UDC 575.633.11
https://doi.org/10.2298/GENSR2201379F
*Original scientific article*

# EVALUATION OF GRAIN YIELD OF WHEAT GENOTYPES USING STRESS TOLERANCE INDICES

Aref FATEHI[1], Esmail BABARASHI[1], Shahram MEHRI[2*], Mehdi SALAJEGHEH[3]

[1]Department of Agronomy and Plant Breeding, Islamic Azad University, Sanandaj Branch, Iran
[2]Department of Agronomy and Plant Breeding, Pars Abad Moghan Branch, Islamic Azad University, Pars Abad Moghan, Iran
[3]Department of Agronomy, Islamic Azad University, Bam Branch, Iran

Fatehi A., E. Babarashi, S. Mehri, M. Salajegheh (2022). *Evaluation of grain yield of wheat genotypes using stress tolerance indices* - Genetika, Vol 54, No.1, 379-394.

Drought has unfavorable impacts on the success of agriculture in many parts of the world. Providing future populations with enough food would obviously require the evaluation of crop yield, higher potentials, and the provision of yield stability in drought-affected regions. In this research, the drought-tolerance of wheat genotypes was studied in a randomized complete block design and in a three-replication experiment under normal and drought stress conditions. In two consecutive growing seasons, the measurements were aimed at evaluating the stress susceptibility index (SSI), drought tolerance index (TOL), mean productivity (MP, stress tolerance index (STI, harmonic mean (HARM), yield index (YI, and genomic mean productivity (GMP). These parameters described the yields of different genotypes for two years and under both normal and stress conditions. The combined analysis of variance showed that the environment significantly affected grain yield. The mean values of parameters by the drought stress condition were less than those of the non-stress condition. Stress intensity (SI) was 46% and 43% in the first and second year, respectively. In both years, MP, GMP, STI and HARM indices correlated significantly with grain yield under stress and normal conditions. Based on a three-dimensional diagram of these indices, the pishgam and ws-82-9 genotypes were considered as most superior in the first year (both conditions).. Furthermore, the pishgam, alvand, and ohadi genotypes were considered as superior in the second year. According to the bi-plot diagram and based on the first two major components, these genotypes were more tolerant to drought stress. In general, it is suggested that the pishgam shows a higher level of yield sustainability. It was found to be the genotype with the highest yield under both normal and stress conditions. Its grain yield and resistance indices have increased during 80 years of breeding and selection.

*Keywords*: Biplot,Grain yield, Drought tolerance, Indices, Genotype

---

*Corresponding authors:* Shahram Mehri, Department of Agronomy and Plant Breeding, Pars Abad Moghan Branch, Islamic Azad University, Pars Abad Moghan, Iran. E-mail: sh.mehri2000@gmail.com & sh.mehri@iaupmogan.ac.ir

Abbreviations: GMP: Geometric Mean Productivity; HARM: Harmonic Mean Productivity; MP: Mean productivity; SSI: Stress susceptibility index; STI: Stress Tolerance Index; TOL: Tolerance; YI: Yield Index; Yp: Yields under normal conditions; Ys: Yields under stress conditions; YSI: Yield Stability Index.

## INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is an important crop worldwide. It is cultivated on about 217 million hectares in a range of environments, with an annual production of about 750 million tons (FAO, 2019). According to the UN-FAO, agricultural production must increase by 50% by 2050 to meet global demand for food. This goal can be accomplished, in part, by the development of improved cultivars coupled with modern best management practices. Overall, wheat production on farms will have to increase significantly to meet future demand, and in the face of a changing climate that poses risk to even current rates of production (BERES et al., 2020).

Drought can be described as the presence of inadequate amounts of water which can mainly lead to the decrease in plant production (BLUM, 2010). Drought stress is a problem that affects 45% of the world’s geographic area and is a major constraint in wheat production. It is the most important cause of yield reduction in semiarid regions (ALI *et al.*, 2011).

Parallel to global warming, droughts are bound to intensify, thereby increasing the rate of evapotranspiration from plants which, in turn, can have adverse effects on the fertility of agronomic crops in the future (SHARAFI *et al.*, 2014; VOLTAS *et al.*, 2005). past temperature trends show that wheat yield has declined by −5.5% for the period from 1980 to 2010 due to 0.13°C decadal temperature increase (LOBELL *et al.*, 2011). Rising global temperatures, rainfall changes, and extremes in the future are projected to further affect wheat production by mid and end of century (IPCC, 2014; ASSENG *et al.*, 2015). estimated that wheat production is projected to decline by −6% per °C of further global warming. Mid and high latitudes are less affected and may benefit from a warming of 1°C–3°C, while low latitudes close to the Equator are projected to be more affected due to already supra-optimum temperature in those areas (Xiong *et al.*, 2019).

Understanding the responses of plants in dry environments is of great importance and is a fundamental part of producing stress-tolerant crops (ZHAO *et al.*, 2008). However, crop improvement in the face of water stress is a much-complicated task, as drought damage is manifested in various forms at various stages of crop growth. This makes breeding for drought resistance difficult (BLUM, 2005; FUKAI and FISCHER, 2012). Also HABUŠ-JERČIĆ *et al.* (2018) believed that the most evastating environmental stress to wheat production is terminal drought i.e. drought during grain-filling phase. Therefore, breeding for drought resistance must integrate all methods that enable genotype evaluation and selection at all stages of the crop, instead of giving an exclusive focus to the final stage (QU *et al.*, 2008).

Researchers can take advantage of selecting indices that can assist in identifying high-yield genotypes under both stress and non-stress conditions (KAKAEI *et al.*, 2010). The selection of stable genotypes can occur by making use of drought indices that are monitored through plant performance in normal and stress conditions (FARSHADFAR *et al.*, 2013; MOOSAVI *et al.*, 2007; MURSALOVA *et al.*, 2015). To examine and select the best genotypes under each condition, various indices have been introduced. The effectiveness of each index is dependent on the breeding purposes and the target environment. Therefore, evaluating the genotypes under both normal and stress conditions has attracted much research interest. Such evaluations can be used for estimating the stability of yield (BIHAMTA *et al*., 2018). The competency of indices relies on time and the severity of stress in environments that are susceptible to drought stress. The production of higher yields can be achieved through measurements that gauge plant tolerance to drought, especially for breeding superior genotypes in arid and semi-arid areas. Those indices that are effective in selecting stable genotypes for higher yields under stress conditions ought to be identified and used as the criteria involved in the selection process *(BIHAMTA et al*., 2018).

Different indices have been utilized to evaluate the degree of plant tolerance to abiotic stresses. In this regard, the Stress Susceptibility Index (SSI) was introduced by Fischer and Maurer in 1978 . Smaller degrees of SSI indicate more degrees of tolerance to drought. Different indices, including tolerance (TOL), mean productivity (MP), geometric mean productivity (GMP), stress tolerance index (STI), stress susceptibility index (SSI), harmonic mean (HAM), yield index (YI), and yield stability index (YSI) have been employed for screening the stress tolerant genotypes (SANGI *et al*., 2022).

These two indices were introduced by Fernandez in 1992. The harmonic index consists of mean harmonic yield in normal and stress conditions (FERNANDEZ, 1992). The Yield Index (YI is not an appropriate measure to select group A genotypes. However, it correlates with the yield of genotypes under stress conditions (SANGI *et al*., 2022). Yield Stability Index (YSI) is considered as an appropriate index to study the response of genotypes to shortages in water. Genotypes with higher YSI showed minimum amounts of reduction in their yield under stress conditions SANGI *et al*. (2022).

