Biological and Clinical Sciences Research Journal
ISSN: 2708-2261
www.bcsrj.com
DOI: https://doi.org/10.54112/bcsrj.v2022i1.106
Biol. Clin. Sci. Res. J., Volume, ***2022****: 106*
Original Research Article

EVALUATION OF THE TOLERANCE OF RICE (*ORYZA SATIVA*) FOR SUBMERGENCE AND DROUGHT USING VARIOUS YIELD RELATED STRESS INDICES

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(Received, 13th April 2022, Revised 18th September 2022, Published 24th September 2022)

Abstract: *Rice genotypes were evaluated under submergence stress and drought stress in two separate field conditions under Split Plot design consisting of water stress as the main plots, and rice genotype as the sub-plot treatments. Grain yields under non-stress and stressed conditions were used to calculate stress indices. In the first experiment, four rice genotypes (Swarna Sub1, Ciherang Sub1, IR-07-F289 Sub1 and IR-44 Sub1) along with two high yielding local varieties (KSK-133 and Super Basmati) were evaluated under submergence stress in field conditions. Submergence stress was applied at tillering stage for 21 days. Results of stress indices under submergence revealed that yield stability index was the only stress index which showed strong and positive correlation with crop yield under submergence. Biplot graph exhibited that harmonic mean, geometric mean productivity, mean productivity; stress tolerance index and yield index were the best stress indices among all other indices to identify submergence tolerant genotypes. Based on the stress indices and their correlation results, the genotypes can be classified in different groups. Super Basmati performed well under submergence and normal conditions, KSK-133 performed well under normal conditions, IR-44 Sub1 and Swarna Sub1 performed well under submerged conditions. While in the second experiment drought stress was applied for 30 days on four Sub1 genotypes along with Nagina-22 (Drought tolerant check) and IR-64 (drought susceptible check). Harmonic mean and yield index showed strong positive correlation with the yield under drought stress. Biplot graph exhibited that mean productivity, tolerance index, and stress susceptibility index were the best stress indices among all other indices to identify drought tolerant genotypes. Based on the stress indices and their correlation results it was observed that Nagina-22 performed well under drought and normal conditions, IR-64 performed well only under normal conditions, Swarna Sub1 and IR-07-F289 performed well under drought as compare to the normal conditions. As a whole, the findings of this study indicate that classification and selection of superior genotypes under severe stress conditions is more reliable by using stress indices as a base for selection..*

Keywords: Rice, submergence, drought, Sub1, stress tolerance indices

Introduction

With the rapid population growth in the world, the demand for food and grain has highly increased (Muddassir & Al-Zahrani, 2022). Climate change negatively affects the production of major agronomic crops by increasing the rate and severity of biotic and abiotic stresses (Zafar *et al.*, 2020; Zafar *et al.*, 2021). However, worldwide the incidents of flood and drought are increased which reduced the rice production alarmingly (Mohd Ikmal *et al*. 2021). Worldwide, rice is cultivated on 144 million hectares span across 144 countries to accomplish the world growing demand of people (Beena *et al*. 2021). After wheat, rice is Pakistan; most important staple food and top export. It contributes 3.5% in value addition in agriculture and 0.7% of GDP (Anonymous, 2018-19). Rice export during 2018-19 earned valuable foreign exchange of US$ 2 billion. According to Trade Development Authority, Pakistan is the world; fourth-largest exporter of rice and the twelfth-largest producer of rice (Jafar *et al*., 2015; Memon, 2013).

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Rice is mainly grown in various areas of Punjab and Sindh which include Sialkot, Wazirabad, Gujranwala, Sheikhupura, Sargodha, Faisalabad, Jacobabad, Larkana, Badin, Thata, Shikarpur and Dadu (Memon, 2013). The percentages of calories, protein, and fat it contributes to the diet are, respectively, 27%, 20%, and 3%. For the average person in Southeast Asia, it accounts for more than half of their daily calorie and protein intake (Kennedy *et al*., 2003; Chaudhari *et al*., 2018). High temperature, salinity, floods and drought are the major abiotic stresses that affect the rice yield. The increased global population pressure necessitates the demand of increased production of rice. Floods are one of the major constraints for rice production in Asia where flash floods affect 10-15 million hectares of rice fields (Mohanty *et al*., 2013).

These floods may occur more than once in same season causing distress at any growth stage of crops. Rice growers in Bangladesh and India sacrifice up to 4 million tons of rice per annum during floods-enough to feed 30 million individuals. The Philippines lost harvests valued at $65 million due to floods in 2006. Yield loses due to flash floods depends on temperature, turbidity, duration and depth of flood water, soil fertility, fertilizer, seedling density, and age of the crop (Afrin *et al*., 2018). Drought is another important problem in rice production. In Asia, drought is affecting more than 13 million acres of rain-fed lowland rice and 10 million acres of rain-fed upland rice (Mohanty *et al*., 2013). It shortens the plant's life cycle and decreases dry matter deposition across all plant organs. It can occur at any growth stage of the crop. Rice fields that have been damaged by drought or water stress will have stunted plants, curled leaves, delayed blooming, burnt tips, naturally drying (senescence) leaves, and whitehead, but the tiller will still be connected to the stems (Korres *et al*., 2017). Pakistan faced severe flash floods in consecutive five years from 2010 to 2014 (Rehman *et al*., 2016). While, during 2018-19, production of rice in Pakistan was decreased by 3.3% mainly due to dry weather and shortage of water (Anonymous, 2018-19). Thus, erratic monsoon rainfall pattern is becoming one of the majors constrains of rice cultivation in Pakistan.

