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**Research Article**

# Salinity-tolerance related indices for screening rice (*Oryza sativa* L.) cultivars

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**ABSTRACT** - Rice (*Oryza sativa* L.) serves as the main food for more than half of the world's population. Salinity is one of the most important factors which limits rice yield. Eleven rice cultivars were evaluated in a randomized complete block design with three replications under salinity stress and normal conditions. The stress tolerance and sensitivity indices, including the mean productivity (MP), the geometric mean (GMP), the stress tolerance index (STI), the yield index, the yield stability index, the harmonic mean (HM), the stress susceptibility index, the tolerance index and yield loss rate, and principal component analysis were used to evaluate the variation and response of rice cultivars under salinity stress conditions, and to identify the tolerant cultivars. A significant variation was observed among the cultivars for grain yield and stress indices. Principal component analysis using grain yield and stress tolerance indices identified two components including “salinity tolerance component” and “salinity sensitivity index component” with eigenvalues greater than 1, which described a cumulative explanation of 99.39 percent of the variance among the cultivars. MP, GMP, and STI were found to be considered as the most suitable indices for selecting rice cultivars tolerant to salinity. The cluster analysis and the distribution of the cultivars in the biplot diagram obtained based on grain yield, and stress tolerance indices introduced Lenjan Askari, Yasouj, and Kamfirouz as tolerant, and Loudab Champa, Gharib, and Mamassani Domsiah as sensitive cultivars. These tolerant cultivars can be used in breeding programs to improve the salinity tolerance of rice.

## INTRODUCTION

Rice (*Oryza sativa* L.) is the main staple food for more than half of the world's people. Rice cultivation occupies an important position in Iran with a cultivation area of 580,000 ha (Agricultural statistics, 2020). The production of major food crops is threatened by abiotic stresses such as salinity, drought, and high and low temperatures (Arzani & Ashraf, 2016; Calanca, 2017). Salinity is one of the most crucial stress factors affecting agricultural productions (Arzani, 2008; Hoang et al., 2016). Therefore, enhanced crop productivity in the marginal lands and saline regions is an important goal in breeding crop plants, including rice.

Osmotic stress, ionic toxicity, oxidative stress, and nutrient imbalance are the key factors negatively influencing plants’ growth and productivity by salinity stress (Arzani & Ashraf, 2016; Munns & Tester, 2008; Wakeel, 2013). In other words, in terms of the increasing exploitation of natural resources (soil and water) for crop production and the global demand for more food, using low-quality water, especially in arid and semi-arid regions, is inevitable (Jie et al., 2014). In fact, salinity has been introduced as a limiting factor for crop production in arid and semi-arid regions due to high evapotranspiration and insufficient rainfall (Yarami & Sepaskhah, 2015).

Rice is very susceptible to salinity stress which is listed as the most salt-sensitive cereal crop with a threshold of 3 $dSm^{-1}$ for most cultivated varieties (Hoang et al., 2015; Mohammadi-Nejad et al., 2010). It has been reported that rice yield on salt-affected lands is significantly reduced with an estimated yield loss of 30% to 50% annually (Eynard et al., 2005). It has been shown that the sensitivity of rice to salinity is so high that a soil salinity of 6.5 $dSm^{-1}$ resulted in a reduction of more than 50% in its yield (Shannon & Grieve, 1998). In the reproductive stage, rice plants are more susceptible to salt (Mohammadi-Nejad et al., 2010).

Stress tolerance is a multi-genic (quantitative) trait and is due to a number of biochemical and physiological mechanisms (Arzani & Ashraf, 2016; Flowers & Colmer, 2008). Selecting the suitable parents to develop salinity tolerant cultivars possessing a combination of desired characteristics has been already a basic approach used by breeders (Nakhjavan et al., 2012). Different indices have been suggested for the screening of plant genotypes for their responses to various conditions, and the determination of their tolerance and sensitivity (Bahrami et al., 2021). To identify the cultivars tolerant to salinity, indices such as stress sensitivity index and harmonic mean (Fischer & Maurer, 1978), the mean productivity and tolerance indices (Rosielle & Hamblin, 1981), stress tolerance index (Fernandez, 1992), the geometric mean productivity, and yield stability index (Fischer & Maurer, 1978), yield index (Gavuzzi et al., 1997), yield loss index (Golestani Araghi & Assad, 1998) and stress tolerance score (Abdolshahi et al., 2013) have been used.