Similar such studies have been carried out across the globe in recent years (BERES *et al*., 2020). However, the results should be consistent with the particular conditions of regions or countries. A trait in a certain region might have a positive impact on grain yield, while such a result might not apply to another region. For this reason, in most countries (and even in different regions of a country), research is often aimed at finding the relations between different traits. Thus, the aim of this study was to evaluate and determine the superior wheat genotypes in terms of grain yield using drought tolerance indices.

## MATERIALS AND METHODS

### *Plant material and site of experiments*

In the current study, 31 bread wheat genotypes were studied. These were released from 1930 to 2011 (Table 1). The genotypes were obtained from the Department of Seed and Plant Improvement, Kermanshah Agriculture and Natural Resources Research Centre, Kermanshah, Iran. The experiments spanned through the growing seasons of 2017–2018 and 2018–2019 at Sanandaj Research Station of Agriculture and Natural Resources, Kurdistan, Iran. The field was characterized by a clay-loam soil with an average organic matter content of 2.02% and a water pH 7.42. The region receives an average 300 mm of rain each year. The experimental design was a randomized complete block with three replications. Each experimental plot with an area of 7.2 square meters consisted of five lines and the length of each line was four meters. Seedling density was 400 seeds/m2. After harvesting, the grain yield for every experimental unit was measured (per square meter). Measurements also included biomass (per square meter), the harvest index, the 1000-grain weight, and the grain number per spike.

*Table 1. Names and codes of the genotypes*

| | Genotype | Year of release | Origin |
|---|---|---|---|
| 1 | Shahryar | 2002 | Iran |
| 2 | Zarin | 1995 | CIMMYT |
| 3 | Sivand | 2009 | Iran |
| 4 | Kavir | 1997 | Iran |
| 5 | Sabalan | 1981 | Iran |
| 6 | Chamran | 1997 | CIMMYT |
| 7 | WS-82-9 | - | Iran |
| 8 | Marvdasht | 1999 | Iran |
| 9 | Rijaw | 2011 | Iran |
| 10 | Heirmand | 1991 | Iran |
| 11 | Azar-2 | 1999 | Iran |
| 12 | Rasad | 1989 | Iran |
| 13 | Homa-4 | 2010 | Iran |
| 14 | Bezostaya | 1969 | Russia |
| 15 | Kaveh | 1980 | CIMMYT |
| 16 | Ohadi | 2009 | Iran |
| 17 | Sardari | 1930 | Iran |
| 18 | Pishtaz | 2002 | Iran |
| 19 | Golestan | 1986 | CIMMYT |
| 20 | Parsi | 2009 | Iran |
| 21 | Shahpasand | 1942 | Iran |
| 22 | Alvand | 1995 | Iran |
| 23 | Roshan | 1958 | Iran |
| 24 | Mughan-1 | 1973 | CIMMYT |
| 25 | Soisson | 1994 | ------- |
| 26 | Gaspard | 1994 | France |
| 27 | Niknejad | 1995 | ICARDA |
| 28 | Gascogne | 1994 | ------- |
| 29 | DN-11 | - | Iran |
| 30 | MV-17 | 1993 | Hungary |
| 31 | Pishgam | 2008 | Iran |

*Estimation of drought tolerance indices*

Drought tolerance indices for each genotype were calculated using the following formulas:

$$SI = 1 - \left[ \frac{\bar{Y}s}{\bar{Y}p} \right] \quad SSI = \frac{1-(Ys/Yp)}{SI}$$

(FISCHER and MAURER, 1978)

$$\mathrm{STI} = \left( \frac{\mathrm{Yp}}{\bar{\mathrm{Y}}\mathrm{p}} \right) \left( \frac{\mathrm{Ys}}{\bar{\mathrm{Y}}\mathrm{s}} \right) \left( \frac{\bar{\mathrm{Y}}\mathrm{s}}{\bar{\mathrm{Y}}\mathrm{p}} \right) = \frac{(\mathrm{Yp})(\mathrm{Ys})}{(\bar{\mathrm{Y}}\mathrm{p})^2}$$

(FERNANDEZ, 1992)

$$MP = \frac{Ys + Yp}{2}$$ (HOSSAIN *et al.*, 1990)

$$GMP = \sqrt{(Ys \times Yp)}$$ (FERNANDEZ, 1992)

$$HAM = \frac{2(Ys)(Yp)}{(Ys + Yp)}$$ (FERNANDEZ, 1992)

$TOL = Yp - Ys$ (HOSSAIN *et al.*, 1990)

$$YI = \frac{Ys}{\bar{Y}s}$$ (GAVUZZI *et al.*, 1997)

$$YSI = \frac{Ys}{Yp}$$ (BOUSLAMA and SCHAPAUGH, 1984)

Where Ys is the grain yield of each genotype under drought stressed condition, Yp is the grain yield of each genotype under non-stressed condition, $\bar{Y}s$ and $\bar{Y}p$ are the mean yields of all genotypes under drought stressed and non-stressed conditions, respectively.

*Statistical analysis*

The SAS version 9.3 package was used for determining the analysis of variance, mean comparison, correlation between different treatments and cluster analysis of genotypes based on the Euclidean distance. The 3D plot and the bi-plot display were also used for identifying tolerant and high yielding genotypes using STATISTICA 10 software. The bi-plot display was based on principal component analysis (BIHAMAT *et al*., 2018).

## RESULTS AND DISCUSSION

*Combined ANOVA and genotypic mean yields*

The results of combined variance of analysis for two years (Table 2) showed that the environment significantly affected all traits. There was a significant difference among genotypes, and the interaction between genotypes and the environment showed a significant difference. The mean values of grain yield under drought stress conditions in the first and second year were 43% and 46% less than the yield under normal conditions. To evaluate the response of genotypes to drought stress, the values of grain yield under normal and stress conditions were used for measuring TOL and SSI accordingly (Table 3). In the first year, the average of genotypic yield under favorable conditions was 379.04 g/m$^2$ and the 18 genotypes which had higher yields than average, under normal conditions, were regarded as high-potential yield genotypes. Meanwhile, the remaining 13 genotypes were considered to have low-potential yields. In the former group, genotypes 3, 7, 13, 19, 20, 23, 27, 29 and 31 had higher than average yields under drought stress conditions.

*Table 2. Mean square from combined of variance of 31 wheat genotypes for grain yield*

| Source of Variation | df | Mean square | |
|---|---|---|---|
| | | First year | Second year |
| Environment (E) | 1 | 1368698** | 1043117** |
| Error (R/P) | 4 | 3034.81 | 722.69 |
| Genotype (G) | 30 | 72802** | 8599** |
| Environment * Genotype | 30 | 30698** | 3188** |
| Error (R*G/E) | 120 | 545.51 | 300.468 |
| CV (%) | - | 6.85 | 6.35 |