Climate change has elevated the rate of incidence and severity of abiotic and biotic stresses. The impacts of these stresses on agricultural crop production have been increased significantly in recent decades (Kennedy *et al*., 2003; Chaudhari *et al*., 2018). In diverse environments, the productivity of breeding programs can be increased by having effective knowledge and understanding of the relationships between yield performance of the crops under stress and various selection parameters. In most crops, the primary criteria for determining tolerance to multiple environmental stresses are yield of the plants. In crop improvement projects, breeders use crop stability and its yield as a key measure of stress tolerance under diverse growing conditions (e.g., heat, salinity, floods, droughts and biotic stresses) (Zafar *et al*., 2022; Chaudhry *et al*., 2022). For this reason, screening for tolerance to a given stress relies on both strong performances in stressed and non-stressed circumstances from the crop. Therefore, high-yielding genotypes are those that can withstand adverse conditions or stress tolerant.

Materials and methods

Experimental site and plant material

The experiment was conducted in the fields of Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad during rice cropping season 2019. The experimental material was collected from Plant Breeding and Genetics Division (PBGD) which was comprised of four genotypes having sub-1 gene (Swarna-Sub1, IR-44-Sub1, IR-07-F289-Sub1, Ciherang-Sub1), two high yielding local cultivars (KSK-133, Super Basmati) and drought tolerant and drought susceptible checks (Nagina-22 and IR-64 respectively).

Experimental design

Both experiments were designed in split plot RCBD with 3 replications. The genotypes were taken as sub plot factor while normal and stress (submergence or drought) condition were taken as main plot factors. After 35 days, the seedlings were moved from the moist raised beds to the muddy ground below. Both the inter-row and inter-plant distances were 9 inches. After transplanting, gaps were filled up as needed to guarantee full plant survival. All the necessary agronomic practices were performed during plant growth in normal and stress conditions.

Evaluation of rice genotype under complete submergence in field conditions

A field experiment was conducted to evaluate the impact of submergence on yield and yield contributing traits of rice. For this purpose, five sub-1 genotypes (FR-13A, Swarna-Sub1, IR-44-Sub1, IR-07-F289-Sub1 and Ciherang-Sub1) along-with two high yielding local cultivars (KSK-133 and Super Basmati) were evaluated under field conditions. For 20 days, the newly transplanted seedlings were allowed to get their roots established and heal from the trauma of the transplantation. Then, seedlings were completely submerged by filling the pond with normal canal water for 21 days. The stress was maintained by adding water at daily basis in the pond to overcome the water loss due to percolations or evaporation. The cutting of leaves of plant above the water surface was also done twice in whole stress period to ensure the complete submergence of plant. After completing 21 days of complete submergence, the stress was terminated by draining water out of the pond.

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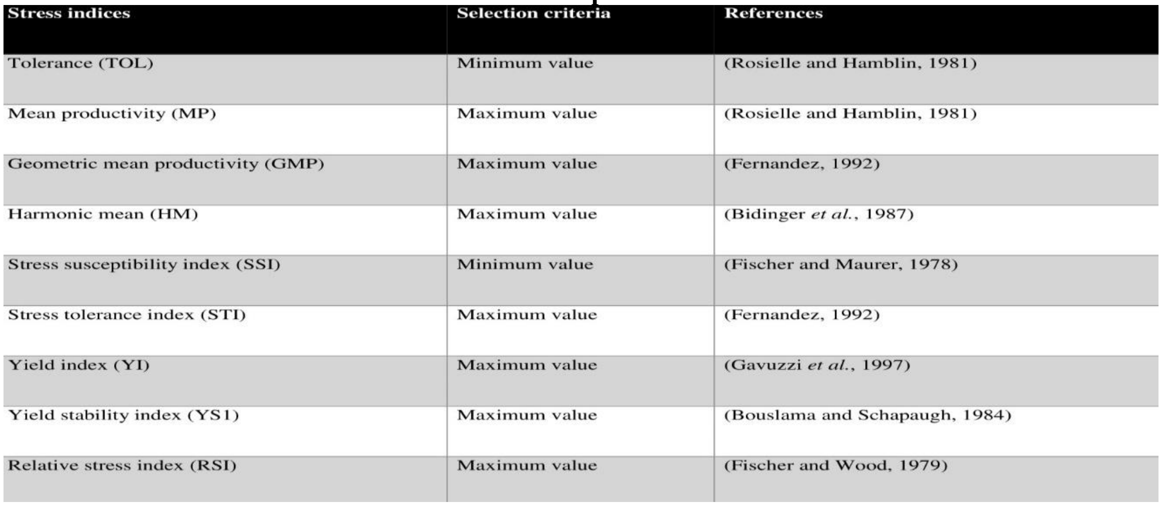
Evaluation of rice genotype under drought in field conditions

Five Sub1 genotypes (FR-13A, Swarna-Sub1, IR-44-Sub1, IR-07-F289-Sub1 and Ciherang-Sub1) were evaluated. Nagina-22 and IR-64 were grown as tolerant and sensitive checks respectively, as both genotypes have been utilized extensively in the past as controls in screening and in a wide range of morphological and physiological studies. The drought stress was applied at booting stage for 30 days. The panicles were harvested, threshed and cleaned manually to separate rice grains from straw. By weighing number of grains per plant, grain yield per plant was obtained.

Estimation of stress indices

Nine stress indices given in Table 1 were calculated for submergence and drought stress which were further analyzed by association analysis (Benesty *et al.*, 2009) and principal component analysis or biplot analysis (Gabriel, 1971).

