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EVALUATING DROUGHT TOLERANCE OF RICE CULTIVARS IN GILAN PROVINCE

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ABSTRACT
A split-plot experiment using the randomized complete block design with three replications was conducted in Gilan Province in 2012 to find drought tolerant cultivars, to select high- yielding cultivars, and to determine suitable indices for evaluating drought tolerance in rice. The major factor was irrigation management (flood irrigation, and irrigation 4 and 8 days after disappearance of water from ground surface) of 10 genotypes (Hashemi, Hybrid No.7, Gohar, Ali Kazemi, Nemat, Hasan Saraei, Kadous, Tarom Dailamani, Fajr, and Bahar). Results indicated that drought stress severely reduced seed yield and that the genotype Gohar had the maximum seed yield under all three irrigation management methods. Moreover, it was found that the STI and SSI indices were the best indices for drought tolerance in rice. Furthermore, the cultivars Gohar, Nemat, and Hashemi under the regime of irrigating 4 days after disappearance of water from soil surface, and the cultivars Gohar, Hybrid 1, and Hashemi under the regime of irrigating 8 days after water disappeared from ground surface, were introduced as drought resistant cultivars.

KEYWORDS: Rice, genotypes, drought stress, indices of drought stress tolerance

INTRODUCTION
Rice is the only cereal exclusively planted for human consumption and constitutes about half the diet of 1.6 billion people in the world. Iran, with the mean annual rainfall of 240 mm, is classified as an arid and semi-arid region. The low precipitation, and its irregular distribution, and high temperatures cause drought stress during the growing season of crop plants in the country and decrease agricultural production (Zeinali Khaneghah *et al.*, 2004). Rice production met local demands until the early 1960s but now, considering the rapid population growth and improved economic conditions of the people, local production does not satisfy demands and large quantities of rice are imported every year. Therefore, production of this crop must be increased through raising yield per unit area (Khodabandeh, 1990), because rice is one of the most important crops faced with severe limitations in area under cultivation (Silva et al., 2007). Drought is the most important limiting factor in rice production in the 40 million hectares of land under its cultivation in Asia (Venuprasad *et al.*, 2007). When water loss through transpiration exceeds water absorption, plants are faced with water shortage and suffer drought stress. Drought stress can influence the anatomy, morphology, physiology, biochemistry, and almost all aspects of plant growth and development (Koochaki and Soltani, 1997). Considering the water crisis of recent years, it seems necessary that attention must be paid to various irrigation methods that enable us to optimize water use. Increased efficiency in water use, reduced irrigation, and saving water usage to use it in other places and at other times are among the main goals of reduced irrigation. Pantuwan *et al.* (2004) studied responses of rice cultivars to drought stress in the vegetative stage using indices of drought tolerance. They showed employing the index of drought tolerance was less efficient than using yield for improving yield under stress conditions, but recommended that indices of drought tolerance be used when a large number of genotypes are evaluated . In another study, Pantuwan *et al.* (2002) compared results obtained from indices at different stages of growth in rice plants and recommended these indices be employed only for the flowering stage. Yamboo and Ingram (1998) studied the indices of drought stress in rice cultivar IR64 with irrigation cessation of 5, 10, and 15-day intervals starting from 10, 25, 40, 55, 70, 85, and 100 days after seeding. They demonstrated that irrigation reduction during the vegetative stage did not significantly influence seed yield, and that drought stress lasting for a 5-10 day period in the reproductive stage reduced yield by 25-40%.