* and **: significant at 5 and 1% probability levels, respectively

*Table 3. Mean grain yield under drought stress (Ys) and normal conditions (Yp) with eight stress indices. First year (2017-2018)*

| Nu. | Genotypes | YP ($g/m^2$) | YS ($g/m^2$) | SSI | TOL ($g/m^2$) | MP ($g/m^2$) | GMP ($g/m^2$) | HARM | YI | YSI | STI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Shahryar | 408.65 | 194.33 | 1.12 | 214.32 | 301.49 | 281.80 | 263.40 | 0.98 | 0.48 | 1.15 |
| 2 | Zarin | 422.35 | 197.03 | 1.14 | 225.32 | 309.69 | 288.47 | 268.71 | 1.00 | 0.47 | 1.21 |
| 3 | Sivand | 411.44 | 242.15 | 0.88 | 169.29 | 326.80 | 315.64 | 304.87 | 1.22 | 0.59 | 1.45 |
| 4 | Kavir | 422 | 196.33 | 1.14 | 225.67 | 309.17 | 287.84 | 267.98 | 0.99 | 0.47 | 1.20 |
| 5 | Sabalan | 362.67 | 207.5 | 0.91 | 155.17 | 285.09 | 274.32 | 263.97 | 1.05 | 0.57 | 1.09 |
| 6 | Chamran | 415.67 | 180.28 | 1.21 | 235.39 | 297.98 | 273.75 | 251.49 | 0.91 | 0.43 | 1.09 |
| 7 | WS-82-9 | 457.01 | 299.33 | 0.74 | 157.68 | 378.17 | 369.86 | 361.73 | 1.51 | 0.65 | 1.99 |
| 8 | Marvdasht | 275.67 | 260.7 | 0.12 | 14.97 | 268.19 | 268.08 | 267.98 | 1.32 | 0.95 | 1.05 |
| 9 | Rijaw | 351.24 | 167.97 | 1.11 | 183.27 | 259.61 | 242.89 | 227.26 | 0.85 | 0.48 | 0.86 |
| 10 | Heirmand | 292.64 | 190.51 | 0.75 | 102.13 | 241.58 | 236.12 | 230.78 | 0.96 | 0.65 | 0.81 |
| 11 | Azar-2 | 395.65 | 158.2 | 1.28 | 237.45 | 276.93 | 250.18 | 226.02 | 0.80 | 0.40 | 0.91 |
| 12 | Rasad | 402.68 | 150.57 | 1.34 | 252.11 | 276.63 | 246.23 | 219.18 | 0.76 | 0.37 | 0.88 |
| 13 | Homa-4 | 379.84 | 216.32 | 0.92 | 163.52 | 298.08 | 286.65 | 275.65 | 1.09 | 0.57 | 1.19 |
| 14 | Bezostaya | 424.39 | 194.62 | 1.16 | 229.77 | 309.51 | 287.39 | 266.86 | 0.98 | 0.46 | 1.20 |
| 15 | Kaveh | 345.1 | 209.34 | 0.84 | 135.76 | 277.22 | 268.78 | 260.60 | 1.06 | 0.61 | 1.05 |
| 16 | Ohadi | 378.62 | 238.15 | 0.79 | 140.47 | 308.39 | 300.28 | 292.39 | 1.20 | 0.63 | 1.31 |
| 17 | Sardari | 374.29 | 134.21 | 1.37 | 240.08 | 254.25 | 224.13 | 197.58 | 0.68 | 0.36 | 0.73 |
| 18 | Pishtaz | 378.48 | 117.24 | 1.47 | 261.24 | 247.86 | 210.65 | 179.02 | 0.59 | 0.31 | 0.65 |
| 19 | Golestan | 408.65 | 212.24 | 1.03 | 196.41 | 310.45 | 294.50 | 279.38 | 1.07 | 0.52 | 1.26 |
| 20 | Parsi | 425.36 | 231.25 | 0.98 | 194.11 | 328.31 | 313.63 | 299.61 | 1.17 | 0.54 | 1.43 |
| 21 | Shahpasand | 329.67 | 192.32 | 0.89 | 137.35 | 261.00 | 251.80 | 242.92 | 0.97 | 0.58 | 0.92 |
| 22 | Alvand | 380.66 | 165.47 | 1.21 | 215.19 | 273.07 | 250.97 | 230.67 | 0.84 | 0.43 | 0.92 |
| 23 | Roshan | 382.46 | 202.12 | 1.01 | 180.34 | 292.29 | 278.03 | 264.47 | 1.02 | 0.53 | 1.12 |
| 24 | Mughan-1 | 365.25 | 150.67 | 1.26 | 214.58 | 257.96 | 234.59 | 213.34 | 0.76 | 0.41 | 0.80 |
| 25 | Soisson | 200.3 | 140.68 | 0.64 | 59.62 | 170.49 | 167.86 | 165.28 | 0.71 | 0.70 | 0.41 |
| 26 | Gaspard | 350.3 | 242.7 | 0.66 | 107.60 | 296.50 | 291.58 | 286.74 | 1.23 | 0.69 | 1.24 |
| 27 | Niknejad | 420.25 | 215.32 | 1.04 | 204.93 | 317.79 | 300.81 | 284.75 | 1.09 | 0.51 | 1.32 |
| 28 | Gascogne | 313.66 | 180.36 | 0.91 | 133.30 | 247.01 | 237.85 | 229.03 | 0.91 | 0.58 | 0.82 |
| 29 | DN-11 | 381.33 | 240.32 | 0.79 | 141.01 | 310.83 | 302.72 | 294.83 | 1.21 | 0.63 | 1.33 |
| 30 | MV-17 | 413.67 | 155.07 | 1.34 | 258.60 | 284.37 | 253.27 | 225.58 | 0.78 | 0.37 | 0.93 |
| 31 | Pishgam | 480.32 | 368.24 | 0.50 | 112.08 | 424.28 | 420.56 | 416.88 | 1.86 | 0.77 | 2.57 |
| | Mean | 379.04 | 201.66 | 0.98 | 177.38 | 290.35 | 274.56 | 259.97 | 1.02 | 0.54 | 1.13 |
| | Max | 480.32 | 368.24 | 1.47 | 261.24 | 424.28 | 420.56 | 416.88 | 1.86 | 0.95 | 2.57 |
| | Min | 200.30 | 117.24 | 0.12 | 14.97 | 170.49 | 167.86 | 165.28 | 0.59 | 0.31 | 0.41 |
| | LSD 0.05 | | | - | - | - | - | - | - | - | - |

These were considered as drought tolerant genotypes with high-yield potential. Genotypes 1, 2, 4, 6, 11, 12, 14, 22 and 30 were identified not only as the ones with high yield potential, but also as genotypes that are susceptible to drought. On the other hand, the remaining 13 genotypes performed below-average yield under optimal conditions, and were grouped as genotypes with low-yield potential. In the latter group, genotypes 5, 8, 15, 16 and 26 showed grain yields that were higher than average, under stress condition. These were considered as low-yield genotypes, but tolerant to drought. The other 8 genotypes were not only lower yielding in potential but were also susceptible to drought.

