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Bioscience Research

Print ISSN: 1811-9506 Online ISSN: 2218-3973

Journal by Innovative Scientific Information & Services Network

RESEARCH ARTICLE BIOSCIENCE RESEARCH, 202219(4):1801-1808. OPEN ACCESS

Correlation studies of yield components and grain quality of *Oryza sativa* under drought stress

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The purpose of the current research was to investigate 6 rice genotypes (Swarna-Sub1, IR-44-Sub1, IR-07-F289-Sub1, Ciherang-Sub1, Nagina-22 and IR-64) under reproductive stage drought stress. Field experiment was laid out with triplicate randomized complete block design in split-plot fashion. The drought stress was applied at booting stage to onwards for 30 days. Results of ANOVA indicated that drought stress significantly reduced the overall performance of all the genotypes under study. Correlation studies showed that grain yield per plant was highly significant and positively correlated with fertile spikelets per panicle, fertility percentage and harvest index while highly significant negatively correlated with panicle length and sterile spikelets per panicle. Nine drought stress indices were also calculated for grain yield per plant. GM, HM, YI, YSI and RSI showed highly significant positive correlation with crop performance under drought conditions thus these indices can be used for the selection of drought tolerant genotypes. The first two principal components (eigenvalues > 1) described 99.29% of the overall variation in yield performance, according to PCA data. Nagina-22 and Swarna Sub1were identified as superior genotypes based on the results of indices and their association and PCA analysis. The information obtained from this study can be exploited in future drought screening and breeding programs.

Keywords: Rice, drought, correlation, PCA

INTRODUCTION

The frequency and intensity of natural catastrophes have increased due to climate change in many regions around the globe (Kim and Jehanzaib, 2020; Coronese et al. 2019). The agricultural sector suffers the most from the effects of drought, which include crop loss and low production, which impair people's access to food and way of life (Rasul, 2021). At the moment, drought is the main cause of famines (Qtaishat et al. 2022). In the world, rice is one of the most significant grains, making up about 27% of all grains consumed (FAO 2016). Rice development, productivity, and yield are most negatively impacted by drought stress since it needs more water than other paddy field crops to survive (Upadhyaya and Panda, 2019). Rice yield is significantly impacted by drought stress at every stage of growth, from germination to reproduction (Kumar *et al.* 2020). Reactive oxygen species (ROS), grain yield, cell proliferation, and biomass production are all negatively impacted by drought (Sohag et al. 2020). Drought reduces agricultural profitability by lowering grain weight and sterility (Toor et al. 2020; Kumar et al. 2020). Additionally, drought stress has an impact on how plants absorb, move, and store nutrients, particularly phosphorus (Abdelaal et al. 2021).

When choosing a new variety, farmers and consumers take grain quality into consideration (Weltzien et al. 2019). In the Indian subcontinent, medium- to long-grain rice is extremely popular (Verma et al. 2018). Its quality is influenced by its milling, market, nutritional, cooking, and eating characteristics (Sultana *et al.* 2022). The physical traits of rice, such as grain size, shape, and appearance, as well as its cooking and eating qualities, grain elongation, gel consistency, aroma, minerals, vitamins, phenolics, flavonoids, and antioxidant activity, make it a widely consumed food (Sharma and Khanna, 2019). There must be an improvement in grain quality that has no impact on yield for the good of all rice producers and consumers. Even though many traditional cultivars don't yield much grain, whether they are cultivated in tropical or temperate climates, they are still delicious and good for cooking (Fahad et al. 2019). Being often consumed, cooked rice requires improvement in both its eating and cooking qualities (ECQ). Greater grain yields, higher nutritional value, and improved water efficiency are all characteristics of drought-resistant rice types (Custodio et al. 2019; Zhou et al. 2020). The most promising drought-resistant cultivars can be found by examining morphophysiological and grain quality characteristics (Nahar et al. 2018).

A field experiment was done to find and evaluate rice genotypes with higher yield and grain quality under drought stress due to the detrimental effects of drought on rice. The purpose of this study was to look at the genetic parameter variability and the connections between yield and other aspects of rice grain production.