Table 1: List of nine important stress indices



Stress indices	Selection criteria	References
Tolerance (TOL)	Minimum value	(Rosielle and Hamblin, 1981)
Mean productivity (MP)	Maximum value	(Rosielle and Hamblin, 1981)
Geometric mean productivity (GMP)	Maximum value	(Fernandez, 1992)
Harmonic mean (HM)	Maximum value	(Bidinger *et al.*, 1987)
Stress susceptibility index (SSI)	Minimum value	(Fischer and Maurer, 1978)
Stress tolerance index (STI)	Maximum value	(Fernandez, 1992)
Yield index (YI)	Maximum value	(Gavuzzi *et al.*, 1997)
Yield stability index (YSI)	Maximum value	(Bouslama and Schapaugh, 1984)
Relative stress index (RSI)	Maximum value	(Fischer and Wood, 1979)

Results and discussion

Estimation of stress indices under submergence stress

Under submergence stress, maximum mean value for yield was observed in IR-44-Sub1 followed by Super Basmati and Swarna Sub1. All nine stress indices were calculated for submergence stress and presented in Table 2. According to the TOL index (tolerance index), genotypes with lowest values are more stress tolerant (Anwaar *et al.*, 2020; Kamrani *et al.*, 2018; Nazari and Pakniyat, 2010; Poudel *et al.*, 2021). Accordingly, IR-07-F289-Sub1 (-1.260) was most tolerant to submergence stress followed by Swarna Sub1 (-0.77), IR-44-Sub1 (-0.334), Ciherang Sub1 (5.76), Super Basmati (9.91) and KSK-133 (11.320). According to Sánchez-Reinoso *et al.* 2020, Choudhary *et al*. 2021 and Sharifi-Zagheh *et al*. 2022 genotypes with high values for the STI, HM, GMP, and MP indices may be characterized as tolerant because they operate well in non-stress and stressful environment. In this case, for these indices Super Basmati and KSK-133 had the highest values followed by IR-44 Sub1, Ciherang Sub1, Swarna Sub1 and IR-07-F289 Sub1. Similar results were also observed by Abarshahr *et al.* (2011), Rahimi *et al.* (2013) and Abbasian *et al.* (2014). When comparing yield losses under stressful and non-stressful circumstances, the SSI only identifies those genotypes that suffer minimum losses under stress; an SSI >1 indicates more than average vulnerability to stress (Gholamhoseini, 2020; Moustafa, 2021). Among all genotypes, KSK-133 and Super Basmati had SSI > 1. While, all Sub1 genotypes had STI < 1 indicating that all Sub1 genotypes are not susceptible to submergence stress.

Gholamhoseini (2020) and Choudhary *et al.* (2021) reported that RSI and YSI produced similar ranking patterns in the characterization of tolerant genotypes used in this study. For YSI and RSI, IR-07-F289-Sub1 showed maximum values and KSK-133 had minimum values among all genotypes. The use of a single index for identifying tolerant genotypes raises certain questions. Calculation of average sum of ranks (ASR) for all indices to select potentially superior genotypes can be helpful as the lower the value of ASR, the more superior the genotype (Mourad *et al.*, 2021; Pour-Aboughadareh *et al.*, 2021). In this case, Super Basmati (ASR= 2.64; SD = 1.91), IR-44 Sub1 (ASR = 2.73; SD = 0.91), and Swarna Sub1 (ASR = 3.54; SD =1.44) were the most tolerant genotypes in completely submerged conditions. While, KSK-133 had maximum value of ASR (4.01) indicating that it was least tolerant genotype among all (Table 3).

Estimation of stress indices under submergence stress

All nine stress indices were calculated for submergence stress and presented in Table 2. If we use the TOL index, we can see that genotypes with lowest values are higher tolerant to stress. Accordingly, IR-07-F289-Sub1 (-1.260) was most tolerant to submergence stress followed by Swarna Sub1 (-0.77), IR-44-Sub1 (-0.334), Ciherang Sub1 (5.76), Super Basmati (9.91) and KSK-133 (11.320). Genotypes with high indices of stress tolerance (STI, HM, GMP, MP) may be considered tolerant since they perform efficiently in both non-stressful and stressful conditions. In this case, Super Basmati and KSK-133 had the highest values for these indices followed by IR-44 Sub1, Ciherang Sub1, Swarna Sub1 and IR-07-F289 Sub1. Similar results were also observed by Abarshahr *et al.* (2011), Rahimi *et al.* (2013) and Abbasian *et al.* (2014). The SSI only reveals genotypes that experience minimal losses under stress; an SSI > 1 shows above-average susceptibility to stress when comparing yield losses under stressful and non-stressful settings. Among all genotypes, KSK-133 and Super Basmati had SSI >1. While, all Sub1 genotypes had STI < 1 indicating that all Sub1 genotypes are not susceptible to submergence stress. Genotypic stability in both stressful and non-stressful situations may be measured using one of three indices YI, RSI, or YSI. In characterizing tolerant genotypes, YSI and RSI showed identical ranking patterns. For YSI and RSI, IR-07-F289-Sub1 showed maximum values and KSK-133 had minimum values among all genotypes. It may be difficult to determine which genotypes are tolerant based on a single index alone. Calculation of average sum of ranks (ASR) for all indices to select potentially superior genotypes can be helpful as the lowest the value of ASR, the most superior the genotype. Here, though, Super Basmati (ASR = 2.64; SD = 1.91), IR-44 Sub1 (ASR = 2.73; SD = 0.91), and Swarna Sub1 (ASR = 3.54; SD = 1.44) were the most tolerant genotypes in completely submerged conditions. While, KSK-133 had maximum value of ASR (4.01) indicating that it was least tolerant genotype among all (Table 3).