*Table 4. Mean grain yield under drought stress (Ys) and normal conditions (Yp) with eight stress indices. Second year (2018-2019)*

| Nu. | Genotypes | YP ($g/m^2$) | YS ($g/m^2$) | SSI | TOL ($g/m^2$) | MP ($g/m^2$) | GMP ($g/m^2$) | HARM | YI | YSI | STI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Shahryar | 329.33 | 171.67 | 1.11 | 157.67 | 250.50 | 237.77 | 225.69 | 0.87 | 0.52 | 0.82 |
| 2 | Zarin | 383.50 | 203.33 | 1.09 | 180.17 | 293.42 | 279.25 | 265.76 | 1.03 | 0.53 | 1.13 |
| 3 | Sivand | 439.83 | 213.33 | 1.20 | 226.50 | 326.58 | 306.32 | 287.31 | 1.08 | 0.49 | 1.36 |
| 4 | Kavir | 364.00 | 196.67 | 1.07 | 167.33 | 280.33 | 267.56 | 255.36 | 0.99 | 0.54 | 1.04 |
| 5 | Sabalan | 293.37 | 224.00 | 0.55 | 69.37 | 258.68 | 256.35 | 254.03 | 1.13 | 0.76 | 0.96 |
| 6 | Chamran | 448.50 | 218.33 | 1.19 | 230.17 | 333.42 | 312.93 | 293.69 | 1.10 | 0.49 | 1.42 |
| 7 | WS-82-9 | 421.20 | 226.67 | 1.07 | 194.53 | 323.93 | 308.99 | 294.73 | 1.15 | 0.54 | 1.39 |
| 8 | Marvdasht | 376.13 | 216.33 | 0.99 | 159.80 | 296.23 | 285.25 | 274.68 | 1.09 | 0.58 | 1.18 |
| 9 | Rijaw | 328.03 | 203.33 | 0.88 | 124.70 | 265.68 | 258.26 | 251.05 | 1.03 | 0.62 | 0.97 |
| 10 | Heirmand | 232.70 | 161.67 | 0.71 | 71.03 | 197.18 | 193.96 | 190.79 | 0.82 | 0.69 | 0.55 |
| 11 | Azar-2 | 354.03 | 185.00 | 1.11 | 169.03 | 269.52 | 255.92 | 243.01 | 0.94 | 0.52 | 0.95 |
| 12 | Rasad | 329.33 | 168.67 | 1.13 | 160.67 | 249.00 | 235.69 | 223.08 | 0.85 | 0.51 | 0.81 |
| 13 | Homa-4 | 350.13 | 190.67 | 1.06 | 159.47 | 270.40 | 258.38 | 246.89 | 0.96 | 0.54 | 0.97 |
| 14 | Bezostaya | 434.20 | 170.67 | 1.41 | 263.53 | 302.43 | 272.22 | 245.02 | 0.86 | 0.39 | 1.08 |
| 15 | Kaveh | 294.67 | 193.33 | 0.80 | 101.33 | 244.00 | 238.68 | 233.48 | 0.98 | 0.66 | 0.83 |
| 16 | Ohadi | 357.50 | 260.33 | 0.63 | 97.17 | 308.92 | 305.07 | 301.28 | 1.32 | 0.73 | 1.35 |
| 17 | Sardari | 293.37 | 185.00 | 0.86 | 108.37 | 239.18 | 232.97 | 226.91 | 0.94 | 0.63 | 0.79 |
| 18 | Pishtaz | 384.80 | 195.00 | 1.14 | 189.80 | 289.90 | 273.93 | 258.83 | 0.99 | 0.51 | 1.09 |
| 19 | Golestan | 314.60 | 181.67 | 0.98 | 132.93 | 248.13 | 239.07 | 230.33 | 0.92 | 0.58 | 0.83 |
| 20 | Parsi | 366.17 | 196.67 | 1.07 | 169.50 | 281.42 | 268.35 | 255.89 | 0.99 | 0.54 | 1.05 |
| 21 | Shahpasand | 271.70 | 171.67 | 0.85 | 100.03 | 221.68 | 215.97 | 210.40 | 0.87 | 0.63 | 0.68 |
| 22 | Alvand | 436.37 | 235.00 | 1.07 | 201.37 | 335.68 | 320.23 | 305.48 | 1.19 | 0.54 | 1.49 |
| 23 | Roshan | 330.20 | 227.67 | 0.72 | 102.53 | 278.93 | 274.18 | 269.51 | 1.15 | 0.69 | 1.09 |
| 24 | Mughan-1 | 292.50 | 177.67 | 0.91 | 114.83 | 235.08 | 227.96 | 221.06 | 0.90 | 0.61 | 0.76 |
| 25 | Soisson | 335.83 | 180.67 | 1.07 | 155.17 | 258.25 | 246.32 | 234.94 | 0.91 | 0.54 | 0.88 |
| 26 | Gaspard | 306.37 | 176.67 | 0.98 | 129.70 | 241.52 | 232.65 | 224.10 | 0.89 | 0.58 | 0.79 |
| 27 | Niknejad | 325.87 | 183.67 | 1.01 | 142.20 | 254.77 | 244.64 | 234.92 | 0.93 | 0.56 | 0.87 |
| 28 | Gascogne | 299.87 | 165.00 | 1.04 | 134.87 | 232.43 | 222.44 | 212.87 | 0.83 | 0.55 | 0.72 |
| 29 | DN-11 | 355.33 | 191.67 | 1.07 | 163.67 | 273.50 | 260.97 | 249.01 | 0.97 | 0.54 | 0.99 |
| 30 | MV-17 | 314.60 | 150.00 | 1.21 | 164.60 | 232.30 | 217.23 | 203.14 | 0.76 | 0.48 | 0.69 |
| 31 | Pishgam | 411.67 | 310.67 | 0.57 | 101.00 | 361.17 | 357.62 | 354.11 | 1.57 | 0.75 | 1.86 |
|  | Mean | 347.60 | 197.83 | 0.85 | 0.99 | 272.72 | 261.52 | 250.88 | 1.00 | 0.58 | 1.01 |
|  | Max | 448.5 | 310.67 | 1.21 | 263.53 | 361.17 | 357.62 | 354.11 | 1.57 | 0.76 | 1.86 |
|  | Min | 232.7 | 150 | 0.41 | 69.37 | 197.18 | 193.96 | 190.79 | 0.76 | 0.39 | 0.55 |
|  | LSD 0.05 | 32.77 | 23.00 | - | - | - | - | - | - | - | - |

In the second year, the average of genotype yield under favorable conditions was 347.60 $g/m^2$ (Table 4). There were 15 genotypes which produced yields higher than average in normal conditions. These were regarded as high potential yield genotypes, while the rest (16 genotypes) were considered as low-potential yield. In the former group, genotypes 2, 3, 6, 7, 8, 16, 22 and 31 showed yields higher than average under drought stress conditions, compared to genotypes that were high-yield potential and drought tolerant. Genotypes 4, 11, 13, 14, 18, 20 and 29 were identified not only as the ones with high yield potential, but as susceptible to drought. On the other hand, the remaining 16 genotypes, in optimal conditions, produced below-average yield. In the latter group, genotypes 5, 9 and 23 had yields higher than average under the stress condition, thereby grouping them as low-yield potential but tolerant to drought. The other 13 genotypes were not only low-yield in potential but were also susceptible to drought. This classification of genotypes was based on grain yield under normal and stress conditions, along with the measure of all indices pertaining to drought resistance and susceptibility. Also, three-dimensional scatter plots proved the authenticity of this classification, as will be explained in the following sections.

### *Correlation analysis*

The trend of changes in indices was better understood by calculating the Pearson correlation coefficient and by monitoring the changes in the yield of genotypes under stress and non-stress conditions. Under non stress conditions, the grain yield showed positive significant correlations with the grain yield under drought stress conditions in both years. The correlation between yields under drought stress conditions with the SSI index was negative in both years. Meanwhile, the MP, GMP, HARM, YI and STI indices showed positive significant correlations with each other and with the grain yield ($P \leq 0.01$) under both conditions in both years. Repeatable correlations were found between MP, GMP, HARM, YI and STI for two years. The relationships between indices can be supported by the correlation coefficient analysis (Table 5).