MATERIALS AND METHODS

Six rice genotypes (Swarna-Sub1, IR-44-Sub1, IR-07-F289-Sub1, Ciherang-Sub1, Nagina-22, and IR-64) were tested under drought stress. The experiment was performed using a split plot RCBD with 3 replications. While normal and drought conditions were considered the main plot elements, genotypes were considered as sub-plot factors. On the moist raised beds, seeds were sown, and after 35 days, seedlings were transplanted to the field's well-puddled soil. The distance between each plant and row was 9 inches. After transplanting, gap-filling was also used as necessary to guarantee complete plant establishment. For 30 days, the drought stress was applied during booting. The following parameters were measured at harvesting time: plant height (cm), primary branches per panicle, productive tillers per plant, unfilled spikelets per panicle, filled spikelets per panicle, panicle length (cm), fertility percentage, grain yield per plant (g), biological yield per plant (g), head rice recovery (%), harvest index, grain length (mm), cooking grain length (mm), and elongation ratio.

Statistical analyses

The data of drought stress experiments was analyzed by analysis of variances (Steel et al. 1997). The association of traits related to yield and grain quality was analyzed by correlation analysis (Kwon and Torrie, 1964). Nine stress indices TOL, MP, GMP, HM, SSI, STI, YI, YSI and RSI were calculated for drought stress which were further analyzed by association analysis and principal component analysis or biplot analysis by *i*PASTIC online toolkit (Pour-Aboughadareh et al. 2019).

RESULTS

The results of ANOVA for individual experiments under control and drought conditions revealed that all the genotypes were highly significant for all the traits under study indicating the validity of further statistical analysis (Table 1, 2). To find out the interaction of genotypes with treatments, split plot ANOVA (combined ANOVA) was also performed (table 3). Interaction of genotypes with treatments (normal and drought) was highly significant of all the traits under study. Variability plays a vital role for the selection of superior genotypes (Hasan et al. 2020). The genotypes exhibiting high variability under drought condition should be selected and hybridize between them to create the maximum genetic diversity that further increase the choice of desirable genotypes (Sakran et al. 2022). Rice varieties cultivated during a drought have significantly lower grain yields and other yield related traits than under normal conditions. The mean performances of all the genotypes for yield and quality related parameters under normal and drought conditions are presented in Fig.1 and Fig.2 respectively. Nearly all of the rice genotypes cultivated under water deficit conditions showed a reduction in yield. (Yang *et al.* 2019) observed a 23.2% to 39% loss in grain yield. (Melandri *et al.* 2020) found that a reduction in grain yield from 30% to 60% in rice genotypes under booting stage drought.

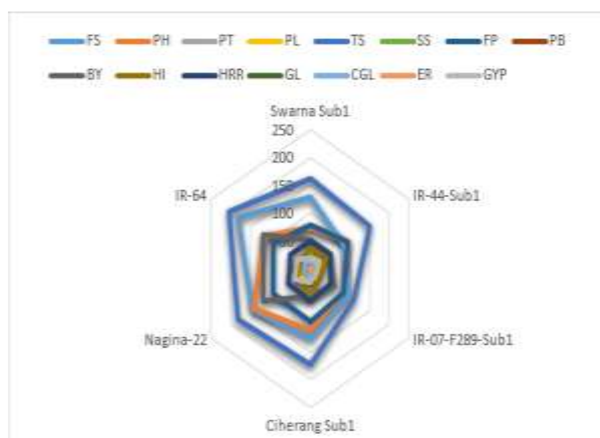

Figure1: mean performance of rice genotypes under normal conditions

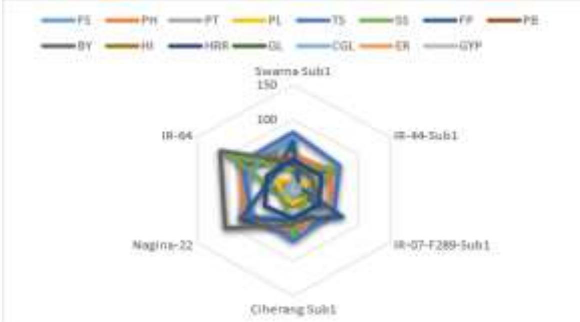

Figure 2: mean performance of rice genotypes under drought

Correlation

Under normal conditions (fig. 3), grain yield plant^{-1} exhibited highly significant and positive linkage with plant height (0.93), panicle length (0.47), total spikelets panicle^{-1} (0.76), fertile spikelets per panicle (0.67), primary branches per panicle (0.69), biological yield per plant (0.79) and cooking grain length (0.59). While under drought stress conditions, grain yield plant^{-1} manifested highly significant and positive association with fertile spikelets per panicle (0.62), fertility percentage (0.73) and harvest index (0.77) while highly significant negative linkage with panicle length (-0.64) and sterile spikelets per panicle (-0.68) as represented in fig. 4. These results were similar to (Haider *et al.* 2020) for fertile spikelets per panicle and fertility percentage (Seyoum *et al.* 2012; Hossain *et al.* 2018) for panicle length and sterile spikelets per panicle (Tiwari *et al.* 2019; Nithya *et al.* 2020).