Association analysis of stress indices under submergence

Pearson correlation based on the actual values of indices across all genotypes presented in Table 4 revealed that TOL, MP, GMP, HM, SSI and STI were strongly correlated with crop performance under normal conditions (Yp). The highly significant correlation reveals that these indices can be used alternatively to select best genotype under normal conditions. These stress indices can be used to select Group A genotypes. The ability to separate Group A genotypes by association of these indices were also observed by Abarshahr*et al.* (2011), Ajalli and Salehi, (2012), Rahimi *et al.* (2013) and Abbasian *et al.* (2014). While, YSI and RSI exhibited a strong negative correlation with the crop yield under normal conditions (Yp) but not with the Ys. Furthermore, YSI was the only stress index which showed strong and positive correlation with crop yield under submergence. In Fig. 1 it can be seen clearly that Super Basmati is in Group A which means that it performed well under stress and normal conditions. KSK-133 is in Group B revealing that it performed well under normal conditions as compared to the submergence stress. IR-44 Sub1 and Swarna Sub1 fall into Group C which means that they performed well under stress as compared to the normal conditions. IR-07-F289 Sub1 falls into Group D which shows that its yield was less among all genotypes under stress as well as normal conditions.

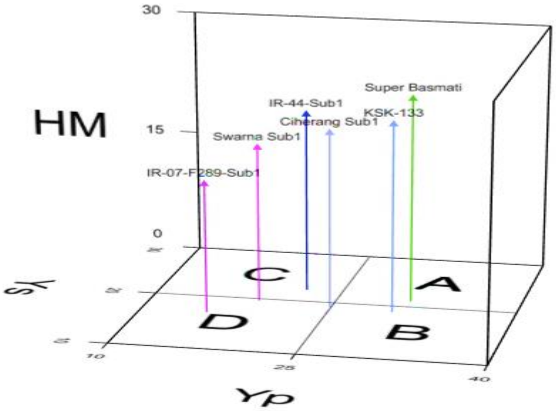


Fig 1: Rendered three-dimensional plot based on HM index and yield performance (Yp and Ys) of rice genotypes under submergence

Principal Component Analysis under submergence

Analysis using principal components showed that the first component explained 79.16% of the variance in the key stress indices excluding Ys and YI (Table 5). To isolate resistant genotypes from susceptible ones, the first part included effective selection criteria with main stress indicators.The biplot graph also showed that the stress indices Ys, HM, GMP, MP, STI, and YI were the most efficient in determining stress-tolerant genotypes (Fig 2). Semahegn*et al.* 2020 and Sánchez-Reinoso*et al.* 2020 also observed similar results. The biplot also revealed that Super Basmati performed well under submergence and drought conditions as compared to all genotypes under study.

Table 2: Stress indices of rice genotypes under complete submergence conditions

[Citation: Amjad, I., Kashif, M., Akhter, S., Nazar, M.Z.K., Latif, A., Latif, A., Sarfraz, S., Shahbaz, U., Ahsan, M.T., Shamim, F., Shahzadi, N., Khalid, M.N., Qamar, Z.U. (2022). Evaluation of the tolerance of rice (*Oryza sativa*) for submergence and drought using various yield related stress indices. *Biol. Clin. Sci. Res. J.,* **2022***: 106*. doi: https://doi.org/10.54112/bcsrj.v2022i1.106]

	Stress Indices										
	Yp	**Ys**	**TOL**	**MP**	**GMP**	**HM**	**SSI**	**STI**	**YI**	**YSI**	**RSI**
Swarna Sub1	18.85	19.62	-0.77	19.24	19.23	19.23	-0.24	0.66	1.00	1.04	1.26
IR-44-Sub1	21.98	22.31	-0.33	22.14	22.14	22.14	-0.09	0.87	1.14	1.02	1.23
IR-07-F289-Sub1	15.50	16.76	-1.26	16.13	16.12	16.11	-0.47	0.46	0.85	1.08	1.31
Ciherang Sub1	24.89	19.13	5.76	22.01	21.82	21.63	1.34	0.85	0.97	0.77	0.93
Super Basmati	31.02	21.11	9.91	26.07	25.59	25.12	1.85	1.16	1.08	0.68	0.82
KSK-133	30.12	18.80	11.32	24.46	23.80	23.15	2.17	1.01	0.96	0.62	0.75

Table 3: Rank table of rice genotypes for stress indices under submergence

Genotypes	**Yp**	**Ys**	**TOL**	**MP**	**GMP**	**HM**	**SSI**	**STI**	**YI**	**YSI**	**RSI**	**SR**	**AR**	**SD**
Swarna Sub1	5	3	2	5	5	5	2	5	3	2	2	39	3.54	1.44
IR-44-Sub1	4	1	3	3	3	3	3	3	1	3	3	30	2.73	0.91
IR-07-F289-Sub1	6	6	1	6	6	6	1	6	6	1	1	46	4.18	2.52
Ciherang Sub1	3	4	4	4	4	4	4	4	4	4	4	43	3.91	0.30
Super Basmati	1	2	5	1	1	1	5	1	2	5	5	29	2.64	1.91
KSK-133	2	5	6	2	2	2	6	2	5	6	6	44	4.00	1.95

Yp = Yield under normal conditions, Ys = Yield under stress, SR = Sum of ranks, AR= Average sum of ranks, SD = Standard deviation of ranks

Table 4: Pearson correlation of nine stress indices under submergence

Variables	**YSI**	**YI**	**STI**	**SSI**	**HM**	**GMP**	**MP**	**TOL**	**Ys**	**Yp**
RSI	-0.4	0.91**	0.33	-0.97**	-0.79	-0.82	-0.85	-0.97**	-0.13	-0.95**
YSI		-0.13	-0.84*	-0.99**	-0.8	-0.83*	-0.85*	-0.99**	-0.13	-0.95**
YI			0.63	0.13	0.69	0.65	0.62	0.1	0.99**	0.4
STI				0.84	0.99	0.97	0.97**	0.83*	0.63	0.96**
SSI					0.8	0.83	0.85*	0.99**	0.13	0.95**
HM						0.99	0.99**	0.78	0.69	0.94**
GMP							0.98**	0.82*	0.65	0.96**
MP								0.84*	0.62	0.97**
TOL									0.1	0.95**
Ys										0.42

