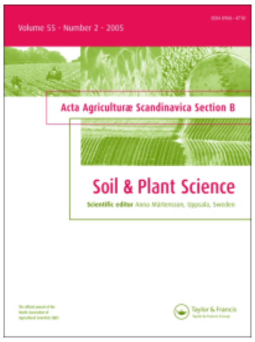

Acta Agriculturae Scandinavica, Section B — Soil & Plant Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/sagb20

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To cite this article: Bishnu Prasad Kandel, Laxmi Prasad Joshi, Subarna Sharma, Prabha Adhikari, Barsha Koirala & Kumar Shrestha (2022) Drought tolerance screening of rice genotypes in mid-hills of Nepal using various drought indices, Acta Agriculturae Scandinavica, Section B — Soil & Plant Science, 72:1, 744-750, DOI: 10.1080/09064710.2022.2072382

To link to this article: https://doi.org/10.1080/09064710.2022.2072382

Published online: 22 May 2022.

ACTA AGRICULTURAE SCANDINAVICA, SECTION B — SOIL & PLANT SCIENCE
2022, VOL. 72, NO. 1, 744–750
https://doi.org/10.1080/09064710.2022.2072382

Taylor & Francis
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RESEARCH ARTICLE

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Drought tolerance screening of rice genotypes in mid-hills of Nepal using various drought indices

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ABSTRACT

Drought is a major abiotic factor causing rice yield loss in rainfed and drought-prone areas, so screening of the cultivars for drought tolerance is crucial. Our study screens 10 commercial rice cultivars grown in the mid-hills of Nepal and four pipeline genotypes. Our objective is to identify the superior drought-tolerant cultivar and suitable indices for screening. The 14 rice genotypes were evaluated under both drought stress and non-stress conditions in randomized complete block design with three replications. The yield reduction for the cultivars ranged from 12-54% during water-stressed conditions. The drought indices mean productivity, geometric mean productivity and stress tolerance index showed a positive and high correlation with grain yield. Based on drought indices, genotype NR 119 showed the highest mean productivity, geometric mean productivity, stress tolerance index and lowest yield loss. Further, principal component analysis bolsters our results by clustering similar drought indices and drought-tolerant cultivars. The NR 119 is followed by Chaite 5 and Chaite 4 as a drought-tolerant genotype, therefore, we recommend it for drought-prone areas of the mid-hill region of Nepal. We identified mean productivity, stress tolerance index and geometric mean productivity as important drought indices, so we recommend using this for drought screening.

ARTICLE HISTORY
Received 24 January 2022
Accepted 26 April 2022

KEYWORDS
Drought indices; abiotic stress; rice genotypes; cultivars; drought tolerance; yield loss

Introduction

Rice (*Oryza sativa* L.) is a major cereal crop grown and consumed in Asia. About 90% of the global rice is produced and consumed in Asia (IRRI 2013). Drought is considered a major yield-reducing factor in rainfed farming land of south Asia affecting more than 23 million ha of cultivated field (Huke and Huke 1997). It is predicted that 15 million hectares of flood irrigated rice crops in Asia will experience water shortage by the end of 2025 (Tuong and Bouman 2001). Rice is highly sensitive to drought stress during its critical growing stages, like the pre-flowering and grain filling stage. Losses due to drought are severe in south Asian countries like Nepal, India and Bangladesh. In Nepal, rainfed rice accounts for 57% of the total rice cultivation area. Annually the rice is grown in 1.46 million hectares with a production of 5.15 million tons i.e. 3.67 ton ha^{-1} yield (MoALC 2017/18). Among the total cultivated area, 0.8 million hectares are estimated to be drought-prone areas (MoAD 2015/16). Rice needs adequate water supply to complete its life cycle and is vulnerable to drought conditions than other crops (Bray et al. 2000). In Nepal, about 44% of rice-growing areas rely on monsoon rain for its successful cultivation (Tripathi et al. 2019). High fluctuation in rainfall patterns over several years has resulted in a decline in cultivation area and has become a major challenge for rice farming.