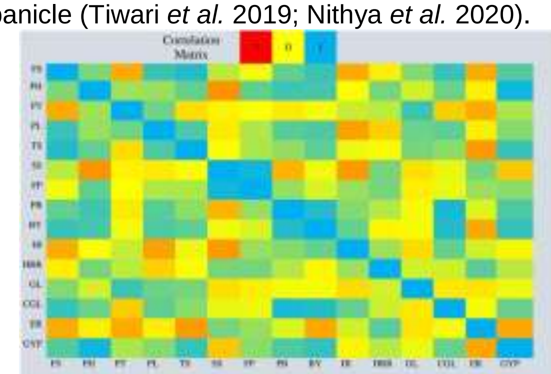

Figure 4: Correlation matrix under normal conditions

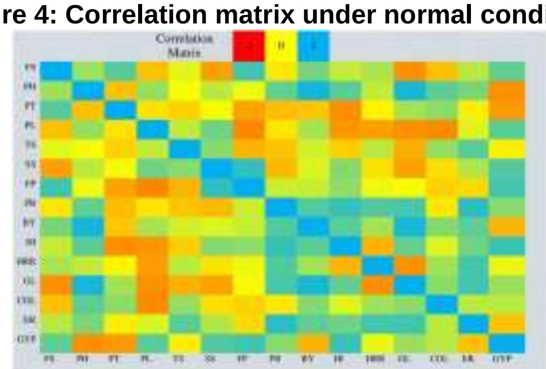

Figure 4: Correlation matrix under drought

Drought stress indices based on grain yield

Results of nine stress indices and their ranking are presented in Table 4 and 5. The IR-07-F289-Sub1 had the lowest TOL value, followed by Swarna Sub1 and IR-44-Sub1. A lower TOL rating shows a cultivar's excellent stress tolerance capabilities (Raman et al. 2012; Kumar et al. 2014). Swarna Sub1 ranked highest in terms of Ys, HM, YI, YSI, and RSI. The stress susceptibility index measures the yield drop induced by drought versus normal conditions (Saeidi and Abdoli, 2015). Lesser SSI values suggest lower yield differences between non-stress and stress conditions, implying greater drought tolerance. SSI is a yield stability indicator (Armioun et al. 2010; Mardeh et al. 2006). Swarna Sub1 had the lowest SSI value, followed by IR-07-F289-Sub1, and IR64 had the highest. Another probable cause of variation in SSI is the timing of drought stress in connection to the development of various genotypes or a lack of adaptation to unfavorable circumstances. This study's findings are consistent with previous findings (Raman et al. 2012). The stress tolerance index (STI) was used to identify genotypes with good production under both drought and normal conditions (Pakniyat, 2010; Saed-Moucheshi *et al.* 2022). A high STI number indicates a stronger tolerance to stress. Nagina-22 has the highest STI value. It could be challenging to isolate tolerant genotypes using just one indication. ASR for all indices may be utilized to identify potentially superior genotypes; the lower the value, the more desirable the genotype (Pour-Aboughadareh *et al.* 2019). Swarna Sub1 has the lowest ASR value in our sample, followed by Nagina-22.

A heat map built on indices' actual values and ranking patterns across all genotypes found that TOL, MP and SSI are strongly correlated with grain yield under control conditions (Yp) and GM, HM, YI, YSI and RSI showed highly significant positive correlation with crop performance under drought conditions (Ys) (fig. 5). These indices can be used to select genotypes with high potential yield and drought tolerance, as shown by the highly significant correlations between them and yield under drought conditions (Pour-Aboughadareh et al. 2019).

The PCA results showed that the first two PCs with eigenvalues > 1 explained 99.29% of the overall variation in yield performance and stress indices (Table 6). In contrast to PC2, which was positively impacted by all indices with the exception of YSI and RSI, PC1 was positively impacted by Yp, TOL, SSI, and MP. Therefore, selection based on high PC1 and PC2 values could aid in identifying genotypes that are drought-tolerant (Table 6). Nagina-22 and Swarna Sub1 were selected as preferable genotypes, and the results of the 3D plot support this (Fig. 6).

