Evaluation of Drought Tolerance Indices for Screening Some of Super Sweet Maize (Zea mays L. var. saccharata) Inbred Lines

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ABSTRACT
Drought is the most common cause of severe crop production shortage in developing countries, and global warming is predicted to further exacerbate drought’s impact. The present study investigates the efficiency of drought tolerance indices in classifying 24 super sweet maize inbred lines with the highest yield potential and drought tolerance performance. The experiment was conducted as a completely randomized block design with 4 replications. Twenty indices were compared based on grain yield, under two environments (Non-Stressed and Drought-Stress condition) during the 2018 growing season. All drought indices revealed significant differences among inbred lines, except GM. Results in ranking method, indicate that STI, GMP, MP, HARM, MRP, REI and RDY are suitable indicators because of positive correlations among each other and also the highest correlation with grain yield (GY) in both environments. Cluster analysis and three-dimensional plots, showed inbred lines with the highest tolerance to drought, in both conditions. The first three principle components (PCs) explained 96.34% of total variation and the PC1 can be nominated as a potentially stable yield. The Biplot diagram based on PCs, and drought tolerance indices showed that MP, GMP, STI, HARM, MRP, REI, MSTIK1, MSTIK2 and Y1 were the best indices for screening tolerant inbred lines such as MCH87002/19-1, MPA90010/51-1 and MSH90011/82-1.

INTRODUCTION
Maize is counted as the fifth most produced crop (FAO, 2018) and also a source of energy for humans and animals with exceeded 1000 million tons production in 2017/2018. Water is one of the main limiting factors when most of the agricultural land of the world is considered semi-arid.

Standard sweet corn is a mutant type of corn by a mutation at the sugary (su) locus. Lately, several new mutants on sweet corn founded to increase the eating quality, mainly the sugary enhanced (se) and shrunken-2 (sh²) genes. Shrunken-2 sweet corn (super-sweet) is at least two to three times sweeter and the conversion of sugar to starch is negligible.

Selection of the suitable genotypes under water-stress conditions is one of the most important goals in breeding programs (Richards, Rebetzke, Condon, & van Herwaarden, 2002). Wide-ranging molecular, morphological, and physiological traits could be used for improving the drought tolerance in crops (Barker et al., 2005; Cushman & Bohnert, 2000; Flowers, 2004; Hasegawa, Bressan, Zhu, & Bohnert, 2000; Holmberg & Bülow, 1998; Ingram & Bartels, 1996; Munns, 2002).

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Fernandez & Kuo (1993) stated that the identification of genotypes based on drought tolerance could be difficult when the interaction between genotypes and the environment happened. Fernandez & Kuo (1993) classified plants according to their reactions in drought-stress and non-stress environments into 4 groups: A) genotypes with the best and highest performance under both conditions, B) with the best performance only in optimal conditions, C) best performance in drought-stress condition, D) weak performance in both conditions. Various drought indices were determined and used for the identification of best drought-tolerant genotypes. Several reports demonstrate the important role of Stress Tolerant Index (STI) and Geometric Mean Productivity (GMP) as the most suitable indices to identify resistant genotypes in drought-stress conditions (Darkwa, Ambachew, Mohammed, Asfaw, & Blair, 2016; Gholinezhad, Darvishzadeh, & Bernousi, 2014; Golabadi, Arzani, & Mirmohammadi Maibody, 2006; Mehrabi, Homayoun, & Daliri, 2011; Moghaddam & Hadizadeh, 2002; Naghavi, Aboughadareh, & Khalili, 2013; Ramirez-Vallejo & Kelly, 1998; Rosielle & Hamblin, 1981).

This study evaluated some drought tolerance indices that are able to distinguish high grain yield super sweet maize inbred lines under drought stress and non-stress conditions.

### MATERIALS AND METHODS

#### Plant Material and Growing Conditions

The current study was conducted at the Khorasan Razavi Agricultural and Natural Resources Research and Education Institute Center, Mashhad, I.R. Iran during the 2018 growing season. Table 1 showed the climate conditions of the experimental field. The material was comprised of 24 super sweet maize inbred lines (S6 and S7 selfing generations) that derived from the F2 generation of commercial super sweet maize single cross hybrids (Table 2). These inbred lines were under two conditions (non-stress and drought-stress conditions). The experiment was laid out on a randomized complete block design (RCBD) with 4 replications for each condition. Each plot was of 3 m and 0.75 m in length and width spacing between rows, respectively. The density of plants was 70000 plant/ha. The amounts of applied irrigation water were based on 50% allowing water depletion for non-stress and 80% in drought-stress conditions.

#### Sampling and Measurements of Grain Yield Traits

Data on various traits such as kernel number, rows number, ear weight (g/1.5 m²), ear dry weight (g/1.5 m²), plant height (cm), ear length (cm), and ear diameter (mm) were measured.