The crucial step for sustaining the future development of rice production is screening for varieties tolerant to drought (Pandey and Shukla 2015; Singh et al. 2018). The selection of the best varieties to perform well in drought-prone areas depends on selecting high-yielding genotypes having drought tolerance. But attaining drought tolerance exclusively dependent on yield is difficult due to its complex heritability (Anwaar et al. 2020). Alternatively, some statistical parameters like drought indices could be used to select the

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Supplemental data for this article can be accessed at https://doi.org/10.1080/09064710.2022.2072382
This article has been corrected with minor changes. These changes do not impact the academic content of the article.

genotype of high yield and drought tolerance (Yadav and Bhatnagar 2001; Anwaar et al. 2020). These indices are formulated based on a mathematical relationship between yield under water-stressed and non-stressed conditions. The different indices to determine the drought tolerance of a cultivar are as follows: tolerance level (TOL), mean productivity (MP), geometric mean productivity (GM), stress tolerance index (STI) and stress susceptibility index (SSI). The genotypes with a high amount of MP, GM and STI indexes and low amount of SSI are considered as tolerant genotypes in wheat (Mohammadi et al. 2008). The STI index has more advantages for the selection of suitable cultivars in both stress and non-stress conditions (Nouraein et al. 2013). In rice, the cultivars showing low SSI and TOL with high STI values are considered drought-tolerant cultivars (Adhikari et al. 2019). Only a few research papers have discussed about the suitable drought indices for screening the drought-tolerant rice genotype. Most of the drought screening research has been conducted on wheat. A genotype with high MP and GMP and STI has the best indexes to evaluate drought tolerance (Hooshmandi 2019). Most of the rice varieties grown in Nepal perform well under water-saturated conditions but they perform poorly under water stress. To mitigate that farmers have been growing different drought-tolerant rice genotypes in recent years. However, the drought tolerance screening of these cultivars has been reported in a few cultivars and regions. In addition, Nepal is rich in a diverse agro-ecological regime so not all the cultivars are suitable in all areas (Kandel and Shrestha 2020). So, there is a need for region-specific drought screening trials before recommending a cultivar to that specific region. Here, our objective is to conduct a drought tolerance screening of the commercial cultivars grown in the mid-hills of Nepal and to identify the suitable drought indices in rice for drought tolerance screening.

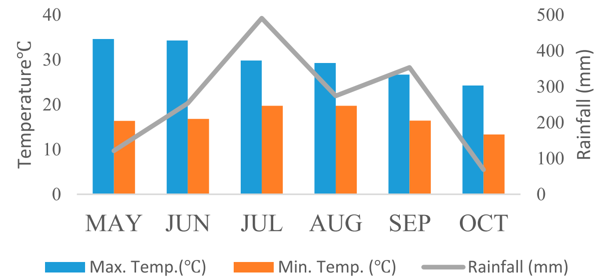

Figure 1. Climatic details of research area during crop period (May to Oct) in 2019.

Materials and methods

Research area and rice genotypes

The experiment was conducted in the research field of the Institute of Agriculture and Animal Science (IAAS), Lamjung located at 650 masl with latitude 28° 7′ 41.93″ N and longitude 84° 24′ 51.23″ E during the rainy season of 2019. Agroclimatic details of experiment site were shown in Figure 1. The soil was sandy clay loam and fertile with an assured irrigation facility. The experiment was carried out in randomised complete block design (RCBD) with three replications. A total of 13 rice genotypes as listed in Table 1 were used as an individual treatment. Among 13 genotypes Bahuguni 1, Chaite 5, Radha 11, Radha13, Ghaiya 2 and Chaite-4 are commercially grown cultivars in the mid-hills of Nepal. Manabahu is a popular local variety at the research location whereas Sukhadhan 5 is high yielding and popular variety for mid hill so used as standard check. DRR 44, NR-601-1-9, NR 119 and NR 1190 are genotypes evaluated in mid-hill environment. Sawa Mansuli Sub 1 is chosen for water stagnant varieties and help to comparative study. Sukhadhan 5 Seeds of 12 rice varieties were obtained from the regional agriculture research station (RARS), Khajura Banke, and one local check variety (Manabahu) from local farmers from

Table 1. List of rice cultivars used in research.