Table 1: Results of ANOVA under normal conditions

SOV	DF	FS	PH	PT	PL	TS	SS	FP	PB	BY	HI	HRR	GL	CGL	ER	GYP
Rep	2	31.96	30.97	0.52	0.20	3.76	7.49	5.16	0.00	158.01	73.81	0.05	0.01	0.05	0.07	8.24
Geno	5	3582.27**	1903.35**	44.45**	42.75**	2965.36**	246.74**	127.34**	4.55**	3481.36**	322.54**	37.11**	1.22**	3.18**	0.22**	218.89**
Error	10	10.92	14.03	2.94	1.53	1.41	22.08	9.78	0.01	55.59	21.90	0.05	0.02	0.01	0.02	1.57

Table 2: Results of ANOVA under drought

SOV	DF	FS	PH	PT	PL	TS	SS	FP	PB	BY	HI	HRR	GL	CGL	ER	GYP
Rep	2	4.51	21.95	15.17	6.20	2.00	604.63	130.33	0.00	581.87	11.18	1.01	0.08	0.05	0.07	0.12
Geno	5	2332.95**	475.63**	68.49**	44.54**	193.89**	3309.33**	2420.79**	9.18**	4184.45**	85.93**	7.61**	0.95**	1.43**	0.09**	8.01**
Error	10	4.38	15.31	3.83	6.81	0.62	522.76	261.97	0.02	104.84	8.68	0.16	0.02	0.04	0.01	0.15

Table 3: Combined ANOVA of rice genotypes under normal and drought conditions

SOV	DF	FS	PH	PT	PL	TS	SS	FP	PB	BY	HI	HRR	GL	CGL	ER	GYP
Rep(R)	2	8.5	0.9	5.04	4.32	2.9	240.2	42.4	0.01	604.06	69.43	0.72	0.04	0.05	0.06	3.97
Treat(T)	1	49217.4**	14731**	22.56	245.8**	75698**	11374*	13272**	275.6**	1469.7	8035.6**	1010.71**	59.21**	151.09**	6.1**3	4521.2**
Error (R× T)	2	28	52	10.65	2.09	2.9	371.9	93	0.03	135.82	15.56	0.33	0.05	0.01	0.04	4.38
Geno(G)	5	4709.3**	1916.7**	78.38**	81.45**	2035**	1482.9**	950.3**	4.05**	7528.92**	163.15**	15.85**	1.32**	0.65**	0.06**	98.63**
T × G	5	1205.9**	462.3**	34.56**	5.84	1123**	2073**	1597.9**	9.69**	136.88	245.32**	28.88**	0.85**	3.96**	0.23**	128.27**
Error R×T×G	20	7.7	14.7	3.39	4.17	1	272.4	135.9	0.01	80.22	15.29	0.1	0.01	0.01	0.06	0.86

Table 4: Stress indices of rice genotypes under

Genotype	Yp	Ys	RC	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
Swarna Sub1	18.85	5.13	72.77	13.72	11.99	9.84	8.07	0.82	0.15	1.85	0.27	2.48
IR-44-Sub1	21.98	0.99	95.50	20.99	11.48	4.66	1.89	1.07	0.03	0.36	0.05	0.41
IR-07-F289-Sub1	15.51	3.93	74.63	11.57	9.72	7.81	6.27	0.84	0.10	1.42	0.25	2.31
Ciherang Sub1	24.89	2.31	90.72	22.58	13.60	7.58	4.23	1.02	0.09	0.83	0.09	0.84
Nagina-22	38.84	3.18	91.82	35.66	21.01	11.11	5.87	1.03	0.19	1.15	0.08	0.74
IR-64	31.03	1.08	96.53	29.96	16.06	5.78	2.08	1.08	0.05	0.39	0.03	0.32

Table 5: Rank table of rice genotypes for stress indices

Genotype Code	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	5	6	6	5	5	57	5.18	0.98
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	6	5	5	6	6	52	4.73	1.42