Evaluation of cultivar performance with respect to indices of tolerance and sensitivity is one of the methods used in studying response of cultivars to abiotic stresses such as drought. No reports have been published so far on evaluation of Iranian rice genotypes regarding drought tolerance by using indices of tolerance and sensitivity, but drought tolerance using these indices has been evaluated for other crops. Zarei *et al.* (2007) used them to study drought tolerance in bread wheat and noticed that there was a strong correlation between the index of drought tolerance and proline concentration in flag leaf, and that cell membrane stability improved with increases in proline concentration. In an experiment carried out in Egypt, it was found that 6-10 day irrigation intervals did not have any significant effects on the yield of the resistant cultivar ITT. They also observed that the yield of an upland variety with the customary irrigation interval of 6 days did not decrease when this interval was raised to 10 days (Ibrahim et al., 1995). Results of a study in the dry season indicated that irrigation intervals of 4 and 8 days increased yield by one ton or more compared to the 10-day irrigation interval (Bauman, 2001). Water shortage in crop production is steadily getting worse, while expansion of existing water resources and finding new ones entail great costs. Improving water use efficiency seems to be necessary in utilizing water for future food security, especially in Asia where current rice production must increase by 70% before 2025 (Tang 1999). Research was conducted at the Rice Research Institute of Mazandaran to study the effects water stress at different stages of growth of rice plants had on yield, and to determine the amount of water used in growing rice cultivars Tarom and Nemat. It was found that there were no significant differences between the treatments for the Tarom cultivar, and that the maximum yield was achieved in the treatment with the water regime of alternate flooding and drying (0-5 cm) which saved water usage by 33% compared to the treatment of constant flooding (Saadati, 1998). Khorshidi Benam et al. (2006) concluded from their study that, in screening resistant and sensitive varieties, genotypes with greater geometric mean productivity (GMP) and lower sensitivity to stress index (SSI) were considered tolerant. Azizinia and Ghannadha (2004) concluded from their study on determining the best indices for drought tolerance in native wheat cultivars that the GMP, MP, and STI indices were the best because they had positive and very significant correlations with Y_p and Y_s. Sadeghi *et al.* (2010) also selected these three as the best indices of drought tolerance. It was reported by Pirdashti et al. (2005) that water shortage influenced growth, development and yield of cultivars. In their research, water stress during vegetative growth reduced plant height and, during the flowering stage, it decreased the number of fertile panicles and percentage of filled seeds, and caused the greatest reduction in yield compared to other growing stages. The conclusion Azizinia and Ghannadha (2004) made from their research on determining the best indices of drought tolerance in native wheat cultivars was that the GMP, MP, and STI indices were the best and had positive and very significant correlations with Y_p and Y_s . The purposes of our research were to compare rice genotypes with respect to tolerance or sensitivity to drought stress, to determine suitable genotypes for cultivation under the applied irrigation regimes, to make optimal use of water, and to increase water productivity.

MATERIALS AND METHODS

In producing an improved variety, plant breeders either knowingly or unknowingly use a kind of selection index because improved varieties must possess minimum standards in commercial production. Fernandez (1992) said expression of genotype performance under stress and non-stress conditions could be divided into the following four groups:

1. Genotypes with the same performance under both conditions (group A)
2. Genotypes with good performance only in non-stress environments (group B)
3. Genotypes with high performance in stress environments (Group C)
4. Genotypes with weak performance in both environments (Group D)

On this basis, he stated that the best selection criterion for stress is a criterion that distinguishes group (A) from the other groups.

Terms related to indices of drought resistance are as follows:

Y_p = The performance of each genotype under non-stress conditions

Y_s = The performance of each genotype under stress conditions

$\overline{Y_p}$ = The mean performance of all genotypes in non-stress conditions

$\overline{Y_s}$ = The mean performance of all genotypes under stress conditions

Using plant performance under non-stress conditions (Y_p) and stress conditions (Y_s), the following indices were calculated to determine the extent of tolerance or sensitivity of genotypes to drought stress:

SSI = $(1 - (Y_s / Y_p)) / \text{SI}$

$$SI = (1-(\overline{Y}_S / \overline{Y}_P)$$

$$STI = (Y_P / \overline{Y}_P)(Y_S / \overline{Y}_S)(\overline{Y}_S / \overline{Y}_P) = (Y_P)(Y_S)/(\overline{Y}_P)^2$$

$$TOL = Y_P - Y_S$$

$$MP = (Y_P + Y_S)/2$$

$$GMP = \sqrt{(Y_P)(Y_S)}$$

In the above relations, SI is the stress intensity and has an inverse relationship with stress susceptibility index (SSI); i.e., when SI increases, SSI decreases and vice versa. In general, the smaller the value of this index is, the less the genotype will be susceptible to stress and the greater its resistance will be. Selection based on the SSI index will lead to selecting genotypes with low yield under normal conditions but will high yield under stress conditions. Therefore, the main shortcoming of this index is that it cannot distinguish group A genotypes from group C genotypes. Fernandez (1992) proposed the STI index as the stress tolerance index to be used for identifying genotypes with high yield under both stress and non-stress conditions. The larger the value of the STI index is, the greater the drought tolerance of the genotype will be (which will further increase its potential yield). The STI index distinguishes Group A genotypes from Groups B and C genotypes.