Varieties	Parents	Yield (ton/ha)	Year released	Remarks
Bahuguni 1	IR81896-B-B-195/3*IR05F102	5.5	2018	Released variety
Chaite 4	BG 34-8/IR28/IR2095-625-1-2-32	–	–	Pipeline cultivar
Chaite 5	PJ 17/ PJ 18	4.6	2018	Released variety
DRR 44	IR71700-2-47-1-1-2/IR 03L 120	5–5.5	–	Evaluation phase
Ghaiya 2	MTU/WKA, KAIKU	3.4	1987	
Manabahu*	–	–	–	Local landraces
NR 119	–	–	–	Evaluation phase
NR 1190	–	–	–	Evaluation phase
NR-601-1-9	–	–	–	Evaluation phase
Radha 11	Selection from TCA-80-4	4.0	1995	Released variety
Radha 13	Masuri/ IR38701-49-2-6	3–4.2	2017	Released variety
Sawa Mansuli Sub 1	Sambha masuri/ IR49830-7-1-2-3	3.5–4	2011	Released variety
Sukhadhan 5**	IR 72022-46-2-3-3-2/ Swarna	3.2–4.2	2014	Released variety

*Local check, **standard check, Source (MoAD 2015/16; MoALC 2017/18).

Sundarbazar, Lamjung. Each genotype was examined under both rainfed (stress) and irrigated (non-stress) conditions.

Experimental details

Rice seedlings were raised in a dry seedbed for 25 days and then rice seedlings were transplanted in well-puddled soil in the 3 m × 3 m plot size and 20 cm × 20 cm crop spacing. Both the fields (stress and non-stress) were fertilised with 6 ton ha^{-1} of farmyard manure (FYM) and chemical fertiliser at 100:30:30 kg NPK ha^{-1}were applied in both field conditions. A half dose of nitrogen and a complete dose of phosphorous, potassium and FYM was applied at field preparation and the remaining half dose of nitrogen was split into tillering and panicle initiation stages. Various intercultural operations like weed management and insect-pest management were carried out repeatedly. In non-stress field conditions, five cm of stagnant water was maintained from transplanting to a month before harvesting by providing water by rain or by supplementary irrigation when required (Singh et al. 2018). Whereas in the stress field conditions, water was maintained for a month after transplanting, and then the field was drained to allow them to dry for stress to develop. There was no supplemental irrigation provided after the drainage (Singh et al. 2018).

Drought tolerance indices and statistical analysis

All the data were collected from the 1m^2 area of each plot except grain yield which was measured from whole plot i.e. 9 m^{-2}. The well-matured plants were harvested manually with help of sickle and left in the field to dry for three days and then threshed by beating on a hard floor. Grain yield ton ha^{-1} was measured at a 12% moisture level by using Equation (1). Several drought tolerance indices were computed based on a mathematical relationship between yield under drought stress and non-stressed conditions (Table 2). Data were recorded in MS Excel (version 19) and analyzed through the R package (3.6.1). The ANOVA test was conducted to see the significant difference between the genotypes and the least significant difference (LSD) was computed at a 5% level of significance. The correlation between the drought indices and yield during stress and non-stress was carried out by SPSS version 25. A principal components analysis (PCA) was carried out to explore the statistical correlation between genotypes during the stress conditions by using Minitab version 14.

$$\text{Grain yield (ton ha}^{-1}) = \frac{\text{Plot yield (kg)} \times (100 - \text{grain moisture content\%}) \times 10,000\text{m}^2}{(100 - 12) \times \text{net plot area (m}^2)} \quad (1)$$

Results and discussions

Mean performance of drought indices

All drought tolerance indices showed a highly significant difference between the rice cultivars, as shown in Table 3. A significant difference was observed between the mean grain yield under stress and non-stress condition for all cultivars which indicates the difference in performance between two different conditions. In tolerance index (TOL), the least TOL value was recorded for Chaite 5 (0.65), which was statistically at par with NR 119, Chaite 4, Manabahu, NR 1190, Ghaiya 2 and NR-601-1-9. The lower value of TOL indicates the higher stress-tolerant ability of a given cultivar. The stress susceptibility index (SSI) value of NR 119 was statistically at par with Chaite 4 and Chaite 5. The lower SSI value suggests higher yield stability. Similar result was reported by Adhikari et al. (2019), genotypes having lower SSI have high drought-tolerant capacity. Singh et al. (2018) also reported stress-tolerant cultivars had lower TOL. Drought indices like TOL and SSI are important as they favour genotypes with good yield under drought stress conditions. Other drought indices like MP, GM and STI are used to identify the genotype that produces high yield under both stress and non-stress conditions. The

Table 2. Drought tolerances indices tolerance index (TOL), mean productivity (MP), geometric mean productivity (GM), stress tolerance index (STI), yield stability index (YSI), stress susceptibility index (SSI) was calculated using grain yield under non- stress (Y_P) and stress (Y_S) conditions.