Mirdar Mansuri et al. (2011) stated that the geometric mean (GMP) and stress tolerance index (STI) are suitable indices to guarantee the yield stability and evaluate high-yield genotypes under stress conditions. They reported that according to the correlation coefficient values among the indices, the mean productivity (MP), GMP, the harmonic mean (HM), and STI indices have high correlations with yield in both normal and stress conditions. Ranjbar and Rousta (2011) identified STI as an effective index to select wheat genotypes under salinity stress conditions. They reported that the correlation analysis at 60 and 100 mM salinity showed that the yield has the highest significant positive relationship with the indices of HM, stress tolerance, and stress sensitivity.

Using the principal component analysis (PCA) on 17 tolerance characteristics and indices at NaCl concentrations of 60 and 100 mM, four and five components were introduced which described 90.70% and 92.38% of the total phenotypic variations, respectively (Mirdar Mansuri et al., 2011). Gregoria et al. (1997) believed that sensitive and tolerant cultivars could be distinguished based on the visible symptoms of salinity stress in rice. In addition to the phenotypic study to identify the response of cultivars to salinity, the indices of sensitivity or tolerance have been used to classify cultivars with respect to their response under stress and no-stress conditions into four groups. These groups include genotypes with high yield in both conditions ( Group A), genotypes with the desired yield under normal conditions (Group B), genotypes with respectable yield under stress conditions (Group C) and genotypes with low yield under both conditions (Group D) (Fernandez, 1992). Rice cultivars vary in their response to salinity. There is notable genetic variation among rice cultivars for sensitivity and tolerance to salinity (Mohammadi-Nejad et al., 2010). The objectives of the present study were to identify the best indices for the selection of salinity-tolerant genotypes and screen the rice cultivars with high salinity tolerance.

## MATERIALS AND METHODS

This study was carried out in the greenhouse of the Faculty of Agriculture, Yasouj University, Yasouj, Iran. Eleven rice cultivars (Table 1) were evaluated in a randomized complete block design with three replications under salinity stress (88 mM NaCl and $CaCl_2$) and normal conditions. The seeds were sterilized with sodium hypochlorite (0.5%) for one minute and placed in Petri dishes covered with filter paper, in May 2012. After the germination, the seeds (incubated at 25 ± 1°C ) were transferred to the suitable containers (20×15×5 cm) filled with 50% sand and 50% silt until the seedlings reached the 2 to 3-leaf stage. The transplants were transferred to the pots, 18 cm in height and 21 cm in diameter, filled with sandy-silt soil. Three seedlings of each cultivar were planted at equal distances in each pot. The pots were placed in plots with 79 × 97 cm in dimensions, insulated with plastic. The plants were watered with Hoagland solution (pH 6.5). Salinity stress was applied two weeks later; when the plants reached 4-leaf plant stage. The salinity level of the plots was considered Zero (normal) and 88 mM (stress) by adding NaCl and $CaCl_2$ with a ratio of 20:1 to Hoagland's base solution (Richards, 2012). The solution was refreshed every eight days, and then the plots were washed with Hoagland solution to prevent salt accumulation in the pots (Qados, 2011). The grain production of three plants in a pot was tested under stress and normal circumstances after harvesting in September 2012, and salinity stress tolerance indices were determined based on the results (Table 2).

All data were standardized with the formula $Z = (X-\mu)/\sigma$, where Z is the standard score, X the observed value, $\mu$ is the total mean, and $\sigma$ is the standard deviation. Microsoft Excel was used to calculate the stress tolerance indices based on the equations. A comparison of the means for stress and normal conditions was performed using Duncan's Multiple Range Test (DMRT) at a probability level of 0.05. Simple Pearson correlations were calculated using SAS V.9.1 software. The principal component analysis was performed using standardized means both under stress and normal conditions by Statgraphics V.18.1.01 software. Finally, using the first and second principal components, a biplot diagram was created. Ward's least variance approach based on Euclidean distance was used to do cluster analysis (after data standardization). The number of clusters was determined by $T^2$ Hoteling (Brereton, 2015; MacGregor, 1994) and verified by Beale's F test, and then the dendrogram was drawn. The normality of data was controlled by Kolmogorov-Smirnov test with the SPSS V.22 software.

