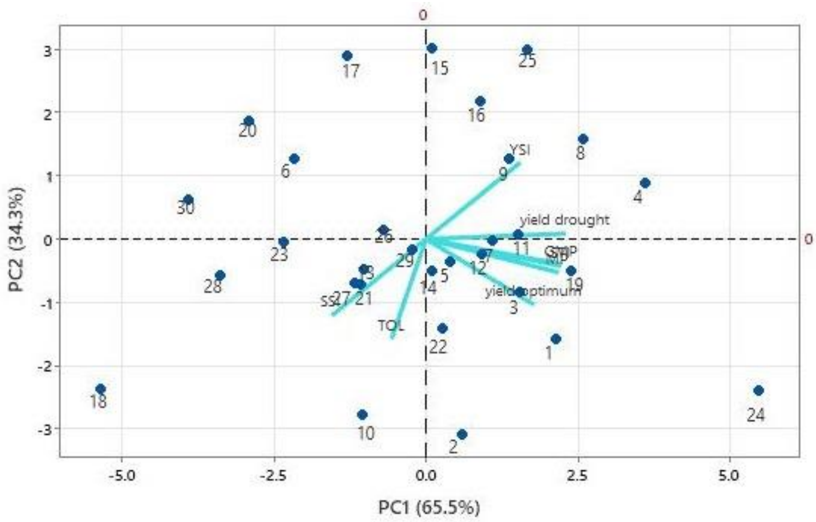

Figure 2. PCA biplot analysis of various drought tolerant indices and genotypes.

4. Conclusion

Results from our study suggest that genotype IRE1621661 has paramount performance in both environmental conditions and is suitable for cultivation under drought-prone and rainfed areas of the inner plains of Nepal to cope with a yield penalty. However, stability in yield drought tolerant indices suggests that genotype IRE16L1661 with a low value for TOL and SSI, and a higher value for YSI, which makes it suitable for drought-prone areas. Thus, genotypes IRE1621661 and IRE16L1661 can be suggested for further testing for their response to agronomic practices and commercial cultivation in drought-prone / rainfed areas.

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