Drought tolerance indices	Formula equation	Reference
Tolerance index	TOL = Yp − Ys	(Rosielle and Hamblin 1981; Hossain et al.1990; Anwaar et al. 2020)
Mean Productivity index	MP = (Yp + Ys)/2	(Rosielle and Hamblin 1981; Hossain et al.1990; Adhikari et al. 2019)
Geometrical mean productivity	GMP = $\sqrt{(Ys \times Yp)}$	(Fernandez 1992; Adhikari et al. 2019)
Stress tolerance index	STI = Yp × Ys/(Yp)^2	(Fernandez 1992; Anwaar et al. 2020)
Yield stability index	YSI = Ys/Yp	(Bouslama and Schapaugh 1984)
Stress susceptibility index	SSI = 1 − (Ys/Yp) / SI, while SI = 1 − (Ys/Yp)	(Fisher and Maurer 1978; Adhikari et al. 2019; Anwaar et al. 2020)

Table 3. Mean performance of different drought indices of rice.

Genotype	Ys (ton/ha)	Yp (ton/ha)	MP	TOL	GM	STI	YSI	SSI	Yield loss (%)
Bahuguni1	3.75[cd]	5.74[a]	4.74[bc]	1.99[b]	21.51[bc]	0.87[bc]	0.65[e]	1.27[b]	35
Chaite 4	3.95[bcd]	4.72[cd]	4.33[cd]	0.77[c]	18.67[cd]	0.75[cd]	0.84[ab]	0.59[ef]	16
Chaite 5	4.45[b]	5.11[bc]	4.77[bc]	0.65[c]	22.83[bc]	0.93[bc]	0.87[a]	0.48[f]	13
DRR 44	4.27[bc]	5.95[a]	5.10[ab]	1.68[b]	25.37[ab]	1.03[ab]	0.72[cde]	1.03[bcd]	28
Ghaiya 2	3.34[de]	4.24[de]	3.79[de]	0.90[c]	14.42[de]	0.58[de]	0.78[bc]	0.78[de]	21
Manabahu (local)	2.06[g]	2.87[f]	2.46[f]	0.80[c]	5.91[f]	0.24[f]	0.72[cde]	1.02[bcd]	28
NR 119	5.10[a]	5.79[a]	5.44[a]	0.69[c]	29.52[a]	1.20[a]	0.88[a]	0.43[f]	12
NR 1190	2.24[g]	3.08[f]	2.66[f]	0.84[c]	6.96[f]	0.28[f]	0.73[cde]	1.00[bcd]	27
NR-601-1-9	3.07[ef]	3.97[e]	3.52[e]	0.90[c]	12.19[e]	0.49[e]	0.77[bcd]	0.83[cde]	23
Radha 11	4.17[bc]	5.98[a]	5.07[ab]	1.81[b]	24.94[ab]	1.01[ab]	0.69[de]	1.1[bc]	30
Radha 13	4.08[bc]	5.86[a]	4.97[ab]	1.77[b]	23.91[bc]	0.97[bc]	0.70[de]	1.11[bc]	30
Sawa Mansuli Sub 1	2.58[fg]	5.59[ab]	4.09[de]	3.01[a]	14.45[de]	0.59[de]	0.46[f]	1.97[a]	54
Sukhadhan 5 (std chk)	3.98[bcd]	5.63[ab]	4.80[bc]	1.65[b]	22.75[bc]	0.92[bc]	0.70[cde]	1.09[bcd]	29
LSD (0.05)	0.61	0.52	0.54	0.32	4.80	0.19	0.075	1.04	
CV (%)	10.03	6.22	7.52	14.26	15.25	15.25	6.11	57.64	
F test	**	**	**	**	**	**	**	**	
Grand mean	3.62	4.96	4.29	1.35	18.72	0.76	0.85	1.08	27

**Significant at 0.01 level, Ys: yield under stress, Yp: yield under non-stress, MP: mean productivity, TOL: Tolerance index, GM: geometric mean productivity, STI: stress tolerance index, YSI: yield stability index, SSI: stress susceptibility index. The letters (a-g) indicate the least significant difference (LSD) test rankings; a represents the highest followed by b to g. The similar letters represent that the means are significantly at par with each other.

NR 119 has the highest MP, GM and STI values in comparison to other genotypes. The high value of STI implies that it shows an intensive tolerance to drought (Hooshmandi 2019). Similarly, the high value of MP implies that it can perform well under both conditions. The genotypes with high amounts of MP and STI index and low amount of SSI indexes are considered as tolerant genotypes against drought (Mohammadi et al. 2008). Based on these indices, NR 119 can be considered as the tolerant genotype against drought.