*Table 5. Correlation coefficients between grain yield under normal and drought stress conditions and among various indices.*

| | | YP | YS | SSI | TOL | MP | GMP | HARM | YI | YSI | STI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YP | | **1** | 0.37* | 0.37* | 0.62** | 0.84** | 0.72** | 0.60** | 0.37* | -0.37* | 0.68** | |
| YS | | 0.52** | **1** | -0.72** | -0.51** | 0.81** | 0.91** | 0.96** | 1.00** | 0.72** | 0.92** | |
| SSI | | 0.45* | -0.50** | **1** | 0.95** | -0.18 | -0.36* | -0.50** | -0.72** | -1.00** | -0.39* | |
| TOL | 2018-2019 | 0.80** | -0.09 | 0.87** | **1** | 0.10 | -0.10 | -0.25 | -0.51** | -0.95** | -0.14 | 2017-2018 |
| MP | | 0.93** | 0.80** | 0.10 | 0.53** | **1** | 0.98** | 0.93** | 0.81** | 0.18 | 0.96** | |
| GMP | | 0.87** | 0.88** | -0.04 | 0.40* | 0.99** | **1** | 0.99** | 0.91** | 0.36* | 0.99** | |
| HARM | | 0.78** | 0.94** | -0.18 | 0.26 | 0.95** | 0.99** | **1** | 0.96** | 0.50** | 0.98** | |
| YI | | 0.52** | 1.00** | -0.50** | -0.10 | 0.79** | 0.87** | 0.94** | **1** | 0.72** | 0.92** | |
| YSI | | -0.47** | 0.50** | -0.99** | -0.89** | -0.12 | 0.03 | 0.17 | 0.50** | **1** | 0.39* | |
| STI | | 0.85** | 0.89** | -0.07 | 0.36* | 0.98** | 1.00** | 0.99** | 0.89** | 0.06 | **1** | |

### *Principal component analysis*

Drought indices were processed by principal component analysis and showed that the first two components justified the greatest variance (97.01%) as 60.01% of the total changes belonging to the first component and 37.02% of them was related to the second component (Table 6). Also, the second year showed that the first two components justified the highest variance (99.45%) as 64.01% of the total changes which were attributed to the first component and 35.44% of them related to the second component. During the two years, the first component was more influenced by yield in both conditions, while the MP, GMP, STI, HARM and YI were characterized by high and positive coefficients. As a result, this component put emphasis on resistance to drought. This component can assist researchers in the selection of top genotypes in both conditions. The second component also contains positive and high coefficient for SSI and TOL, along with a negative coefficient for YSI. It is also susceptible to stress and, therefore, high degrees of this component represent greater susceptibility to drought.

*Table 6. Results of principal component analysis for Yp, Ys and drought tolerance indices of 31 wheat genotypes in two years*.

| | 2017-2018 | | 2018-2019 | |
|---|---|---|---|---|
| Traits | Component 1 | Component 2 | Component 1 | Component 2 |
| YP | 0.41 | 0.35 | 0.33 | 0.29 |
| YS | 0.38 | -0.32 | 0.36 | -0.23 |
| SSI | -0.02 | 0.58 | -0.04 | 0.52 |
| TOL | 0.17 | 0.45 | 0.14 | 0.49 |
| MP | 0.39 | 0.16 | 0.39 | 0.11 |
| GMP | 0.40 | 0.09 | 0.39 | 0.03 |
| HARM | 0.41 | -0.04 | 0.39 | -0.05 |
| YI | 0.38 | -0.22 | 0.36 | -0.23 |
| YSI | 0.04 | -0.54 | 0.03 | -0.53 |
| STI | 0.41 | 0.08 | 0.39 | 0.01 |
| Eigenvalue | 6.05 | 2.96 | 6.4 | 3.54 |
| Percent of variation | 0.60 | 0.37 | 0.64 | 0.35 |
| Cumulative percentage | 0.60 | 0.97 | 0.64 | 0.99 |

### *Biplot and 3D plot analysis*

According to the Biplot (Figures 1), suitable genotypes in the first year included Ws82-9, Ohadi, Gaspard, DN-11 and Pishgam. In the second year, the Pishgam, Ws82-9, Ohadi, Marvdasht and Alvand were identified as appropriate genotypes, as a result of their position in the front of top indices. These genotypes also showed the highest yield under both conditions.

To classify the genotypes and identify the ones that are appropriate, three dimensional diagrams can provide more accurate assessments. Accordingly, this diagram was designed using STI which correlated significantly with yield in both conditions. Based on the 3D diagram, genotypes can be classified into 4 groups (A, B, C, and D). Based on the three-dimensional diagrams obtained from STI and yield in both conditions (Figures 2), the genotypes were classified into 4 groups. In the first year, the A group comprised the Pishgam, Ws82-9, Gaspard, DN-11 and Sivand genotypes. In the second year, the A group comprised Pishgam, Ohadi, Ws82-9, Marvdasht and Alvand genotypes.

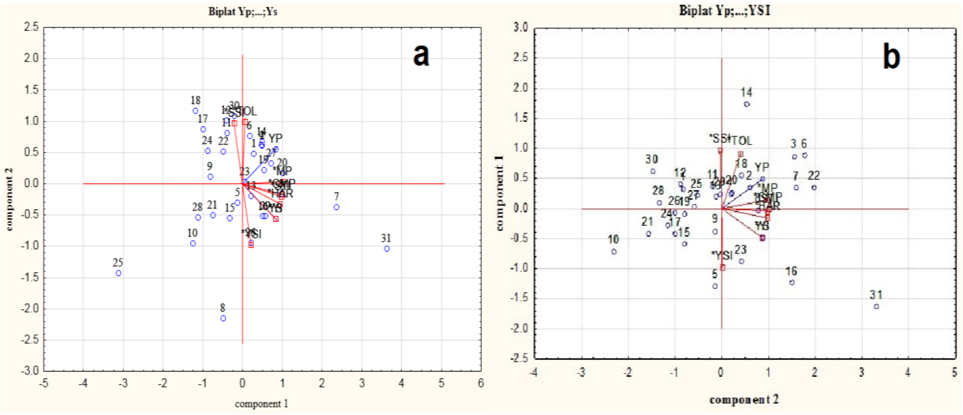

Fig. 1. Biplot based on first and second components of drought tolerance indices in the firs (a) and second (b) year.

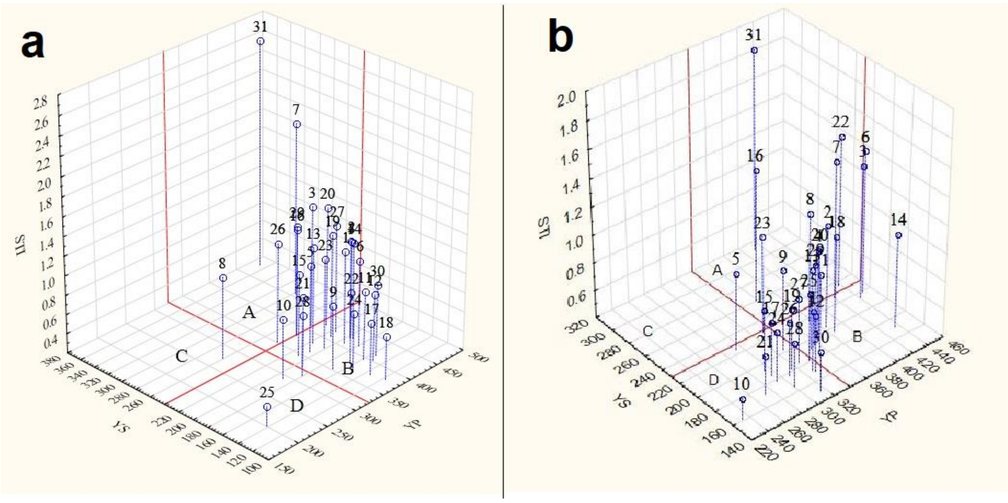

Fig. 2. Three-dimensional plot between Yp, Ys and STI in the firs (a) and second (b) year.

