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Evaluation of Yield and Drought Resistance Indices of Rice Cultivars

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Abstract

Drought is a wide-spread problem seriously effects on rice (*Oryza sativa* L.) production and quality, also it is becoming an increasingly problem in many regions of the world. The objective of this study was to evaluate the ability of several selection indices to identify drought resistant cultivars (Shiroudi, Domsiah (local variety), Koral, IR70358-84-1-1, IR70358-84-1-2, WAB56-125, and IR80357-B-B12-3) under a variety of environmental conditions. Seven rice cultivars differing in yield performance were grown in separate experiments under rain-fed (non-irrigated) and irrigated conditions at the Research Farm of Gonbad Kavous University in 2010. A split-plot design was used with three replications. In flooding condition irrigation was conducted until maturity while in the drought condition, irrigation was watered to 40 days after transplantation then irrigation was discontinued. For rice plants survival and continued growth in drought conditions, irrigation was conducted a 14-day interval. Sowing was done in April and seedling density was 200 seeds per square meter. Six selection indices including stress susceptibility index (SSI), stress tolerance index (STI), tolerance (TOL), mean productivity (MP), geometric mean productivity (GMP), and harmonic mean (HM) were calculated based on yield and yield component under drought-stressed and irrigated conditions. The results showed that MP, GMP, STI and HM indices for yield and yield components were more effective in both drought-stressed and irrigated conditions. Selection of superior cultivar based on indices can be different for yield component. It is concluded that grain yield and filled grain number traits can be used to select superior cultivar under non stress and stress conditions.

Keywords

Drought, Grain Yield, Resistance Indices, Rice, Yield Component

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1. Introduction

Drought is a major problem in rain-fed lowland rice in South and Southeast Asia, and genotypes that produce high yields in drought-prone areas are required. However the development of resistant cultivars, is hampered by low heritability for drought tolerance and a lack of effective selection strategies [19]. In Asia, approximately 34 million ha of shallow rain-fed lowland rice and 8 million ha of upland rice, totaling approximately one-third of the total Asian rice area [17], are subject to occasional or frequent drought stress. The use of yield as an index for adaptation to drought stress in rice [12, 21, 1] may be considered as a reasonable approach, as grain yield is a major attribute of interest in most plant breeding programs. According to Fernandez [10], genotypes can be divided into four groups based on their yield response to stress conditions: (1) genotypes producing high yield under both water stress and non-stress conditions (group A), (2) genotypes with high yield under non-stress (group B), (3) stress (group C) conditions and (4) genotypes with poor performance under both stress and non-stress conditions (group D). The question is: should breeding for stress-prone environments

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rely on selection under both potential and stress conditions or on selection in either environment alone?

Some researchers believe in selection under favorable condition [27, 30, 25, 3]. Selection in the target stress condition has been highly recommended too [6, 7, 26]. Selected rain-fed lowland rice genotypes that yield well under one type of drought stress environment may not perform well in other drought environments [22, 23].

To differentiate drought resistance genotypes, several selection indices have been suggested on the basis of a mathematical relationship between favorable and stress conditions [9, 17]. Tolerance (TOL) [20, 8], mean productivity (MP) [20], stress susceptibility index (SSI) [11], geometric mean productivity (GMP) and stress tolerance index (STI) [10] have all been employed under various conditions. Fischer and Maurer [11] explained that genotypes with an SSI of less than a unit are drought resistant, since their yield reduction in drought condition is smaller than the mean yield reduction of all genotypes [5].

Pantuwan and et al [22] examined response of rice varieties to drought stress at vegetative stage using drought tolerance indices. They reported that use of efficiency drought tolerance indices for improving of yield in stress condition. Bansal and Sinha [2] evaluated wheat accessions based on the stability in grain yields of various species grown across a range of soil moisture conditions, and concluded that species with a smaller linear regression coefficient have a higher drought resistance. The aim of this study was to evaluate the ability of several selection indices to identify drought resistant cultivars.