Table 5: Principal Component Analysis of different stress indices of rice genotypes under submergence stress

Factors	**PC1**	**PC2**	**PC3**
Yp	0.99	0.11	0.04
Ys	0.50	0.86	0.03
TOL	0.91	0.41	0.05
MP	0.99	0.13	0.02
GMP	0.98	0.18	0.01
HM	0.97	0.23	0.01
SSI	0.91	0.39	0.05
STI	0.98	0.15	0.07
YI	0.51	0.86	0.03
YSI	0.91	0.39	0.05
RSI	0.91	0.39	0.05
Eigenvalue	8.71	2.26	0.02
Variability (%)	79.16	20.61	0.20
Cumulative %	79.160	99.77	99.98

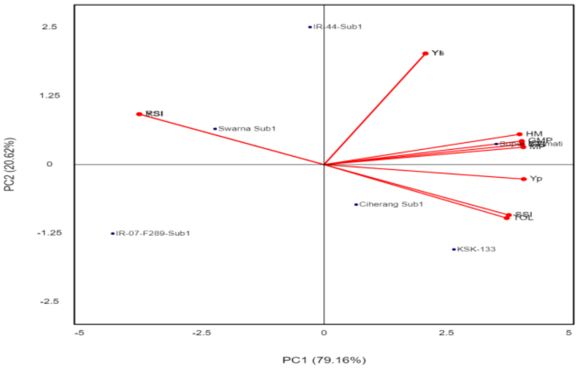


Fig 2. Graphical bi-plot display of stress indices and rice genotypes evaluated under submergence stress condition

Estimation of stress indices under drought stress

Stress indices of six rice genotypes were calculated related to grain yield under normal and drought conditions. All nine stress indices are presented in Table 6. For TOL index, the genotypes having minimum value is considered as drought tolerant. According to this, IR-07-F289-Sub1 (11.57) was

[Citation: Amjad, I., Kashif, M., Akhter, S., Nazar, M.Z.K., Latif, A., Latif, A., Sarfraz, S., Shahbaz, U., Ahsan, M.T., Shamim, F., Shahzadi, N., Khalid, M.N., Qamar, Z.U. (2022). Evaluation of the tolerance of rice (*Oryza sativa*) for submergence and drought using various yield related stress indices. *Biol. Clin. Sci. Res. J.,* **2022***: 106*. doi: https://doi.org/10.54112/bcsrj.v2022i1.106]

most tolerant to drought stress followed by Swarna Sub1 (13.72), IR-44-Sub1 (20.99) and Ciherang Sub1 (22.58). For MP, Nagina-22 had maximum value (21.01) followed by IR-64 (15.64), Ciherang Sub1 (13.60) and Swarna Sub1 (11.99). Minimum value for MP index was observed in IR-07-F289 Sub1 (9.72). Nagina-22 again showed maximum value for GMP (11.10) and minimum value was observed in IR-44 Sub1 (4.66). High values for the stress indices STI, MP, GMP, and HM indicate a genotype is likely to be stress resistant and useful for use in both normal and drought conditions (Dorostkar *et al*., 2015; Abd El-Mohsen *et al*., 2015).

Among all genotypes, only two genotypes IR-44 Sub1 and Ciherang Sub1 had SSI values less than 1 showing minimum reduction in yield under drought as compare to the normal conditions. For YSI and RSI, all genotypes showed similar ranking patterns as presented in Table 7. Swarna Sub1 showed maximum values for these indices followed by IR-07-F289-Sub1 and Ciherang Sub1. Identifying tolerant genotypes based on a single index could be problematic as different ranking patterns were observed in rice genotypes for different stress indices. Calculation of average sum of ranks (ASR) for all indices to select potentially superior genotypes can be helpful as the lower the value of ASR, the more superior the genotype. In this case, Swarna Sub1 (ASR = 1.91; SD = 1.38), Ciherang Sub1 (ASR = 3.55; SD = 0.52), and Nagina-22 (ASR = 2.82; SD = 1.66) were the most tolerant genotypes under drought (Table 7).

Association analysis under drought

Pearson correlation based on the actual values of indices across all genotypes presented is presented in Table 8. TOL and MP showed positive and strong correlation with yield under normal conditions. These two indices were also positively correlated with each other showing that these indices can be used interchangeably for selection of high yielding genotypes under normal conditions. HM and YI showed strong positive correlation with the yield under drought stress while SS1 showed negative correlation with the yield under drought. Naghavi *et al*. (2013) also reported that Yield in stress and non-stress conditions were significantly and positively correlated with GMP, MP, YI, TOL and RDI and negatively correlated with SSI. Based on the stress indices and their correlation results, the genotypes can be classified in four different groups (Abarshahr *et al.*, 2011; Ajalli and Salehi, 2012; Rahimi *et al.*, 2013 and Abbasian *et al.*, 2014). In figure 3 it can be seen clearly that Nagina-22 is in Group A which means that it performed well under stress and normal conditions. IR-64 and Ciherang Sub1 were in Group B revealing that it performed well under normal conditions as compare to drought. Swarna Sub1 and IR-07-F289 Sub1 fall into Group C which means that they performed well under drought as compare to the normal conditions. IR-44 Sub1 falls into Group D which shows that its crop yield was less among all genotypes under drought as well as normal conditions.