## RESULTS AND DISCUSSION

A significant difference was observed among the cultivars in their yields under salinity stress and normal conditions according to the ANOVA analysis (Table 3).

Under normal conditions, Mousa-Tarom and Hasan Saraie cultivars had the lowest grain yield with an average of 0.66 and 0.52 g/pot in grain yield, respectively (Table 4). Under stress and normal conditions, Lenjan Askari and Yasouj cultivars showed the highest grain yield. The comparison of means showed a significant difference between the cultivars concerning SSI, MP, TOL, STI, GMP, YSI, YI, and SI.

The best indices were identified by correlation analysis between grain yield and salinity tolerance indices under stress and normal conditions (Table 5). According to the results of correlation analysis, MP, GMP, and STI can be considered the most suitable indices for screening salinity-tolerant cultivars. Izaddoost et al. (2013), Gholizadeh et al. (2014), and Najaphy and Geravandi (2011) also reported a positive and significant correlation between the TOL and SSI indices. The correlations between MP, GMP, and STI were positive and significant in this research. Since the correlation of STI and MP and GMP was higher, the STI index is introduced to be more effective in distinguishing cultivars tolerant to salinity.

PCA results for grain yield under stress and normal conditions (Table 6) showed that among 12 components, only the first two components (see below) had eigenvalues greater than 1, and more than 99.39% of the variations are described by the first two components (Fig. 1). Grain yield under stress conditions and GMP, STI, and HM had the highest positive values (> 0.3) in the first component. The angle formed by these components with the axis of the first principal component was less than 90° (Fig. 1) which means that their correlations with the first component were positive. However, these values for SSI and YR were negatively high.

**Table 1.** Characteristic of the rice genotypes used in this study

| Genotype Code | Genotype name | Days to maturity | Height situation |
|---|---|---|---|
| 1 | Gharib | 130-145 | Semi dwarf |
| 2 | Yasouj | 150-160 | Tall |
| 3 | Loudab-Champa | 150-160 | Semi-dwarf |
| 4 | Loudab-Shahri | 150-160 | Dwarf |
| 5 | 304 | 130-145 | Dwarf |
| 6 | Askari-Lenjan | 150-160 | Tall |
| 7 | Kamfirouz | 150-160 | Tall |
| 8 | Mamassani-Domsiah | 170-180 | Tall |
| 9 | Mousa-Tarom | 170-180 | Tall |
| 10 | Hasan-Saraie | 170-180 | Tall |
| 11 | Dular | 170-180 | Semi dwarf |

**Table 2.** Salinity stress tolerance indices and their related equations

| Index Symbol | Title | Formula $^{\Psi}$ | Reference |
|---|---|---|---|
| TOL | Tolerance Index | TOL= $Y_P$-$Y_S$ | Rosielle and Hamblin (1981) |
| MP | Mean Productivity | MP=$(Y_P+Y_S)/2$ | Rosielle and Hamblin (1981) |
| GMP | Geometric Mean Productivity | GMP=$\sqrt{Yp \times Ys}$ | Fischer and Maurer (1978) |
| STI | Stress Tolerance Index | STI= $((Y_P)\times(Y_S))/\ \overline{(YP)}^2$ | Fernandez (1992) |
| SSI | Stress Susceptibility Index | SSI=(1-(Ys/Yp)) /SI | Fischer and Maurer (1978) |
| HM | Harmonic Mean | HM=$(2\times Y_P\times Y_S)/(Y_P+Y_S)$ | Fischer and Maurer (1978) |
| YI | Yield Index | YI=$Y_S/\overline{Ys}$ | Gavuzzi et al. (1997) |
| YSI | Yield Stability Index | YSI= $Y_S/Y_P$ | Bouslama and Schapaugh Jr (1984) |
| SI | Stress Intensity | SI=1-$(\overline{Ys}/\overline{Yp})$ | Fischer and Maurer (1978) |
| YR | yield reduction ratio | Yr=1-$(Y_S/Y_P)$ | Golestani Araghi and Assad (1998) |

$^{\Psi}$ Yp: yield under normal; Ys: yield under stress; $\overline{Y}_P$: the mean yield of all cultivars under normal; $\overline{Y}_S$: the mean yield of all cultivars under stress; and SI: stress intensity.