2. Materials and Methods

Seven rice cultivars including Shiroudi, Domsiah (local variety), Koral, IR70358-84-1-1, IR70358-84-1-2, WAB56-125, and IR80357-B-B12-3 were chosen for study based on their reputed differences in yield performance under irrigated (IR) and non-irrigated (NIR) conditions. This study was conducted at dry land research station, Gonbad Kavous (45 m above sea level, 37°160'N; 55°12'E) University, in Golestan Province (northeast of Iran) in 2010. Rainfall rate during the drought stress (1 Aug to 11 Sep) was 20.6 mm average. Irrigated plots were watered at planting, tillering, jointing, flowering and grain filling stages. Non-irrigated plots received no water other than rainfall. The soil texture was clay-loam (27% clay, 36% silt and 37% sand) with 0.82% organic matter and a pH of 6.4. A split-plot design was used with three replications. In flooding condition irrigation was conducted until maturity while in the drought condition, irrigation was watered to 40 days after transplantation then irrigation was discontinued. For rice plants survival and continued growth in drought conditions, irrigation was conducted a 14-day interval. Sowing was done in April and seedling density was 200 seeds per square meter. Plots consisted of six rows with 6 meters long and spaced 25 cm apart. The seedling rate for each cultivar was 25 seedlings per square meter. All plots received 150 kg N/ ha in two splits; 75 kg N/ ha was applied as N.P.K at planting; and 75 kg N/ ha as urea at tillering stage. The total dry weight and grain yield were measured by harvesting 4.2 m^2 of the central part of each plot at crop maturity. Ten plants were randomly chosen from each plot to measure the number of filled grains per spike, grain weight and productive tillers number.

(1) $SSI = 1 - (Ys / Yp) / SI$, while $SI = 1 - (\hat{Y}s / \hat{Y}p)$ [11].

Where Ys is the yield of cultivar under stress, Yp the yield of cultivar under irrigated condition, $\bar{Y}_s$ and $\bar{Y}_p$ the mean yields of all cultivars under stress and non-stress conditions, respectively, and $1- (\bar{Y}_s / \bar{Y}_p)$ is the stress intensity.

(2) $MP= \frac{YP+YS}{2}$ [16].

(3) $TOL = Yp - Ys$ [16].

(4) $STI= \frac{YP\times YS}{(MP)^2}$ [10].

(5) $GMP = \sqrt{YP\times YS}$ [10].

(6) Yield stability index $(YSI) = \frac{Ys}{Yp}$ [4].

Data were analyzed using SAS for the analysis of variance and Duncan's multiple range tests or the LSD value was employed for the mean comparisons.

3. Results

The results of analyses of variance for grain yield, grain weight, productive tillers and grains/spike are presented in Table 1. The cultivars showed significant differences in grain yield and other traits. The main effect of moisture regimes was highly significant for the measured traits. The interaction between cultivars × moisture was highly significant except productive tillers number. Grain yield of cultivars varied, particularly under stress conditions. Shiroudi produced the highest grain yield in irrigated and non- irrigated conditions. IR83752-B-B-12-3, WAB56-125 and Koral had the lowest grain yield in non-irrigated condition (Table 2). IR752-B-B-12-3 was the most productive in irrigated and the least productive in non-irrigated conditions. Grain yield under irrigated condition was positively correlated with rain-fed condition suggesting that a high potential yield under optimum condition cause improved yield under stress condition. Thus, indirect selection for a drought-prone environment based on the results of optimum condition will be efficient. These results are in contrast with Ceccarelli and Grando [7] and Bruckner and Frohberg [5] who found that landraces of barley and wheat with low yield potential were more productive under stress condition. The lack of response to improved environmental conditions may be related to a lack of adaptation to high-moisture conditions [8].

Table 1. Mean squares for agronomic traits of rice cultivars.

S.O.V.	D.F.	Mean squares			
		Grain yield	100-Grain weight	Filled grains/spike	Productive tillers number
Moisture (M)	1	1444820.80**	0.74**	1333705629**	64509.53**
Error	4	2984.47	0.00	392391	494.88
Cultivar (C)	6	640155.38**	0.41**	909631984**	113434.42**
C xM	6	148527.87**	0.032**	63634434**	1016.42^{ns}
Error	72	1696.15	0.00	1897287	458.66
CV		12.62	2.59	10.67	7.53

Ns: No significant difference ** $p < 0.01$.

Table 2. Grain yield, filled grain/spike, grain weight, productive tillers of the cultivars in irrigated (IR) and non-irrigated (NIR) environment.

Cultivar	Grain yield (kg/ha)			Filled grains/spike		100-Grain weight (g)		Productive tillers	
	IR	NIR	Y.R^a(%)	IR	NIR	IR	NIR	IR	NIR
Shiroudi	9974. 8	4563.4	54.3	31587.5	20312.5	1.3	1.1	391.6	355.8
Domsiah	4598.8	2461.3	46.5	23745.9	12590.3	1.2	1.1	396.6	359.5
IR10358-84-1-1	3241.7	2221.1	31.5	8945.9	7195.8	1.2	1	348.9	298.4
IR70358-84-1-2	3665.2	2762.9	24.7	15927.1	11004.2	1.5	1.2	280.3	220.7
WAB56-125	2447.9	1242.5	49.9	9720.9	4145.8	1.3	1.2	214.9	153.4
IR83752-B-12-3	4437.3	637.1	85.7	15445.9	7541.6	1.1	1	311.6	259.2
Koral	1943.4	1459.2	25.0	7754.2	4788.9	1.6	1.5	203	182.3
Mean	4334.2	2192.5	45.4	16161.1	9654.2	1.4	1.2	306.7	261.4
LSD (5%)	502.6	239.6		1694	773.8	0.1	0.1	26.3	12.3

LSD: least significant difference at 5% level of significance. IR: irrigated; NIR: non-irrigated.