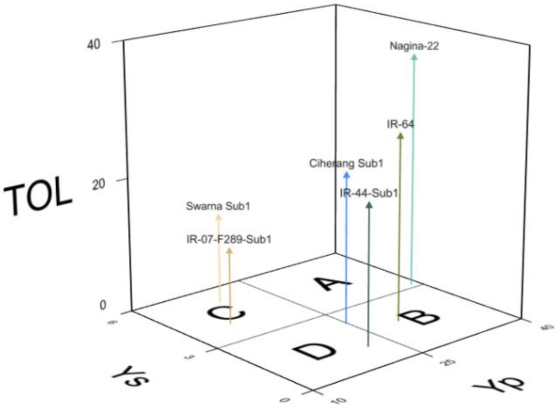


Fig 3: Rendered three-dimensional plot based on TOL index and yield performance (Yp and Ys) of rice genotypes under drought stress

Principal Component Analysis under drought

According to the findings of principal component analysis, the first component was responsible for explaining 64.05 percent of the variance with key stress indices, excluding Yp, TOL, MP, GMP, and STI (Table 9). Furthermore, biplot graph exhibited that MP, Yp, TOL, and SSI were the most effective stress indicators for identifying drought tolerant genotypes (Fig 4). The biplot also revealed that Nagina-22 performed well under drought conditions as compare to normal conditions among all genotypes under study. These results were in accordance with the Rahimi *et al.* (2013), Abbasian *et al.* (2014) and Ghiasy *et al.* (2014)**.**

Table 6: Stress indices of rice genotypes under drought

Genotypes	Yp	Ys	RC	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
Swarna Sub1	18.85	5.13	72.79	13.72	11.99	9.83	8.07	0.82	0.16	1.79	0.27	2.37
IR-44-Sub1	22.1	0.99	95.50	20.99	11.48	4.66	1.89	1.08	0.03	0.34	0.04	0.39
IR-07-F289-Sub1	15.1	3.93	74.65	11.57	9.72	7.80	6.27	0.84	0.10	1.37	0.25	2.21
Ciherang Sub1	25.2	2.31	90.72	22.58	13.60	7.58	4.23	1.02	0.09	0.81	0.09	0.81

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Nagina-22	38.8	3.17	91.84	35.67	21.01	11.10	5.86	1.04	0.20	1.11	0.08	0.71
IR-64	29.6	1.67	94.36	27.93	15.64	7.03	3.16	1.07	0.08	0.58	0.06	0.49

Table 7: Rank (R), Rank Mean (RM), Standard Deviation of Ranks (SDR) and Rank Sum (RS) of stress indices under drought

Genotype	Yp	Ys	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI	SR	AR	SD
Swarna Sub1	5	1	2	4	2	1	1	2	1	1	1	21	1.91	1.38
IR-44-Sub1	4	6	3	5	6	6	6	6	6	6	6	60	5.45	1.04
IR-07-F289-Sub1	6	2	1	6	3	2	2	3	2	2	2	31	2.82	1.66
Ciherang Sub1	3	4	4	3	4	4	3	4	4	3	3	39	3.55	0.52
Nagina-22	1	3	6	1	1	3	4	1	3	4	4	31	2.82	1.66
IR-64	2	5	5	2	5	5	5	5	5	5	5	49	4.45	1.21

Yp = Yield under normal conditions, Ys = Yield under drought stress, SR = Sum of ranks, AR= Average sum of ranks, SD = Standard deviation of ranks

Table 8: Pearson correlation of nine stress indices under drought

Variables	YSI	YI	STI	SSI	HM	GMP	MP	TOL	Ys	Yp
RSI	0.96**	0.91*	0.33	-0.98**	0.86*	0.4	-0.51	-0.76	0.91*	-0.65
YSI		0.92*	0.34	-0.96**	0.47	0.32	-0.56	-0.77	-0.16	-0.57
YI			0.69	-0.91*	0.99**	0.73	-0.13	-0.46	0.99**	-0.31
STI				-0.34	0.77	0.99**	0.62	0.32	0.69	0.47
SSI					-0.86*	-0.4	0.51	0.77	-0.91*	0.66
HM						0.81	-0.01	-0.35	0.99**	-0.19
GMP							0.57	0.26	0.73	0.42
MP								0.94**	-0.13	0.98**
TOL									-0.46	0.99**
Ys										-0.31

Table 9: Principal Component Analysis of different stress indices of rice genotypes under drought

Factors	PC1	PC2	PC3
Yp	0.55	0.83	0.05
Ys	0.96	0.26	-0.02
TOL	0.67	0.73	0.05
MP	0.39	0.92	0.04
GMP	-0.53	0.85	-0.01
HM	-0.92	0.38	-0.03
SSI	0.98	0.14	-0.06
STI	-0.47	0.87	-0.05
YI	-0.96	0.26	-0.02
YSI	-0.98	-0.13	0.06
RSI	-0.98	-0.13	0.06
Eigenvalue	7.04	3.91	0.02
Variability (%)	64.05	35.59	0.23
Cumulative %	64.05	99.64	99.88

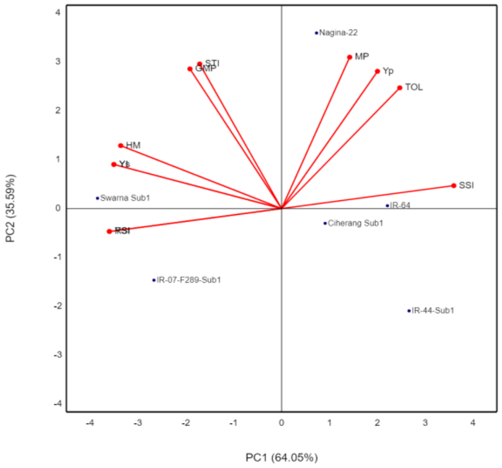

Fig 4: Graphical bi-plot display of stress indices and rice genotypes evaluated under drought stress conditions

Conclusion

According to numerous writers, choosing stable genotypes should be based on a number of parameters. The genotypes can also be divided into other categories based on the stress indices and the correlation results obtained from them. Our study showed that selection based on yield stability index (YSI) will identify lines with much greater performance under complete submersion for flood-prone areas. The discovery of high yielding genotypes will take place for the locations with

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severe drought issues and increased frequency of drought occurrence based on mean productivity, tolerance index, and stress susceptibility index.