Figure 3 illustrates the trends of change in the values of MP, GMP and STI indexes, as well as grain yield during the year of release. Also, a regression line for MP, GMP and STI indexes, as well as grain yield, corresponded with the years of release and with the years of introduction of the genotype. In all cases, there was an increase in the whole trend, during the period in which the genotypes developed (from 1930 to 2011). The regression line indicated that improvements in grain yield were 0.753 t/ha per year, while the MP, GMP and STI indexes saw increases of 0.753, 0.760 and 0.006 per year, respectively (Figure 3).

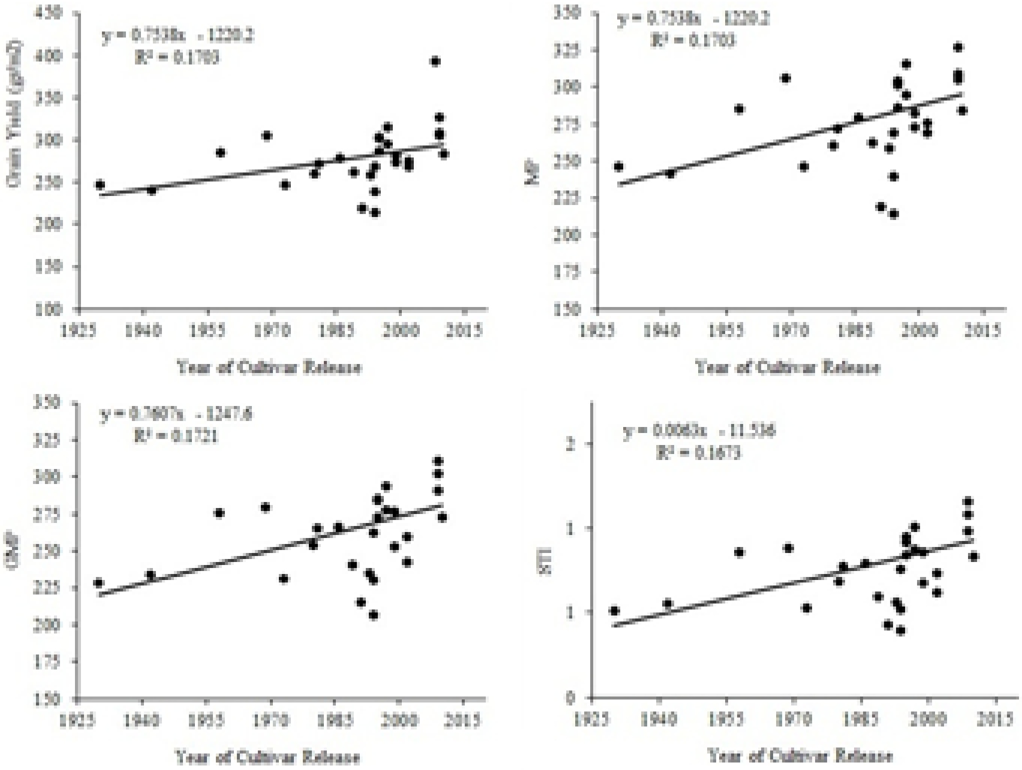

Fig. 3. Relationship between grain yield, MP, GMP and STI indexes with the year of cultivar released over 80 years

## DISCUSSION

Highly significant differences among the grain yields of the various genotypes indicate the existence of genetic variation and the possibility of selection for suitable genotypes in both types of environments. Also, significant differences between grain yield under drought stress and non-stress conditions indicate the existence of genetic variation and the possibility of selection for favorable genotypes in both environments (Table 2). The use of selected indices in screening different genotypes for their tolerance to drought can be used for increasing the yield in both stress and non-stress conditions. Furthermore, it can be used simultaneously to identify superior genotypes under both conditions. In fact, it is expedient to plan breeding programs based on the yield under both conditions and according to the accompanying use of relevant indices. In other words, selected genotypes, based on these indices, not only prove the high stability of their yields, but also produce high amounts of yield on average under both conditions (BASAFA and TAHERIAN, 2010).

BIHAMAT *et al.*, (2018) Suggested that indices which are discussed under stress and non-stress conditions can correlate substantially with grain yield. In fact, they are introduced as the best indices because of their ability to identify high-yield genotypes (group A genotypes) under both conditions. Based on grain yield under stress and non-stress conditions, the correlation analysis between drought resistance indices (Table 5) showed that MP, GMP, HARM and STI are highly capable of separating superior genotypes in both conditions, while other indices can only distinguish between susceptible and resistant genotypes, even when these genotypes have low-potential yields or are not capable of producing favorable yields in stress conditions. FARSHADFAR *et al.* (2012) proved that MP, GMP, STI, YI, YSI and SSI correlate with yield in both conditions of stress and non-stress. Correlation coefficient represents a measure of the genetic relationship between traits and may supply an important criterion of the selection methods (GOLPARVAR *et al.*, 2015). Therefore, these indices were introduced as the best when considering the identification of superior genotypes (FARSHADFAR *et al.*, 2012). Furthermore, biplot analysis was used for grain yield in bread wheat (MEHARI *et al.*, 2015; KARAMAN, 2020; AKTAS, 2020). These results are consistent with previous reports on barley (SARDOUIE-NASAB *et al.*, 2014) and on wheat (BIHAMAT *et al.*, 2018).

For a better understanding of the relationships between screening methods for plant tolerance to drought and, furthermore, to separate resistant, tolerant and susceptible genotypes from each other, a principal component analysis (PCA) was used for the data of each year based on the rank correlation matrix. Accordingly, selection was based on a combination of indices that may provide useful criteria for improving plant resistance to drought. In the first year, the first two PCAs accounted for 97% of the total variation and, in the second year, the first two PCAs accounted for 99% of the total variation (Table 6). PARCHIN *et al.* (2013) made use of the principal component analysis and suggested that selection is performed best when it is based on the first component that brings about superior genotypes by selection under both conditions, while the second component leads to the selection of susceptible genotypes. SANGI *et al.* (2022) Stated that if the first component increases and the second component decreases, high-yield genotypes will be selected, whereas the opposite will lead to the selection of low-yield genotypes. Principal component analysis has been used for research on barley (ZARE, 2012), oat (ZAHERI and BAHRAMINEJAD, 2012) and wheat (FARSHADFAR *et al.*, 2012; SISODIA and RAI, 2017; ZEBARJADI *et al.*, 2012). DOROSTKAR *et al.* (2015) proposed that appropriate genotypes could be selected based on high values of STI, MP and GMP, along with a low value of SSI. Using principal component analysis, previous research has indicated that genotypes are favored when the first component has a high value and the second component has a low value.