Yield reduction by drought

Yield reduction caused by drought stress for each cultivar of rice is an important index to evaluate the yield changes of a cultivar in stress conditions to its non-stress conditions. From Table 3, the highest yield reduction was observed on Sawa Mansuli Sub 1 (54%) followed by, Bahuguni-1 (35%), Radha 11 (30%), Radha 13 (30%). Manabahu was a low yielder but stable genotypes in both environments. NR119, Chaite 5 and Chaite 4 were the top performers in stress conditions. The percent yield lost due to drought was the lowest for NR119 (12%) which outperform the Sukhadhan 5, which has a yield loss of 29%. Here, the yield reduction by drought conditions ranges from 12% to 54% with an average of 27%, as shown in Table 4. Our result is consistent with the findings by Singh et al. (2018) on rice cultivars study but the cultivars were different. They have found the mean yield reduction of 35% which is closer to our 27% mean yield reduction. Rashidi et al. (2011) have reported that the yield reduction in wheat caused by drought stress ranges from 13% to 76% with mean of 55%, which is slightly higher than the rice. Hooshmandi (2019) reported a 34.03% mean reduction of wheat yield due to stress condition which is closer to our 27% mean yield reduction in rice. The ability of cultivars to perform well in stress condition is noted as a key indicator for crop stability. The lower value of yield reduction indicates better drought-tolerant ability. Thus, NR 119, Chaite 5 and Chaite 4 are the drought-tolerant cultivars since they have the lowest yield reduction by drought.

Correlation of drought indices

The best drought indices are those which has a high correlation with yield under both stress and non-stress

Table 4. Correlations between drought indices of rice.

	Ys	Yp	MP	TOL	GM	STI	YSI	SSI
Ys	1							
Yp	.837**	1						
MP	.887**	.866**	1					
TOL	.177 ns	.687**	.379	1				
GM	.974**	.866**	.917**	.264 ns	1			
STI	.783**	.837**	.787**	.465 ns	.796**	1		
YSI	.184 ns	−.234 ns	.098 ns	−.665*	.192 ns	−.158 ns	1	
SSI	−.474 ns	.011 ns	−.302 ns	.649*	−.457 ns	−.089 ns	−.656*	1

*Significant at 0.05 level, **significant at 0.01 level, ns: non-significant, Ys: yield under stress, Yp: yield under non-stress, MP: mean productivity, TOL: Tolerance index, GM: geometric mean productivity, STI: stress tolerance index, YSI: yield stability index, SSI: stress susceptibility index.

conditions (Hooshmandi 2019). The correlation results from Table 4 indicate that yield under stress conditions (Ys) has a highly positive and significant correlation with Yp, MP, GM and STI. In contrast, SSI showed a negative and non-significant association with stress condition yield. Similarly, non-stress condition (Yp) showed a positive significant association with TOL, MP, GM and STI while Yp showed negative and non-significant association with YSI. Here, in both conditions, MP, GM and STI showed a positive and significant correlation with the yield. A similar result was obtained in a drought study in wheat cultivar (Hooshmandi 2019). A positive and significant correlation between STI, GM and MP with Yp and Ys had also been previously reported by other researchers (Sio-Se Mardeh et al. 2006; Jafari et al. 2009; Ilker et al. 2011; Ghobadi et al. 2012; Toorchi et al. 2012). Selection based on these indexes results in the identification of genotypes with high yield stability in both environments and can be introduced as the best evaluation indexes for stress tolerance (Hooshmandi 2019). Ys and Yp were found to be in positive and significant correlations, similar results between Yp and Ys were reported by Nouraein et al. (2013) and Rahimi et al. (2013) in wheat and rice, respectively. The correlation implies that cultivars with high yield potential under a non-stress environment can anticipate superior yield under a stress environment as well. Based on this correlation analysis, drought-tolerant indices like STI, GM and MP can be used for the selection of the drought-tolerant rice genotypes.

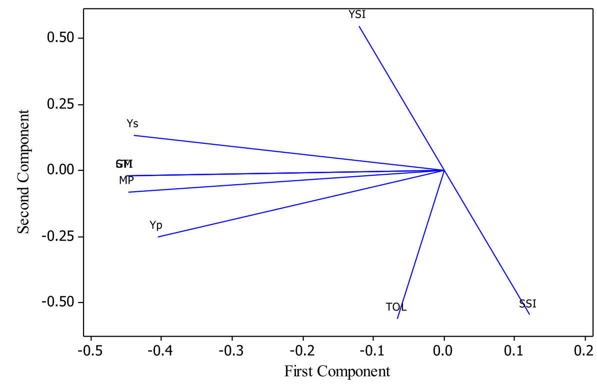

Figure 2. Principal component analysis of drought tolerance indices collected from 13 rice genotypes.