Conflict of interest

The authors declared absence of conflict of interest.

References

Abarshahr, M., Rabiei, B., and SamizadehLahigi, H. (2011). Assessing Genetic Diversity of Rice Varieties under Drought Stress Conditions. *Notulae Scientia Biologicae* **3**, 114-123.

Abbasian, A., Mohaddesi, A., Aminpanah, H., Ghasemi, S.M.S., Javadi, M., and Ebrahimian, M. (2014). Evaluation of rice cultivars in different irrigation treatments based on sensitive and tolerance indices. *Poljoprivredai Sumarstvo* **60**, 251.

Afrin, W., Nafis, M.H., Hossain, M.A., Islam, M.M., and Hossain, M.A. (2018). Responses of rice (Oryza sativa L.) genotypes to different levels of submergence. *Comptes Rendus Biologies* **341**, 85-96.

Ajalli, J., and Salehi, M. (2012). Evaluation of drought stress indices in barley (Hordeum vulgare L.). *Annals of Biological Research* **3**, 5515-5520.

Anonymous. (2018-19). Economic survey. Government of Pakistan, Finance Division, Economic Advisor's Wing, Islamabad, Pakistan.

Anwaar, H.A., Perveen, R., Mansha, M.Z., Abid, M., Sarwar, Z.M., Aatif, H.M., ud din Umar, U., Sajid, M., Aslam, H.M.U., Alam, M.M., and Rizwan, M. (2020). Assessment of grain yield indices in response to drought stress in wheat (Triticum aestivum L.). *Saudi Journal of Biological Sciences* **27**, 1818-1823.

Beena, R., Kirubakaran, S., Nithya, N., Manickavelu, A., Sah, R.P., Abida, P.S., Sreekumar, J., Jaslam, P.M., Rejeth, R., Jayalekshmy, V.G., and Roy, S. (2021). Association mapping of drought tolerance and agronomic traits in rice (Oryza sativa L.) landraces. *BMC Plant Biology* **21**, 1-21.

Benesty, J., Chen, J., Huang, Y., and Cohen, I. (2009). Pearson Correlation Coefficient. In Noise Reduction in Speech Processing. *Springer* **2**, 37-40

Chaudhari, P.R., Tamrakar, N., Singh, L., Tandon, A., and Sharma, D. (2018). Rice nutritional and medicinal properties: A. *Journal of Pharmacognosy and Phytochemistry* **7**, 150-156.

Chaudhry, U.F., Khalid, M.N., Aziz, S., Amjad, I., Khalid, A., Noor, H., and Sajid, H.B. (2022). International Journal of Agriculture and Biosciences. Int J Agri Biosci 11, 59-69.

Choudhary, R.S., Biradar, D.P., and Katageri, I.S. (2021). Evaluation of sorghum RILs for moisture stress tolerance using drought tolerance indices. *The Pharma Innovation Journal*, **10**(4): 39-45

Gabriel, K.R. (1971). The biplot graphic display of matrices with application to principal component analysis. *Biometrika* **58**, 453-467.

GiasiOskoei, M., Farah bakhsh, H., and Mohamadinejad, G. (2014). Evaluation of rice cultivars in drought and normal conditions based on sensitive and tolerance indices. Journal of Crop Production 6, 55-75.

Gholamhoseini, M. (2020). Evaluation of sesame genotypes for agronomic traits and stress indices grown under different irrigation treatments. *Agronomy Journal*, **112**, 1794-1804.

Jafar, R.M.S., Rabnawaz, A., Hussain, S., Ahmed, W., and Zhuang, P. (2015). Aptitudes of Pakistani rice industry with respect to global trade. *Journal of Economic Sustainability and Development* **6**: 8-12.

Kamrani, M., Hoseinim Y., and Ebadollahi, A. (2018). Evaluation for heat stress tolerance in durum wheat genotypes using stress tolerance indices. *Archives of Agronomy and Soil Science* **64**, 38-45.

Kennedy, G., Burlingame, B., and Nguyen, V.N. (2003). Nutritional contribution of rice and impact of biotechnology and biodiversity in rice-consuming countries. 59-70. Proceedings of the 20th session of the International Rice Commission. Bangkok, Thailand, 23-26 July 2002. Sustainable rice production for food security, Dat Van Tran(Ed.)Duffy, R.(Ed.).- Rome (Italy): FAO, 2003. Sess. 20 International Rice Commission, Sess. 20 International Rice Commission, Bangkok (Thailand), 23-26 Jul 2002. p. 59-70

Korres, N.E., Norsworthy, J.K., Burgos, N.R., and Oosterhuis, D.M. (2017). Temperature and drought impacts on rice production: An agronomic perspective regarding short-and long-term adaptation measures. *Water Resources and Rural Development* **9**, 12-27.

Memon, N.A. (2013). Rice: Important cash crop of Pakistan. *Pakistan Food Journal* **26**, 21-23.