In the current study, it can be stated that the grain yield, along with the MP, GMP and STI indexes, have increased for 80 years (Figure 3). This has been the result of the fact that plant breeders have so far paid heed to improvements in grain production and will continue to do so by research and development (AMIRI *et al.*, 2015), while bearing in mind the importance of plant tolerance to drought. Accordingly, older genotypes have lower yields but are drought tolerant, compared to recently developed genotypes. Areas that are susceptible to drought stress are in need of plant breeding programs that could lead to the creation of superior genotypes that can produce stable amounts of yield under both favorable and drought conditions. Evaluating wheat genotypes under different levels of drought stress can alleviate acute problems such as the unpredictability of the level and time of drought stress in rain-fed areas. Therefore, plant tolerance to drought can be deemed more reliable in genotypes that show minimum amounts of fluctuation in their yield under various levels of drought stress. Furthermore, the stability of genotypes in terms of yield could be gauged via drought-related indices. As some of these indices describe plant tolerance to drought through similar criteria, the present study revealed highly significant correlations between several of the indices.

## CONCLUSION

The Ys and Yp correlated positively and significantly with MP, GMP, HARM, YI and STI. Such substantial levels of correlation are indications that these indices can be considered as the best predictors of yield under drought stress and non-stress environments. Drought stress significantly reduced the yield of some genotypes, while some others were tolerant to drought, indicating genetic variability in terms of drought tolerance among the genotypes. Therefore, breeders can select suitable genotypes under drought stress, and then compare their performance to conditions of non-stress using MP, GMP, HARM, YI and STI indices as a means of combining information on the performance of yield under both sets of conditions. Based on the STI, MP, GMP, HARM and YI indices, which describe plant tolerance to drought, the Pishgam genotype was identified as the most tolerant genotype in both successive years. This genotype showed the lowest values of indices that describe susceptibility to stress. Under non-stress and drought stress conditions, this genotype produced the highest amount of grain yield. This indicates the superior efficiency of this genotype in producing high amounts of grain yield. It is also a sign of good stability under different environmental conditions, which is of great importance from the viewpoint of plant breeders. The findings of our study indicated that, compared to the older genotypes, new genotypes tend to have high amounts of grain yield but low values of indices that describe drought tolerance. This claim is supported by positive correlations between grain yield and drought tolerance indexes (i.e. MP, GMP and STI).

Received, January 12th, 2021
Accepted December 10th, 2021

## REFERENCES

AKTAS, B. (2020): Evaluation of yield and agronomic traits of new winter bread wheat cultivars. Genetika, *52* (1): 81-96.

ALI, M.A.., K., JABRAN., S., AWAN., A., ABBAS., M., ZULKIFFAL, T., ACET, J., FAROOQ, A., REHMAN (2011): Morpho-physiological diversity and its implications for improving drought tolerance in grain sorghum at different growth stages. Aust. J. Crop Sci., *5* (3): 311.

AMIRI, R., S., BAHRAMINEJAD, S., SASANI, S., JALALI-HONARMAND, R., FAKHRI (2015): Bread wheat genetic variation for grain's protein, iron and zinc concentrations as uptake by their genetic ability. European J. Agronomy, *67*: 20-26.

ASSENG, S., F., EWERT, P., MARTRE, R., PRÖTTER, D.B., LOBELL, D., CAMMARANO, B., KIMBALL, M.J., OTTMAN, G.W., WALL, J., WHITE (2015): Rising temperatures reduce global wheat production. Nature climate change, *5* (2): 143.

BASAFA, M., M., TAHERIAN (2010): Evaluation of drought resistance ecotypes of alfalfa (Medicago sativa) using drought tolerance indices. J. Environ. Stresses Agric., *3* (1): 69-81.

BIHAMTA, M.R., M., SHIRKAVAND, J., HASANPOUR, A., AFAZLIFAR (2018): Evaluationof Durum Wheat Genotypes under Normal Irrigation and Drought Stress Conditions. J. Crop Breeding,*9*(24): 119-136.

BLUM, A. (2005): Drought resistance, water-use efficiency, and yield potential—are they compatible, dissonant, or mutually exclusive? Aus. J. Agric. Res., *56* (11): 1159-1168.

BLUM, A. (2010): Plant breeding for water-limited environments: Springer Science & Business Media.

BOUSLAMA, M., W.T., SCHAPAUGH (1984): Stress tolerance in soybeans. I. Evaluation of three screening techniques for heat and drought tolerance 1. Crop Sci., *24* (5): 933-937.

CHALLINOR, A.J., J., WATSON, D.B., LOBELL, S.M., HOWDEN, D.R., SMITH, N. CHHETRI (2014): A meta-analysis of crop yield under climate change and adaptation. Nature Climate Change, *4* (4): 287.

DOROSTKAR, S., A. DADKHODAIE, B., HEIDARI (2015): Evaluation of grain yield indices in hexaploid wheat genotypes in response to drought stress. Arch. Agr.Soil Sci., *61* (3): 397-413.

FAO (2019). Reducing Post-Harvest Losses. FAO Partnerships Working for the Sustainable Development Goals. Rome: FAO. Available online at: http://www.fao.org/3/ca6344en/ca6344en.pdf (accessed December 06, 2020).

FARSHADFAR, E., M., SAEIDI, S.J., HONARMAND (2012): Evaluation of drought tolerance screening techniques among some landraces of bread wheat genotypes. Eur. J. Exp. Biol., *2* (5): 1585-1592.

FARSHADFAR, E., R., MOHAMMADI, M., FARSHADFAR, S., DABIRI (2013): Relationships and repeatability of drought tolerance indices in wheat-rye disomic addition lines. Aus. J. Crop Sci., *7* (1): 130.

FERNANDEZ, G.C.J. (1992): Effective selection criteria for assessing plant stress tolerance. Proceeding of the International Symposium on Adaptation of Vegetables and other Food Crops in Temperature and Water Stress, Aug. 13-16, Shanhua, Taiwan, 1992.

FISCHER, R.A., R., MAURER (1978): Drought resistance in spring wheat cultivars. I. Grain yield responses. Aus. J. Agric. Res., *29* (5): 897-912.

FUKAI, S., K.S., FISCHER (2012): Field phenotyping strategies and breeding for adaptation of rice to drought. Frontiers in Physiol., *3*: 282.

GAVUZZI, P., F., RIZZA., M., PALUMBO, R.G., CAMPANILE, G.L., RICCIARDI, B., BORGHI (1997): Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. Can. J. Plant Sci., *77* (4): 523-531.

GOLPARVAR, A.R., M.M., GHEISARI, D., NADERI, A.M., MEHRABI, A., HADIPANAH, S.,D SALEHI (2015): Determination of the best indirect selection criteria in Iranian durum wheat (*Triticum aestivum* L.) genotypes under irrigated and drought stress conditions. Genetika, *47* (2): 549-558.

HABUŠ-JERČIĆ, I., M., BARIĆ, S., KEREŠA, A., BOŠNJAK-MIHOVILOVIĆ, M., POLJAK, B., LAZAREVIĆ (2018): Effect of terminal drought on yield and some physiological traits of winter wheat. Genetika, *50* (2): 747-753.

HOSSAIN, A.B.S., R.G., SEARS, T.S., COX, G.M., PAULSEN (1990): Desiccation tolerance and its relationship to assimilate partitioning in winter wheat. Crop Sci., *30* (3). 622-627.

PCC (2014): Climate change 2014: impacts, adaptation, andvulnerability. Part A: global and sectoral aspectsContribution of Working Group II to the Fifth AssessmentReport of the Intergovernmental Panel on Climate Changeeds C B Field, V R Barros, D J Dokken, K J Mach, M DMastrandrea, T E Bilir, M Chatterjee, K L Ebi, Y O Estrada,R C Genova, B Girma, E S Kissel, A N Levy, S Maccracken, PR Mastrandrea and L L White (Cambridge: CambridgeUniversity Press) p 1132.