Table 6: Eigen values, Variability (%) and factor contribution

Factors	PC1	PC2	PC3	PC4	PC5
Yp	0.579	0.811	-0.084	0.004	-0.001
Ys	-0.966	0.253	0.002	0.043	0.000
TOL	0.705	0.705	-0.077	-0.004	-0.001
MP	0.415	0.906	-0.088	0.013	0.000
GMP	-0.595	0.798	0.078	-0.035	-0.042
HM	-0.933	0.356	0.040	0.011	-0.020
SSI	0.986	0.136	0.095	0.019	-0.005
STI	-0.534	0.837	0.102	-0.020	0.052
YI	-0.966	0.253	0.002	0.043	0.000
YSI	-0.986	-0.136	-0.095	-0.019	0.005
RSI	-0.986	-0.136	-0.095	-0.019	0.005
Eigenvalue	7.300	3.623	0.066	0.007	0.005

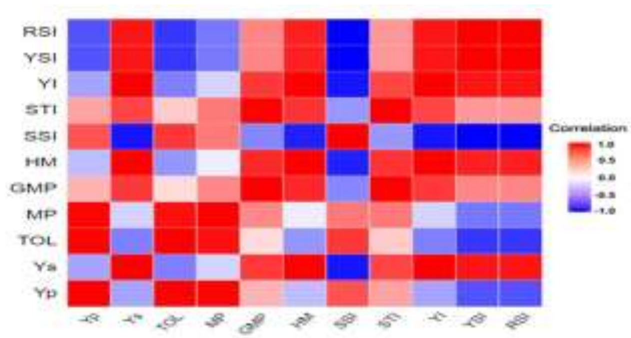

Figure 5: Heat map of correlation matrix based on yield and stress indices

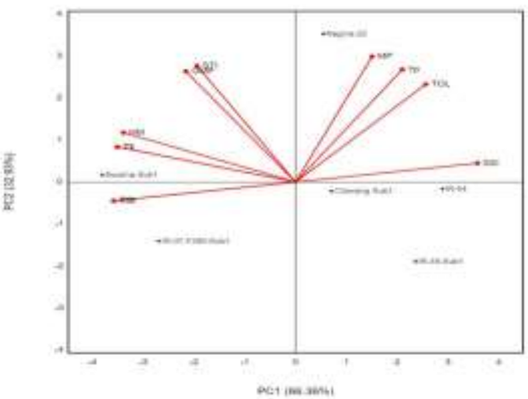

Figure 6: Graphical representation of PCA results

According to Fernandez's theory (Fernandez, 1992), genotypes can be classified into four groups based on their response in terms of yield to various stressful environmental situations. These groups are as follows: (Group A) performance that is relatively consistent in both drought and normal conditions; (Group B) performance that is exceptionally high in normal conditions; (Group C) performance that is exceptionally high in drought; and (Group D) performance that is exceptionally poor in both conditions (Group D). Nagina-22 was placed in group A because of its consistent performance for the entirety of our experiment, including the control settings as well as the drought conditions (fig. 7).

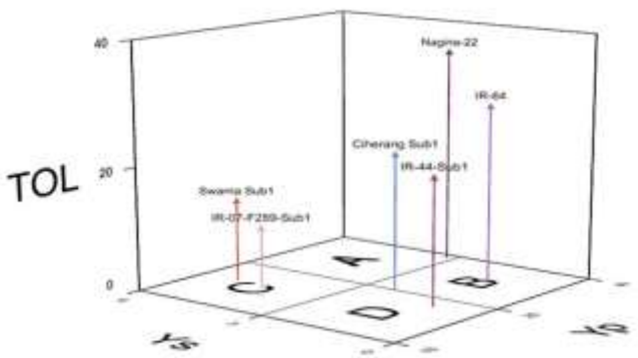

Figure 7: Three-dimensional plot based on TOL index and yield performance (Yp and Ys) under drought

CONCLUSION

According to the results of this study, moisture stress during the reproductive stage dramatically decreased rice production across all genotypes. Fertile spikelets per panicle and fertility percentage should be taken into consideration when choosing rice genotypes under drought stress circumstances because they are positively correlated with grain yield. This study also showed that selection based on the GM, HM, YI, YSI, and RSI drought tolerance indices will lead to the discovery of drought tolerant genotypes with noticeably better and more consistent yield performance.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

ACKNOWLEDGEMENT

We want to thanks anonymous reviewers for their suggestions to this article.

AUTHOR CONTRIBUTIONS

HB, MWJ, SAHS and SS wrote this paper. NS, FS and MR analyzed the data. MIT, FB, SA and KM proof read and edited the manuscript. AK, RUS and TM helped in the revision of manuscript.

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