RESULTS AND DISCUSSION

As results listed in Table 1 indicate, the genotype Gohar had the highest yield under flooding conditions and under stress conditions 1 (irrigation 4 days after disappearance of water from ground surface) with 6470 and 5442 kg/ha, respectively.

Table 1: Values obtained for the indices of drought tolerance under stress conditions 1 (irrigation 4 days after disappearance of water from ground surface).

SSI	STI	GMP	MP	TOL	Y_s	Y_p	Genotypes
1.38	0.86	4579.41	4622	1252	3966(GHI)	5248 (BC)	Hashemi
1.087	0.796	4405.7	4429.5	917	3971(GHI)	4888(CDE)	Hybrid No.7
0.919	1.444	5933.77	5956	1028	5442(BC)	6470(A)	Gohar
0.324	0.594	3805.92	3807.5	219	3698(HI)	3917(FGHI)	Ali Kazemi
0.613	1.045	5049.65	5057.5	563	4776(CDEF)	5339(BC)	Nemat
0.428	0.773	4343.86	4347	330	4182(EFGHI)	4512(DEFG)	Hasan Saraei
1.318	0.854	4565.21	4603.5	1185	4011(GHI)	5196(BCD)	Kadous
0.890	0.685	4087.17	4101.5	685	3759(GHI)	4444(EFGH)	Tarom Dailamani
0.127	0.508	3520.27	3520.5	79	3481(Ij)	3560(Ij)	Fajr
2.3	0.792	4395.95	4537.5	2249	3413(Ij)	5662(B)	Bahar

The value of the stress tolerance index for the genotype Gohar under stress conditions 1 was 1.44, for the genotype Gohar 1.04, and for the genotype Hashemi 0.86. These are the highest values compared to those of the other genotypes and indicate that the higher the value of the STI index is, the more drought resistant the genotype will be. Moreover, the STI index values for the genotypes Fajr, Ali Kazemi, and Tarom Dailamani were 0.508, 0.594, and 0.685, respectively, which were lowest values among the genotypes. Results of research conducted by Noormand-Moayyed (1997), Quisenberry (1982), and Askar et al. (2009) on wheat also led them to the conclusion that the STI index had good performance because it selected genotypes with high yield under both stress and non-stress conditions. The genotype Nemat with 5339 kg/ha under flooding conditions and 4776 kg/ha under stress conditions 1 achieved the second highest yield, and the genotype Hashemi with 5248 kg/ha under flooding conditions and 3996 kg/ha under stress conditions 1 was the third highest yielding genotype. The lowest yielding genotypes were Fajr, Ali Kazemi, and Tarom Dailamani, respectively. Richards (1996) stated that selection based on genotype performance under both stress and non-stress conditions resulted in selecting genotypes with high performance under stress conditions because the desired alleles were selected under drought stress conditions. At the same time, response to selection under non-stress conditions was highest due to the higher hereditability of yield under these conditions compared to stress conditions. In this same relation, considering results of correlation coefficients between various indices and seed yield under conditions of stress and non-stress, it was observed that the indices MP, GMP, and STI had the mentioned characteristic: they had positive and significant correlations with genotype yield under both stress and non-stress conditions at the 1% probability level. Therefore, in our study, lines with high values of these indices were considered the most resistant lines. Table 2 shows the values of the indices of drought tolerance under stress conditions 2 (irrigation 8 days after the disappearance of water from ground surface). The highest yields were those of the Bahar, Hybrid N. 7, and Gohar genotypes, and the values of the STI index for them were 0.679, 0.682, and 0.539, respectively (that were higher compared to those of the other genotypes under this irrigation regime). Moreover, the lowest yields belonged to the genotypes Ali Kazemi, Hasan Saraei, and Fajr that had lower STI index values compared to the other genotypes.

Zarei *et al.* (2007) conducted research on high-yielding wheat genotypes and showed that there were positive and significant correlations between the STI index values and the trait of seed yield under normal and stress conditions. Selection of the indices MP, GMP, and STI as the most suitable indices in our research agrees with results Emamjomeh (1999), Soori et al. (2005), Azizinia and Ghannadha (2004), Kargar et al. (2004), and Maaroofi and Farshadfar (2002) found in their studies.