[a] Percentage of yield reduction under non-irrigated condition.

The cultivars that have high sensitive in reproductive stage thus theirs yield and yield component reduce under drought condition (Table 2). O'Toole and Chang [21] state that one of the main limitations that causes rice yield reduction is water deficit. Also it is showed that if drought stress occurs at a certain stage of growth, different cultivars have different responses [13]. Pirdashti and et al [24] evaluated effect of water deficit stress at growth different stages of rice and expressed that water deficit at vegetative stage significantly reduced plant height and number of tillers, also significantly reduced grains/spike, grain weight and grain yield in reproductive stage.

Resistance indices were calculated on the basis of grain yield and yield component of cultivars also the greater the TOL value, the larger the yield under stress condition observed in shiroudi cultivar (Table 3). TOL correlated with both grains/spike and grain yield under stress (Table 4), therefore these traits can contribute to increased yield under stress and reduce stress susceptibility [10]. For example Koral and IR70358-84-1-2 cultivars had the lowest TOL and SSI for grain yield. IR70358-84-1-2 with relatively high yield under stress conditions but Koral with relatively low yields under stress conditions exhibited low SSI and TOL. Similar results were reported by Clarke et al [8] and Rosielle and Hamblin [28]. However it showed that a selection based on minimum yield decrease under stress with respect to favorable conditions (TOL) failed to identify the best genotypes. IR70358-84-1-1 and Koral cultivars had lowest TOL and SSI for filled grain number (Table 3). TOL imply fewer variations in wet different conditions but low rates of TOL do not implicate high yield in stress and non-stress conditions. So TOL is valid when is considered with high yield. There was not a significant correlation between TOL or SSI and productive tillers number and grain weight under stress and non-stress (Table 4).

Table 3. Grain yield (kg/ha) and tolerance indices of the cultivars.

Cultivar	Yp	Ys	STI	GMP	SSI	MP	TOL	HM
Shiroudi	9974.8	4563.4	2.42	6743.8	1.09	7269.1	5411.5	6257.32
Domsiah	4598.7	2461.3	0.60	3359.5	0.93	3530.0	2137.5	3198.05
IR10358-84-1-1	3241.7	2221.1	0.38	2682.2	0.63	2731.3	1020.6	2634.7
IR70358-84-1-2	3665.2	2762.9	0.53	3179.2	0.49	3214.1	902.3	3144.91
WAB56-125	2477.9	1242.5	0.16	1754.0	1.01	1860.2	1235.4	1653.97
IR83752-B-B-12-3	4437.3	637.1	0.15	1680.5	1.73	2537.2	3800.2	1113.71
Koral	1943.3	1459.2	0.15	1683.3	0.49	1701.3	484.2	1665.47
Mean	4334.2	2192.5	0.62	3011.8	0.91	3263.3	2141.7	2809.73
LSD (5%)	547.3	207.3	0.12	220.35	0.19	278.92	659.09	198.11

Table 4. Simple correlation coefficients between tolerance indices and grain yield, grain weight, grains/spike and Productive tillers of 7 rice cultivars in irrigated (IR) and non-irrigated (NIR) conditions.

Characteristics	**STI**	**GMP**	**SSI**	**MP**	**TOL**	**HM**
IR-yield	0.95**	0.93**	0.360	0.979**	0.905**	0.881**
NIR-yield	0.91**	0.96**	-0.261	0.905**	0.465	0.986**
Grain/spike (IR)	0.96**	0.98**	0.051	0.99**	0.90**	0.98**
Grain/spike (NIR)	0.97**	0.99**	-0.22	0.98**	0.73**	0.99**
1000-Grain weight (IR)	0.94**	0.95**	0.16	0.96**	0.32	0.95**
1000-Grain weight (NIR)	0.97**	0.96**	-0.36	0.96**	-0.36	0.97**
Productive tillers (IR)	0.98**	0.99**	-0.54	0.99**	-0.07	0.99**
Productive tillers (NIR)	0.99**	0.99**	-0.68	0.99**	-0.25	0.99**

Ns: No significant difference ** $p < 0.01$.