**Table 3.** ANOVA analysis data for the salt tolerance indices of the rice cultivars used in this study

| Salt Tolerance Indices | Mean Squares | | |
|---|---|---|---|
| | Block | Genotype | Error |
| Grain Yield Under Normal Condition (YP) | 0.105$^{ns}$ | 0.086$^{*}$ | 0.035 |
| Grain Yield Under Salinity Stress Condition (YS) | 0.014* | 0.010$^{*}$ | 0.004 |
| Tolerance Index (TOL) | 0.041$^{ns}$ | 0.0587$^{ns}$ | 0.037 |
| Stress Susceptibility Index (SSI) | 0.008$^{ns}$ | 0.012$^{ns}$ | 0.007 |
| Mean Productivity (MP) | 0.049$^{*}$ | 0.033$^{*}$ | 0.010 |
| Geometric Mean Productivity (GMP) | 0.043$^{**}$ | 0.028$^{**}$ | 0.007 |
| Stress Tolerance Index (STI) | 0.056$^{**}$ | 0.031$^{**}$ | 0.008 |
| Harmonic Mean (HM) | 0.034$^{*}$ | 0.024$^{*}$ | 0.007 |
| Yield Stability Index (YSI) | 0.005$^{ns}$ | 0.008$^{ns}$ | 0.005 |
| Yield Index (YI) | 0.648$^{*}$ | 0.472$^{*}$ | 0.168 |
| Yield Reduction Ratio (YR) | 0.005$^{ns}$ | 0.009$^{ns}$ | 0.005 |

*and **: significant at 5% and 1% probability levels, respectively, and ns: non- significant.

**Table 4.** The comparison of salinity tolerance indices of the rice genotypes using Duncan's Multiple Range Test (P<0.05)

| Genotype | YP (g/pot) | YS (g/pot) | TOL | SSI | MP | GMP | STI | HM | YSI | YI | YR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gharib | 0.86±0.19ab$^{*}$ | 0.127±0.06bcd | 0.74ab | 1.01ab | 0.50a-d | 0.32bc | 0.14bc | 0.21bcd | 0.16ab | 0.85bc | 0.84ab |
| Yasouj | 1.097±0.28a | 0.230±0.10ab | 0.87a | 0.95ab | 0.66a | 0.49a | 0.33a | 0.37ab | 0.22ab | 1.53ab | 0.78ab |
| Loudab-Champa | 0.867±0.20ab | 0.080±0.09d | 0.79a | 1.07a | 0.48a-d | 0.27c | 0.10c | 0.15cd | 0.10b | 0.55c | 0.90a |
| Loudab-Shahri | 1.04±0.26a | 0.180±0.08a-d | 0.86a | 0.98ab | 0.61abc | 0.43ab | 0.25abc | 0.30a-d | 0.18ab | 1.18abc | 0.82ab |
| 304 | 0.82±0.14abc | 0.133±0.10bcd | 0.67ab | 1.02ab | 0.48a-d | 0.32bc | 0.15bc | 0.22bcd | 0.16ab | 0.87bc | 0.84ab |
| Lenjan-Askari | 1.037±0.17a | 0.256±0.11a | 0.78ab | 0.91b | 0.65ab | 0.52a | 0.35a | 0.41a | 0.25a | 1.73a | 0.75b |
| Kamfirouz | 0.980±0.29ab | 0.197±0.01abc | 0.78ab | 0.98ab | 0.58abc | 0.42ab | 0.28ab | 0.32abc | 0.19ab | 1.32abc | 0.81ab |
| Domsiah | 0.830±0.46abc | 0.096±0.07cd | 0.74ab | 1.06ab | 0.45 a-d | 0.28bc | 0.11bc | 0.17cd | 0.12ab | 0.65c | 0.88ab |
| Mousa-Tarom | 0.663±0.45bc | 0.157±0.07a-d | 0.51ab | 0.92b | 0.41 cd | 0.32bc | 0.14bc | 0.25bcd | 0.14bc | 1.04abc | 0.76b |
| Hasan- Saraie | 0.523±0.39c | 0.113±0.02cd | 0.41b | 0.95ab | 0.32d | 0.24c | 0.08c | 0.19cd | 0.15ab | 0.76bc | 0.76b |
| Dular | 0.833±0.16abc | 0.083±0.03d | 0.76ab | 1.09a | 0.46bcd | 0.26c | 0.09c | 0.15d | 0.09b | 0.54c | 0.91a |

* In each column, means followed by at least a similar letter are not significantly different at 5% probability level. YP: grain yield under normal conditions; YS: grain yield under salinity stress; TOL: tolerance index; SSI: stress susceptibility index; MP: mean productivity; GMP: geometric mean productivity; STI: stress tolerance index, HM: harmonic mean; YSI: yield stability index; YI: yield index; and YR, yield reduction ratio.