Mohanty, S., Wassmann, R., Nelson, A., Moya, P., and Jagadish, S.V.K. (2013). Rice and climate change: significance for food security and vulnerability. *International Rice Research Institute* **14**, 1-14.

MohdIkmal, A., Noraziyah, A.A.S., and Wickneswari, R. (2021). Incorporating drought and submergence tolerance QTL in Rice (Oryza sativa L.) the effects under reproductive stage drought and vegetative stage submergence stresses. *Plants* **10**, 225.

[Citation: Amjad, I., Kashif, M., Akhter, S., Nazar, M.Z.K., Latif, A., Latif, A., Sarfraz, S., Shahbaz, U., Ahsan, M.T., Shamim, F., Shahzadi, N., Khalid, M.N., Qamar, Z.U. (2022). Evaluation of the tolerance of rice (*Oryza sativa*) for submergence and drought using various yield related stress indices. *Biol. Clin. Sci. Res. J.,* **2022***: 106.* doi: https://doi.org/10.54112/bcsrj.v2022i1.106]

Mourad, A.M., Amin, A.E.E.A.Z., and Dawood, M.F. (2021). Genetic variation in kernel traits under lead and tin stresses in spring wheat diverse collection. *Environmental and Experimental Botany* **192**, 104646.

Moustafa, E. (2021). Evaluation of bread wheat advanced lines under salinity conditions using tolerance indices. *Egyptian Journal of Desert Research* **71**, 23-52.

Muddassir, M., and Al-Zahrani, K. H. (2022). General Overview: Awareness of Genetically Modified Food Among Consumers. *International Journal of Agriculture and Biosciences* **11**, 48-52.

Naghavi, M. R., Pour A.A., and Khalili, M. (2013). Evaluation of Drought Tolerance Indices for Screening Some of Corn (Zea mays L.) Cultivars under Environmental Conditions. *Notulae Scientia Biologicae* **5**, 388-393.

Nazari, L., and Pakniyat, H. (2010). Assessment of drought tolerance in barley genotypes. *Journal of Applied Sciences* **10**, 151-156.

Poudel, P.B., Poudel, M.R. and Puri, R.R. (2021). Evaluation of heat stress tolerance in spring wheat (Triticum aestivum L.) genotypes using stress tolerance indices in western region of Nepal. *Journal of Agriculture and Food Research* **5**,100179.

Pour-Aboughadareh, A., Mehrvar, M.R., Sanjani, S., Amini, A., Nikkhah-Chamanabad, H., and Asadi, A. (2021). Effects of salinity stress on seedling biomass, physiochemical properties, and grain yield in different breeding wheat genotypes. *Acta Physiologiae Plantarum* **43**, 1-14.

Rahimi, M., Dehghani, H., Rabiei, B., and Tarang, A.R. (2013). Evaluation of rice segregating population based on drought tolerance criteria and biplot analysis. *International Journal of Agriculture and Crop Sciences* **5**, 194.

Rehman, A., Jingdong, L., Du, Y., Khatoon, R., Wagan, S.A., and Nisar, S.K. (2016). Flood disaster in Pakistan and its impact on agriculture growth (a review). *Global Advanced Research Journal of Agricultural Science* **6**, 39-42.

Sánchez-Reinoso, A.D., Ligarreto-Moreno, G.A., and Restrepo-Díaz, H. (2020). Evaluation of drought indices to identify tolerant genotypes in common bean bush (Phaseolus vulgaris L.). *Journal of Integrative Agriculture* **19**, 99-107.

Semahegn, Y., Shimelis, H., Laing, M., and Mathew, I. (2020). Evaluation of bread wheat (*Triticum aestivum* L.) genotypes for yield and related traits under drought stress conditions. *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science* **70**, 474-484.

Sharifi-Zagheh, A., Gholizadeh, A. Sorkhilalehloom B., and Khodadadi, M. (2022). Identification of Suitable Parents for Essential Oil Yield in Coriander Half-sib Families under Different Environmental Conditions. *International Journal of Horticultural Science and Technology* **9**, 201-212.

Zafar, M. M., Zhang, Y., Farooq, M. A., Ali, A., Firdous, H., Haseeb, M., Fiaz, S., Shakeel, A., Razzaq, A., and Ren, M. (2022). Biochemical and Associated Agronomic Traits in Gossypium hirsutum L. under High Temperature Stress. *Agronomy* **12**, 1310.

Zafar, M.M., Jia, X., Shakeel, A., Sarfraz, Z., Manan, A., Imran, A., Mo, H., Ali, A., Youlu, Y., Razzaq, A., and Iqbal, M.S. (2021). Unraveling Heat Tolerance in Upland Cotton (Gossypium hirsutum L.) Using Univariate and Multivariate Analysis. *Frontiers in Plant Science* **12**, 727835-727835.

Zafar, M.M., Razzaq, A., Farooq, M.A., Rehman, A., Firdous, H., Shakeel, A., Mo, H., Ren, M., Ashraf, M., and Youlu, Y. (2022). Genetic variation studies of ionic and within boll yield components in cotton (Gossypium Hirsutum L.) Under salt stress. *Journal of Nat*

[Citation: Amjad, I., Kashif, M., Akhter, S., Nazar, M.Z.K., Latif, A., Latif, A., Sarfraz, S., Shahbaz, U., Ahsan, M.T., Shamim, F., Shahzadi, N., Khalid, M.N., Qamar, Z.U. (2022). Evaluation of the tolerance of rice (*Oryza sativa*) for submergence and drought using various yield related stress indices. *Biol. Clin. Sci. Res. J.*, ***2022**: 106*. doi: https://doi.org/10.54112/bcsrj.v2022i1.106]