Table 2: Values of the indices of drought tolerance under stress conditions 2 (irrigation 8 days after disappearance of water from ground surface)

SSI	STI	GMP	MP	TOL	Y_s	Y_p	Genotypes
1.033	0.540	3628.66	3878.5	2739	2509(KL)	5248(BC)	Hashemi
0.891	0.539	3626.11	3789	2198	2690(KL)	4888(CDE)	Hybrid No.7
1.194	0.682	4077.73	4520	3900	2570(KL)	6470(A)	Gohar
1.104	0.278	2605.41	2825	2184	1733(M)	3917(FGHI)	Ali Kazemi
1.120	0.508	3520.20	3830	3018	2321(KLM)	5339(BC)	Nemat
1.043	0.395	3104.45	3324	2376	2136(LM)	4512(DEFG)	Hasan Saraei
1.01	0.542	3635.74	3870	2652	2544(KL)	5196(BCD)	Kadous
0.789	0.487	3445.92	3558	1772	2672(KL)	4444(EFGH)	Tarom Dailamani
0.662	0.346	2904.68	2965	1190	2370(KLM)	3560(Ij)	Fajr
0.958	0.672	4829.36	4292.5	2739	2923(JK)	5662(B)	Bahar

Evaluation of drought resistance indices

Tables 3 and 4 present results of correlations between the measured indices of genotype seed yield under stress conditions 1 (irrigation 4 days after disappearance of water from ground surface) and stress conditions 2 (irrigation 8 days after disappearance of water from ground surface). Under stress conditions 1, the MP, GMP, and STI indices had the strongest positive correlations with yield under normal conditions, while the STI index exhibited the strongest positive correlation with yield under stress conditions 1.

The SSI index showed the maximum negative correlation with yield under stress conditions 1, and this indicated the fact that the higher the value of the STI index was the higher the yield of the genotype would be. Regarding stress conditions 2, as obtained results show, the greatest positive correlations with yield were those of the STI index, while the SSI index had negative and strong correlations with yield under stress conditions 2. Considering these results, we can introduce the Gohar, Nemat, and Hashemi genotypes under stress conditions 1, and the Gohar, Bahar, and Hashemi genotypes under stress conditions 2, as drought resistant genotypes. In the study conducted by Jaafari *et al.* (2009), it was found that the GMP and STI indices had strong correlations with seed yield under both stress and non-stress conditions, and that they could be introduced as the best indices for identifying resistant cultivars.

Table 3: Coefficients of correlations between drought resistance indices and seed yield in the 10 studied genotypes under stress conditions (1)

SSI	STI	GMP	MP	TOL	Y_s	Y_p	7
0.624	0.898**	0.918**	0.940**	0.693*	0.669*	1	Y_p
-0.158	0.923**	0.909**	0.882**	-0.071	1		Y_s
0.991**	0.311	0.351	0.407	1			TOL
0.323	0.992**	0.998**	1				MP
0.267	0.996**	1					GMP
0.219	1						STI
1							SSI

Table 4: Coefficients of correlations between drought resistance indices and seed yield in the 10 studied genotypes under stress conditions (2)

SSI	STI	GMP	MP	TOL	Y_s	Y_p	correlations between drought resistance
0.626	0.917**	0.811**	0.965**	0.924**	0.537*	1	Y_p
-0.298	0.824**	0.836**	0.739*	0.173	1		Y_s
0.866**	0.696*	0.567	0.791**	1			TOL
0.407	0.988**	0.907**	1				MP
0.178	0.948**	1					GMP
0.280	1						STI
1							SSI

CONCLUSIONS

Results of our experiment indicated that there were strong positive correlations between the STI index and seed yield, and that the higher the value of the STI index was for a genotype, the more resistant it would be to drought and the higher yield it would have. Conversely, the lower the value of the STI index was for a genotype, the more susceptible it would be to drought and the lower its yield would be. Moreover, the cultivars Gohar, Nemat, and Hashemi under the regime of irrigating 4 days after disappearance of water from ground surface, and the cultivars Gohar, Bahar, and Hashemi under the regime of irrigating 8 days after disappearance of water from ground surface, were introduced as drought resistant genotypes. The genotypes Fajr and Ali Kazemi with the lowest STI index values were the most susceptible among the 10 studied genotypes.

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