**Table 5.** Correlation coefficients of salinity stress indices and grain yield

| | YP | YS | TOL | SSI | MP | GMP | STI | HM | YSI | YI | YR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| YP | 1 | | | | | | | | | | |
| YS | $0.56^{ns}$ | 1 | | | | | | | | | |
| TOL | $0.91^{**}$ | $0.17^{ns}$ | 1 | | | | | | | | |
| SSI | $-0.11^{ns}$ | $-0.87^{**}$ | $0.29^{ns}$ | 1 | | | | | | | |
| MP | $0.97^{**}$ | $0.74^{**}$ | $0.78^{**}$ | $-0.36^{ns}$ | 1 | | | | | | |
| GMP | $0.77^{**}$ | $0.95^{**}$ | $0.45^{ns}$ | $-0.70^{**}$ | $0.90^{**}$ | 1 | | | | | |
| STI | $0.81^{**}$ | $0.92^{**}$ | $0.52^{ns}$ | $-0.62^{*}$ | $0.92^{**}$ | $0.99^{**}$ | 1 | | | | |
| HM | $0.60^{*}$ | $0.99^{**}$ | $0.23^{ns}$ | $-0.84^{**}$ | $0.78^{**}$ | $0.97^{**}$ | $0.96^{**}$ | 1 | | | |
| YSI | $0.06^{ns}$ | $0.86^{**}$ | $-0.32^{ns}$ | $-0.99^{**}$ | $0.33^{ns}$ | $0.67^{*}$ | $0.59^{ns}$ | $0.83^{**}$ | 1 | | |
| YI | $0.55^{ns}$ | $0.99^{**}$ | $0.17^{ns}$ | $-0.88^{**}$ | $0.75^{**}$ | $0.95^{**}$ | $0.91^{**}$ | $0.99^{**}$ | $0.87^{**}$ | 1 | |
| YR | $-0.07^{ns}$ | $-0.86^{**}$ | $0.33^{ns}$ | $0.99^{**}$ | $-0.32^{ns}$ | $-0.67^{*}$ | $-0.6^{ns}$ | $-0.83^{**}$ | $-1.00^{**}$ | $-0.86^{**}$ | 1 |

*and **: significant at 5% and 1% probability levels, respectively, and ns: non- significant. YP: grain yield under normal conditions; YS: grain yield under salinity stress; TOL: tolerance index; SSI: stress susceptibility index; MP: mean productivity; GMP: geometric mean productivity; STI: stress tolerance index, HM: harmonic mean; YSI: yield stability index; YI: yield index; and YR, yield reduction ratio.

Therefore, a choice based on this component will select salinity tolerant cultivars. This component can be called the "salinity tolerance component". SSI, YR, TOL, and the grain yield under normal had the highest positive values when describing the second component, and this component can be called the "salinity sensitivity index". In other words, cultivars with lower values of this component will be more tolerant. Consequently, the biplot resulted from the first and second components concerning the highest values of the components, the cultivars Lenjan Askari, Kamfirouz, Yasouj, and Loudab Shahri are tolerant to salinity stress.

Based on the first and second components of the cultivar distribution, Lenjan Askari has the greatest tolerance to salinity stress. The cultivars Kamfirouz, Yasouj, and Loudab Shahri received the following ranks, respectively. Loudab Champa, Dular, and Mamasani Domsiah were sensitive to salinity, and Loudab Champa showed the highest sensitivity.

Sabouri et al. (2008) studied several local Iranian rice cultivars, including MusaTarom and Hasan Saraei. They introduced them as cultivars with a relatively high combining ability concerning tolerance to salinity. In a study on 49 rice cultivars, Safaei Chaeikar et al. (2018) used PCA and reported that two components describe more than 98 percent of the variance among the indices. They showed that the first component (yield potential and drought tolerance) had a high positive correlation with YS, YP, MP, GMP, HM, and STI, and the second component was positively correlated with DRI (drought response index) and RDI (relative drought index). Tiruneh et al. (2019) investigated genetic variation in 36 upland rice genotypes in southwestern Ethiopia. PCA results showed that the first six principal components represented 75.20 percent of the total variation, and the first and second components described 19.3 and 14.5 percent of the variation, respectively.