Principal components analysis

The two separate principal component analysis (PCA) was conducted to see the impact of drought stress in the genotypes (Figure 2) and to see the impact of genotype performance in the different drought indices (Figure 3). A cluster was formed in the PCA plot (Figure 3) which includes the Ys, Yp, GM, MP and STI which further supports the correlation between them. These drought indices Yp, Ys, STI, MP, GM and STI can be called as drought stress tolerance components. Similar results with positive and high correlation with Yp, Ys, STI and MP were reported (Hooshmandi 2019). In Figure 2, two components in the PCA explained more than 99% variation with an eigenvalue greater than 1 shown in (Table S1). The first component contributed

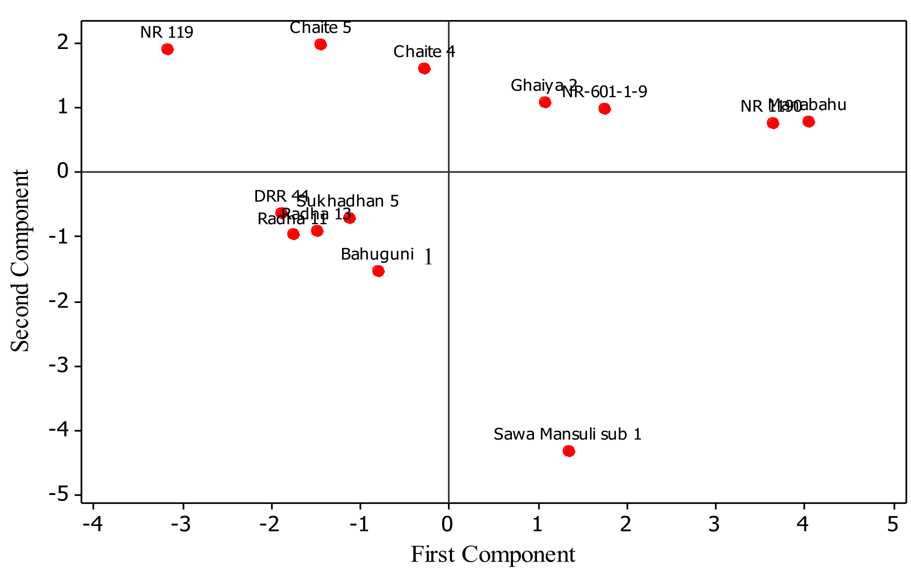

Figure 3. Loading plot for rice varieties and stress indices using first two principal components. ns: non-significant, Ys: yield under stress, Yp: yield under non-stress, MP: mean productivity, TOL: Tolerance index, GM: geometric mean productivity, STI: stress tolerance index, YSI: yield stability index, SSI: stress susceptibility index.

61% of total variation whereas the second component contributed 38% variation in the data. In Figure 2, the genotypes were clustered in PCA plot according to their drought-tolerant nature. The genotypes like NR 119, Chaite 5 and Chaite 4 are grouped in top-left. These genotypes displayed low TOL and less yield reduction due to drought (Tables 1 and 2). Similarly, genotype Sawa Mansuli Sub1 is in the down-right plot which has the highest TOL and yield reduction as well as highest SSI, thus it is a drought susceptible genotype. This clustering of genotypes according to the drought tolerance and susceptibility further bolster our earlier results. Based on PCA analysis and correlation analysis we suggest STI, GM and MP as the major indices for drought screening for rice. As there are very few papers on drought screening in rice our findings would be helpful for future drought screening in rice. Similarly, based on PCA analysis and drought indices analysis the NR 119, Chaite 5 and Chaite 4 genotypes look promising for the drought-prone areas of mid-hills region of Nepal. Thus, this genotype should be promoted to farmer field trials before recommending to rice growers in the drought-prone areas mid-hills region of Nepal.

Acknowledgements

Authors were grateful to Nepal Agriculture Research Council (NARC) and Regional Agriculture Research Station (RARS), Khajura, Banke for providing genetic materials for research.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Data will be available upon request to corresponding email via email.

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