SSI had no correlation with yield under stress and non-stress (Table 4). The Koral, IR70358-84-1-2 and IR70358-84-1-1 cultivars had low yield under both stress and non-stress conditions and showed the lowest SSI. Sio-se Mardeh et al. [29] in their study conducted to assess drought tolerance indices in wheat genotypes under various environmental conditions; concluded that indices such as MP, GMP and STI prove highly effective in identifying those genotypes that produce equal yields in both environments under the moderate stressed conditions. Henderson et al [14] reported that there is no correlation between SSI and yield in non-stress condition (Yp). These criteria may be independent components that participate in adaptation to environmental stress. Thus SSI will not discriminate drought sensitive cultivars under such conditions. No significant correlation was found between grains/spike, productive tillers number and grain weight under stress and SSI (Table 4), showing that SSI will not discriminate drought sensitive cultivars with use of grain yield and yield components under stress conditions.

MP is mean production under both stress and non-stress conditions [28], it be correlates with yield under stress and non stress (Table 4). For this reason, MP was able to differentiate cultivars belonging to group A from the others. As described by Hohls [15] selection for MP should increase yield in both stress and non-stress environments unless the correlation between yields in contrasting environments is highly negative. Koral and WAB56-125, for example, with relatively low yields under stress and non-stress conditions, exhibited low MP values but IR83752-B-12-3 with low yield under stress condition showed relatively high MP value. Difference between stress and non-stress yields in IR83752-B-B12-3 Cultivar was too much in resulting high MP value. Sio-Se Mardeh et al [29] reported that MP can be related to yield under stress only when stress is not too severe and the difference between yield under stress and non-stress conditions is not too much. For this reason, MP was not able to differentiate cultivars belonging to group A from the other. MP is not suitable to choose varieties with high yield under stress [10]. Hossain et al [16] used MP as a resistance criterion for wheat cultivars in moderate stress conditions. STI, GMP and HM are significant correlated with yield under stress and non-stress conditions. (Table 4). We concluded that GMP and STI are able to discriminate group a cultivars only under drought stress conditions. Sio-Se Mardeh et al [29] evaluated drought tolerance indicators in different environments, and showed that under stress moderate condition indices MP, GMP and STI are more efficient for identifying genotypes with high yield.

MP, GMP, STI and HM are positive and significant correlated with yield and yield components under stress and non-stress conditions (Table 4). The mention indices can be used for yield and yield components under stress condition. Shiroudi, Koral, Shiroudi and Domsiah had highest rate for grain/spike, grain weight, productive tillers number traits respectively based on MP, GMP, STI and HM indices. Yield and yield components showed a positive and significant correlation with each other under stress and non-stress conditions. Fernandez [10] has proposed resistance indices for all characteristics, but may be get different results to choose best varieties based on tolerance and sensitivity indices for different traits. The findings of this study showed that should be choosing suitable cultivar on the basis of tolerance and sensitivity indices for yield trait.

4. Discussion

Yield and yield-related traits under stress were dependent of yield and yield-related traits under non- stress condition. As STI, GMP, MP and HM were able to identify cultivars producing high yield in both conditions. Indicators of TOL and SSI couldn't clearly identify cultivars with high yield under both stress and non-stress conditions (group A cultivars). Panthuwan et al [22] believe that potential yield has a large impact on yield only under moderate drought stress conditions, before stress is severe enough to induce a genotype x environment (G x E) interaction for yield. Whether direct or indirect selection is superior depends upon the heritability of the selected trait in stress and non- stress environments and the genetic correlation between stress and non-stress environments.

Van Ginkel et al [30] showed that the traits suitable for a given environment with its own weather conditions may be unsuitable (or even harmful) in another environment. The weakness of this approach is that input responsiveness; so important in the wetter, admittedly less frequent but much more productive years cannot be easily maintained in the germplasm. The method also assumes yield crossover will occur below a certain yield threshold. Evidence for the existence of crossover and non-existence of crossover [25] in environments ranging from moisture stressed to non-stressed has been reported. The theoretical framework to this issue has been provided by other researchers who wrote,“ yield in low and high yielding environments can be considered as separate traits which are not necessarily maximized by identical sets of alleles”. Several researchers have concluded that selection will be most effective when the experiments are done under both favorable and stress conditions [10], [25], [8] and [11].

5. Conclusions

Selection should be based on the tolerance indices calculated by the yield under both conditions (stress and non-stress condition), when the breeder is looking for the cultivars adaptive to a wide range of environments [29]. The findings of this study showed that might be obtained to different results will be obtain to select the best varieties based on the tolerance and sensitivity indices for different traits. To choose a superior cultivar the study should be conducted on the basis of the tolerance and sensitivity indices for yield. According to Fermandez [10] to determine the best drought tolerance index, an indicator that has a high correlation with grain yield under stress and non-stress conditions is suitable. The correlation type increases yield both conditions is introduced as the best indicator. Shiroudi with the highest MP, GMP, STI and HM was identified as resistant cultivar whereas WAB56-125, and Koral with a lower MP, GMP, STI and HM were sensitive cultivars

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