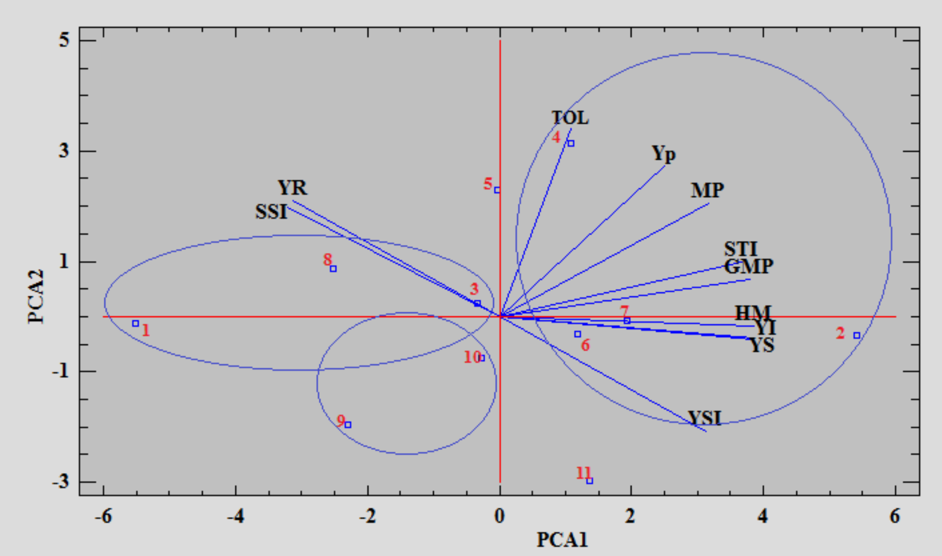


**Fig. 1.** Biplot of the first and second principal components "i. e. salinity tolerance component and salinity sensitivity index component, respectively" based on salinity indices for the genotypes. YP: grain yield under normal conditions; YS: grain yield under salinity stress; TOL: tolerance index; SSI: stress susceptibility index; MP: mean productivity; GMP: geometric mean productivity; STI: stress tolerance index, HM: harmonic mean; YSI: yield stability index; YI: yield index; and YR, yield reduction ratio. Genotypes were 1) Gharib, 2) Yasouj, 3) Loudab-Champa, 4) Loudab-Shahri, 5) 304, 6) Lenjan Askari, 7) Kamfirouz, 8) Mamassani-Domsiah, 9) Mousa-Tarom, 10) Hasan-Saraie, and 11) Dular.

**Table 6.** Results of principal component analysis based on grain yield and salinity stress tolerance indices.

| Salinity tolerance/susceptibility indices | First Component | Second Component |
|---|---|---|
| Grain Yield Under Normal Condition (YP) | 0.23 | 0.44 |
| Grain Yield Under Salinity Stress Condition (YS) | 0.35 | -0.06 |
| Tolerance Index (TOL) | 0.10 | 0.55 |
| Stress Susceptibility Index (SSI) | -0.29 | 0.32 |
| Mean Productivity (MP) | 0.29 | 0.23 |
| Geometric Mean Productivity (GMP) | 0.34 | 0.11 |
| Stress Tolerance Index (STI) | 0.34 | 0.16 |
| Harmonic Mean (HM) | 0.35 | -0.02 |
| Yield Stability Index (YSI) | 0.28 | -0.34 |
| Yield Index (YI) | 0.35 | -0.06 |
| Yield Reduction Ratio (YR) | -0.28 | -0.34 |
| Eigenvalue | 7.97 | 2.95 |
| Relative percentage of variance | 72.54 | 26.84 |
| Cumulative percentage of variance | 72.54 | 99.39 |

Regarding PCA results, it was suggested to use the salinity tolerance indices (Fernandez, 1992), and therefore yields under stress and in normal conditions were drawn as a 3-D graph based on the STI (Fig. 2). Lenjan Askari, Yasouj, Kamfirouz, and Loudab Shahri cultivars were located in region A. Lenjan Askari, Yasouj, Kamfirouz, and Loudab Shahri cultivars had the best stress tolerance scores under salinity stress conditions (Fig 2).