### Table 1. Mashhad annual temperature 2017-2018

| Parameters         | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|--------------------|------|------|------|------|-----|------|------|------|------|------|------|------|
| Rainfall (mm)      | 17.3 | 99.2 | 43.6 | 43.6 | 19.3| 1.8  | 0.9  | 4    | 0.1  | 0    | 8.4  | 0.5  |
| High temperature (°C) | 16.4 | 19.6 | 25   | 33   | 38.9| 40.3 | 40.3 | 42.2 | 35.6 | 31   | 31.2 | 23.9 |
| Low temperature (°C) | -5.8 | -13  | -1.1 | 0.8  | 9.9 | 16.4 | 17.3 | 13.9 | 5.8  | 3.6  | -1.7 | -6.5 |

### Table 2. List of 24 super sweet maize inbred lines

| Entry Code | Name     | S.G. | Entry Code | Name     | S.G.       |
|------------|----------|------|------------|----------|------------|
| 1          | MBA87001/3-2 | S7   | 13         | MPA90001/ 48-1 | S6         |
| 2          | MBA87003/ 4-1 | S7   | 14         | MPA90004/ 49-2 | S6         |
| 3          | MBA87001/ 18-1 | S7   | 15         | MPA90010/ 51-1 | S6         |
| 4          | MCH87002/ 19-1 | S7   | 16         | MSH9001/ 76-1 | S6         |
| 5          | MCH87001/ 22-1 | S7   | 17         | MSH9006/ 76-5 | S6         |
| 6          | MCH87004/ 23-1 | S7   | 18         | MSH90011/ 82-1 | S6         |
| 7          | MCH87001/ 23-3 | S7   | 19         | MSH90015/ 87-1 | S6         |
| 8          | MCH87011/ 25-1 | S7   | 20         | MSH90019/ 89  | S6         |
| 9          | MCH87017/ 26-3 | S7   | 21         | MSG9002/ 96-1 | S6         |
| 10         | MCH87022/ 28-3 | S7   | 22         | MSG9008/ 118-1 | S6         |
| 11         | MCH87025/ 29-3 | S7   | 23         | MSG90012/ 124-1 | S6         |
| 12         | MOB87002/ 37-1 | S7   | 24         | MSG90017/ 124-2 | S6         |

Remarks: S.G. = Selfing Generation
Measurements of Indices
The 20 drought tolerance indices were intended for all of the inbred lines using the corresponding Non-Stress and drought stress plots cited in Table 3.

Statistical Analysis
Morphological traits were measured on 10 randomly plants and grain yields (GY) calculated for the 1.5 m². ANOVA appropriated for randomized complete block design and Duncan’s multiple range tests at 0.01 level of probability were used for statistical analysis and comparing inbred lines (Steel & Torrie, 1984). Correlations between grain yield per plot in each of the water regimes and drought tolerance indices were determined using Minitab ver. 18.

Principal component analysis (PCA), Biplot analysis, Cluster analysis (according to drought tolerance indices, GY and its components under non-stress and drought stress condition), and three-dimensional plots (based Ypi, Ysi, and drought tolerance indices) were used to identify suitable inbred lines. Statistical analysis conducted using Minitab ver.18 and Excel software and also figures were drawn using Sigmaplot ver. 14 software.

Table 3. List of the 20 drought tolerance indices and formula

| No. | Index                      | Formula                                      |
|-----|----------------------------|----------------------------------------------|
| 1   | Mean Productivity (MP)     | (Ypi + Ysi) / 2                             |
| 2   | Mean Relative Performance (MRP) | (Ysi / Ys) * (Ypi / YP)                   |
| 3   | Stress Susceptibility Index (SSI) | 1-(Ysi / Ypi)/SI = 1 - (Ys / Yp)         |
| 4   | Tolerance Index (TOL)      | Ypi – Ysi                                   |
| 5   | Geometric Mean Productivity (GMP) | √(Ypi * Ysi)                               |
| 6   | Relative Efficiency Index (REI) | (Ysi / Ys)*(Ypi / Yp)                  |
| 7   | Stress Tolerance Index (STI) | (Ysi * Ypi) / (Yp)²                       |
| 8   | Modified Stress Tolerance Index 1 (MSTIk1) | ((Ypi)² / (Yp)²) * STI                |
| 9   | Modified Stress Tolerance Index 2 (MSTIk2) | (((Ysi)² / (Ys)²) * STI         |
| 10  | Harmonic Mean Of Yield (HM) | 2 * (Ypi * Ysi) / (Ypi + Ysi)             |
| 11  | Yield Index (YI)           | Ysi / Ys                                    |
| 12  | Sensitivity Drought Index (SDI) | (Ypi - Ysi) / Ypi                     |
| 13  | Relative Drought Index (RDI) | (Ysi / Ypi) / (Ys/Yp)                   |
| 14  | Drought Resistance Index (DI) | Ysi * (Ysi / Ypi)/(Ys)                  |
| 15  | Golden Mean (GM)           | (Ypi + Ysi) / (Ypi - Ysi)                 |
| 16  | Abiotic Tolerance Index (ATI) | (((Ypi - Ysi) / (Yp / Ys)) * (√Ypi * Ysi) |
| 17  | Stress Susceptibility Percentage Index (SSPI) | (((Ypi - Ysi) / (2 * Yp)) * 100            |
| 18  | Stress/Non-Stress Production Index (SNPI) | (3√(Ypi + Ysi) / (Ypi - Ysi) * 3√Ypi * Ysi) |
| 19  | Relative Decrease In Yield (RDY) | 100 – ((Ysi / 100) * Ypi)             |
| 20  | Drought Tolerance Efficiency (DTE) | (Ysi / Ypi) * 100                   |