KARAMAN, M. (2020): Evaluation of yield and quality performance of some spring bread wheat (*Triticum aestivum* L.) genotypes under rainfall conditions. Int. J. Agric. Environ. Food Sci., *4* (1): 19-26.

LOBELL, D., W., SCHLENKER, J., COSTA-ROBERTS(2011). Climate trendsand global crop production since 1980. Science, *33*: 3616–20.

MEHARI, M., M., TESFAY, H., YIRGA, A., MESELE, T., ABEBE, A., WORKINEH, B., AMARE (2015): GGE biplot analysis of genotype-by-environment interaction and grain yield stability of bread wheat genotypes in South Tigray, Ethiopia. Comm. Biometry Crop Sci., *10* (1): 17-26.

MOOSAVI, S.S., B., YAZDI SAMADI, M.R., NAGHAVI, A.A., ZALI, H., DASHTI, A., POURSHAHBAZI (2007): Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes. Desert, *12* (2): 165-178.

MURSALOVA, J., Z., AKPAROV, J., OJAGHI, M., ELDAROV, S., BELEN, N., GUMMADOV, A., MORGOUNOV (2015): Evaluation of drought tolerance of winter bread wheat genotypes underdrip irrigation and rain-fed conditions. Turkish J. Agric. Forestry, *39* (5): 817-824.

PARCHIN, R.A., A., NAJAPHY, E., FARSHADFAR, S., HOKMALIPOUR (2013): Assessment of Drought Tolerance in Genotypes of Wheat by Multivariate Analysis. World App. Sci. J., *22* (4): 594-600.

QU, Y., P., MU, H., ZHANG, C.Y., CHEN, Y., GAO, Y., TIAN, F., WEN, Z., LI (2008): Mapping QTLs of root morphological traits at different growth stages in rice. Genetica, *133* (2): 187-200.

ROSIELLE, A.A., J., HAMBLIN (1981): Theoretical aspects of selection for yield in stress and non-stress environment 1. Crop Sci., *21* (6): 943-946.

SANGI, S.E., A., NAJAPHY, K., CHEGHAMIRZA, R., MOHAMMADI(2022): Assessment of drought tolerance indices for durum wheat (*Triticum durum L.*) genotypes. Environ. Stresses in Crop Sci., 4(4). 901- 911.

SARDOUIE-NASAB, S., G., MOHAMMADI-NEJAD, B., NAKHODA (2014): Field screening of salinity tolerance in Iranian bread wheat lines. Crop Sci., *54* (4): 1489-1496.

SHARAFI, S., K., GHASSEMI-GOLEZANI, S., MOHAMMADI, S., LAK, B., SORKHY (2014): Evaluation of barley genotypes (Hordeum vulgar L.) by drought tolerance indices and multivariate analysis. Int. J. Biosci., (IJB) *4* (7): 117-129.

SISODIA, B.V.S., V.N., RAI (2017): An application of principal component analysis for pre-harvest forecast model for wheat crop based on biometrical characters. Int. Res. J. Agric. Economics and Statistics, *8* (1): 83-87.

VOLTAS, J., H., LOPEZ-CORCOLES, G., BORRAS (2005): Use of biplot analysis and factorial regression for the investigation of superior genotypes in multi-environment trials. Eur. J. Agr., *22* (3): 309-324.

XIONG, W.E.I., S., ASSENG, G., HOOGENBOOM, I., HERNANDEZ-OCHOA, R., ROBERTSON, K. SONDER, D., PEQUENO, M., REYNOLDS, B., GERARD(2019): Different uncertainty distribution between high and low latitudes in modelling warming impacts on wheat. Nature Food, *1*(4): 63- 69.

ZAHERI, A., S. BAHRAMINEJAD (2012): Assessment of drought tolerance in oat (Avena sativa) genotypes. Ann. Biol. Res., *3* (5): 2194-2201.

ZARE, M. (2012): Evaluation of drought tolerance indices for the selection of Iranian barley (Hordeum vulgare) cultivars. Afr. J. Biotech., *11* (93): 15975-15981.

ZEBARJADI, A., T., MIRANY, D., KAHRIZI, M., GHOBADI, R., NIKOSERESHT (2012): Assessment of drought tolerance in some bread wheat genotypes using drought resistance indices. Biharean Biologist, *6* (2).

ZHAO, C.X., L., GUO, C. A., JALEEL, H.B., SHAO, H.B., YANG (2008): Prospects for dissecting plant-adaptive molecular mechanisms to improve wheat cultivars in drought environments. Comp. Rend. Biol., *331* (5): 579-586.

# PROCENA PRINOSA ZRNA GENOTIPOVA PŠENICE POMOĆU INDEKSA TOLERANCIJE NA STRES

Aref FATEHI[1], Esmail BABARASHI[1], Shahram MEHRI[2*], Mehdi SALAJEGHEH[3]

[1]Departman za agronomiju i oplemenjivanje biljaka, Islamski univerzitet Azad, Ogranak Sanandaj, Iran
[2]Departman za agronomiju i oplemenjivanje biljaka, Ogranak Pars Abad Mogan, Islamski univerzitet Azad, Pars Abad Mogan, Iran
[3]Departman za agronomiju, Islamski univerzitet Azad, ogranak Bam, Iran

## Izvod

Suša ima nepovoljan uticaj na uspeh poljoprivrede u mnogim delovima sveta. Obezbeđivanje budućih populacija sa dovoljno hrane očigledno bi zahtevalo procenu prinosa useva, veće potencijale i obezbeđenje stabilnosti prinosa u regionima pogođenim sušom. U ovom istraživanju, otpornost genotipova pšenice na sušu proučavana je u randomizovanom kompletnom blok dizajnu i u eksperimentu sa tri ponavljanja u normalnim uslovima i uslovima stresa od suše. U dve uzastopne sezone, merenja su bila usmerena na procenu indeksa osetljivosti na stres (SSI), indeksa tolerancije na sušu (TOL), srednje produktivnosti (MP, indeks tolerancije na stres (STI), harmonijske sredine (HARM), indeksa prinosa (YI), i genomske srednje produktivnosti (GMP).Ovi parametri su opisivali prinose različitih genotipova za dve godine i u normalnim i u uslovima stresa.Kombinovana analiza varijanse je pokazala da je životna sredina značajno uticala na prinos zrna.Srednje vrednosti parametara prema uslovima stresa od suše bile su manje od onih u stanju bez stresa. Intenzitet stresa (SI) je bio 46% i 43% u prvoj i drugoj godini, respektivno. U obe godine indeksi MP, GMP, STI i HARM značajno su korelirali sa prinosom zrna pod stresom i normalnim uslovima. Na osnovu trodimenzionalnog dijagrama ovih indeksa, pishgam i ws-82-9 genotipovi su smatrani najsuperiornijim u prvoj godini (oba uslova). Osim toga, genotipovi pishgam, alvand i ohadi su smatrani superiornijim u drugoj godini. Prema bi-plot dijagramu i na osnovu prve dve glavne komponente, ovi genotipovi su bili tolerantniji na stres suše. Generalno, sugeriše se da pishgam pokazuje viši nivo održivosti prinosa. Utvrđeno je da je to genotip sa najvećim prinosom u normalnim i stresnim uslovima. Indeksi prinosa zrna i otpornosti su porasli tokom 80 godina oplemenjivanja i selekcije.

Primljeno 12.I.2021.
Odobreno 10.XII. 2021.