The results of PCA and stress tolerance score of this study were comparable to the corresponding results reported by Arzani and Ashraf (2016), Bahrami et al. (2021), Izaddoost et al. (2013), Mohammadi-Nejad et al. (2010), Abdolshahi et al. (2013), and Gholizadeh et al. (2014). Regarding the high genetic variations among the tested cultivars, it is possible to select high-yield cultivars under salinity stress conditions based on the biplot graph. PCA results and the stress tolerance score of this study indicated that cultivars Lenjan Askari, Yasouj, Kamfirouz, and Loudab Shahri had high yields under stress conditions and therefore could be chosen for further studies.

Finally, the cultivars were classified into three groups using a cluster analysis based on the indices evaluated under stress conditions and without stress by slicing the dendrogram (based on the $T^2$ hoteling and verification of Beale's F test) using Ward's method and the Euclidean distance of 16. The cultivars Yasouj, Lenjan Askari, and Kamfirouz, showed the highest tolerance to salinity and were classified in group A , according to the classification of Fernandez (1992) (Fig 3). Majidimehr and Khoshchehreh (2017) classified the rice genotypes into three classes using a cluster analysis by Ward's minimum variance at a Euclidean distance of 16. They reported Gharib and Hasan Saraie cultivars as suitable parents for plant height breeding. These results were confirmed by the biplot distribution diagram and the 3-D graph of yield (not shown) (Fernandez, 1992). In this study, the cultivars were different in terms of yield under stress and under normal circumstances. As a result, evaluating these cultivars based on salinity tolerance indices, particularly STS, STI, MP, and GMP, which have a significant positive correlation with one another, can lead to the selection of genotypes with high yields in both stress and normal conditions, as well as the development of genotypes with salinity adaptability. Ultimately, it could be said that Yasouj, Lenjan Askari, and Kamfirouz, cultivars are suitable parents to develop salinity–tolerant genotypes in breeding programs.

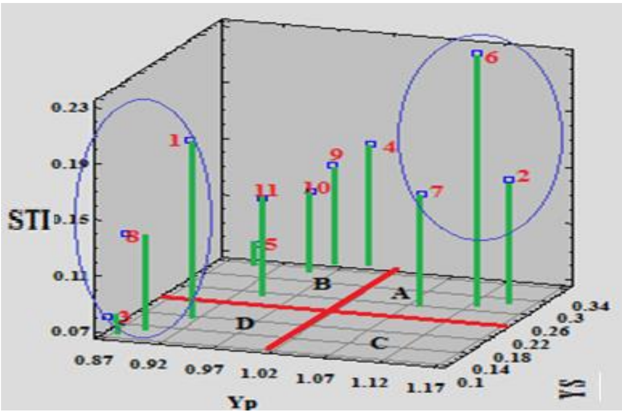


**Fig. 2.** Plotting the three-dimensional distribution of the tested rice genotypes for salinity in this study. YP: grain yield under normal conditions; YS: grain yield under salinity stress; TOL: tolerance index; SSI: stress susceptibility index; MP: mean productivity; GMP: geometric mean productivity; STI: stress tolerance index, HM: harmonic mean; YSI: yield stability index; YI: yield index; and YR, yield reduction ratio. Genotypes were 1) Gharib, 2) Yasouj, 3) Loudab-Champa, 4) Loudab-Shahri, 5) 304, 6) Lenjan Askari, 7) Kamfirouz, 8) Mamassani-Domsiah, 9) Mousa-Tarom, 10) Hasan-Saraie, and 11) Dular.

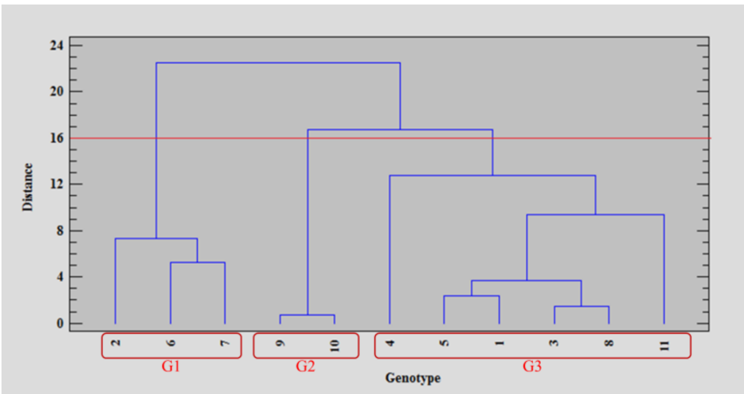


**Fig 3.** The dendrogram obtained from the cluster analysis based on Euclidean distance and salinity indices for 11 rice cultivars tested in this study. Genotypes were 1) Gharib, 2) Yasouj), 3) Loudab-Champa, 4) Loudab-Shahri, 5) 304, 6) Lenjan Askari, 7) Kamfirouz, 8) Mamassani-Domsiah, 9) Mousa-Tarom, 10) Hasan-Saraie, and 11) Dular. G1, G2, and G3 are groups that can be deduced and selected based on this dendrogram.

## CONCLUSIONS

Under stress and normal conditions used in the current study, Lenjan Askari and Yasouj cultivars showed the highest grain yield, and, Mousa-Tarom and Hasan Saraie cultivars had the lowest grain yield under normal conditions. The cultivar Lenjan Askari showed the greatest tolerance to salinity stress. The cultivars Kamfirouz, Yasouj, and Loudab Shahri received the next ranks in terms of salinity tolerance, respectively. Loudab Champa, Dular, and Mamasani Domsiah were sensitive to salinity, and Loudab Champa showed the highest sensitivity. As a result, evaluating these cultivars based on salinity tolerance indices, particularly STS, STI, MP, and GMP, which have a significant positive correlation with one another, can lead to the selection of genotypes with high yields in both stress and normal conditions, as well as the development of genotypes with salinity adaptability. The STI index is introduced to be more effective in distinguishing cultivars tolerant to salinity. Ultimately, it could be said that Yasouj, Lenjan Askari, and Kamfirouz, cultivars are suitable parents to develop salinity–tolerant genotypes in breeding programs.

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**مقاله علمی- پژوهشی**

# شاخص‌های مرتبط با تحمل شوری جهت غربال‌گری ارقام برنج (*Oryza sativa* L.)

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**واژه‌های کلیدی:**

تجزیه به مؤلفه‌های اصلی

شاخص‌های تحمل تنش

شوری

عملکرد دانه

**چکیده** - برنج (*Oryza sativa* L.) غذای اصلی بیش از نیمی از مردم جهان است. شوری یکی از مهمترین عوامل محدود کننده عملکرد برنج است. یازده رقم برنج در آزمایشی در قالب طرح بلوک‌های کامل تصادفی با سه تکرار در شرایط تنش شوری و نرمال بررسی شدند. شاخص‌های تحمل و حساسیت به تنش شامل میانگین تولید (MP)، میانگین هندسی تولید (GMP)، شاخص تحمل به تنش (STI)، شاخص عملکرد (YI)، شاخص پایداری عملکرد، میانگین هارمونیک (HM)، شاخص حساسیت به تنش، شاخص تحمل و نرخ کاهش عملکرد، و تجزیه به مؤلفه‌های اصلی جهت ارزیابی تنوع و واکنش ارقام برنج تحت تنش شوری و شناسایی ارقام متحمل استفاده شدند. تنوع معنی‌داری بین ارقام از لحاظ عملکرد دانه و شاخص‌های تنش دیده شد. تجزیه به مؤلفه‌های اصلی بر اساس عملکرد دانه و نمره تحمل به تنش، دو مؤلفه اصلی شامل مؤلفه های " جزء تحمل شوری" و " جزء شاخص حساسیت به شوری" با مقادیر ویژه بزرگ‌تر از یک را شناسایی کرد که ۹۹/۳۹ درصد از کل تغییرات ژنوتیپ‌ها را توجیه کردند. MP، GMP و STI می‌توانند به عنوان بهترین شاخص‌ها برای گزینش ارقام برنج مقاوم به شوری در نظر گرفته شوند. نتایج تجزیه خوشه‌ای و پراکنش ارقام مطالعه شده بر اساس نمودار بای پلات حاصل از عملکرد دانه و شاخص‌های تحمل به تنش، ارقام لنجان عسکری، یاسوج، و کامفیروز به عنوان ارقام متحمل و ارقام چمپای لوداب، غریب و دم‌سیاه ممسنی به عنوان ارقام حساس معرفی کرد. ارقام متحمل می‌توانند در برنامه‌های به‌نژادی جهت اصلاح تحمل به شوری برنج مورد استفاده قرار گیرند.