Remarks: Ypi = grain yield in non-stress conditions, Ysi = grain yield in drought-stress condition, Yp = yield means in drought condition, Ys = yield mean in non-stress condition
RESULTS AND DISCUSSION

The Effect of Different Irrigation Systems on GY

Results of individual and combined analysis of variation on 24 super sweet maize inbred lines for measured traits under both conditions, showed significant reduction in grain yield (-16.6%) and its components over optimal (Table 4). Various studies confirmed the results (Abd El-Wahed et al., 2015; Barutçular et al., 2016; El-Sabagh, Barutçular, & Saneoka, 2015; Golbasy, Ebrahimi, Khorasani, & Choukan, 2010; Mi et al., 2018; Moser, Feil, Jampatong, & Stamp, 2006; Musvosvi et al. 2018; Pandit et al., 2017; Rashwan, Mousa, El-Sabagh, & Barutçular, 2016; Sah et al., 2020; Zhang, Liu, Wu, & Wang, 2020).

Correlation Analysis

Correlation coefficients showed that all yield components had a positive correlation with GY under both conditions. Table 5 showed the importance of kernel numbers per rows with the highest correlation with GY (0.71) under drought stress conditions. Results are confirmed by Golbasy, Ebrahimi, Khorasani, & Choukan (2010).

The correlation coefficients between Yp, Ys, and drought-tolerance indices were presented in Table 6 to find a suitable drought-tolerant index that must show a significant correlation with GY in both conditions. Results showed a significantly and positively correlation between Yp and TOL (0.51**), MP (0.85**), GMP (0.82**), STI (0.80**), HARM (0.79**), MRP (0.89**), REI (0.80**), MSTIK1 (0.84**), MSTIK2 (0.56**), ATI (0.57**) and SSPI (0.51**). Results also indicate a significant and negative correlation between Yp with RDY (-0.80**). Significant and positive correlation found between Ys and GMP (0.88**), MP (0.86**), STI (0.87**), HARM (0.89**), MRP (0.89**), REI (0.87**), MSTIK1 (0.63**), MSTIK2 (0.89**), YI (0.99**), RDI (0.60**), DI (0.87**) and DTE (0.60**). Table 6 also showed a significant and negative correlation between Ys and TOL (-0.52**), SDI (-0.60**), SSPI (-0.52**) and RDY (-0.87**). Yp and Ys also showed a significant correlation between each other (0.47**).

Drought tolerance indices with the highest correlations with Yp under both conditions (MP, GMP, STI, HARM, MRP, REI, RDY, MSTIK1, MSTIK2, DI, ATI, and YI) were the most suitable indices to select drought-tolerant inbred lines.

Comparing Inbred Lines Based on the Resistance/Tolerance indices

All drought indices revealed significant differences among inbred lines, except GM. Based on STI, MP, GMP, YI, SSPI, MSTIK1, MSTIK2, and Ypi, MCH87002/19-1, MPA90010/51-1, MCH90011/82-1, MSG9002/96-1, and MCH9001/76-1 were found as drought-tolerant inbred lines while MCH87004/23-1, MCH87001/23-3, and MSG90017/124-2 displayed the lowest amounts and recommended as sensitive inbred lines, so other inbred lines could be ranked and classified as semi-tolerance or semi-sensitive (Table 7). According to grain yield in drought stress condition (Ysi), MSTIK2 and YI indices, MCH90011/82-1, MPA90010/51-1 and MCH87002/19-1 were the most relatively tolerant inbred lines with the highest means rank and also low standard deviations while MCH87004/23-1, MCH87001/23-3 and MSG90017/124-2 were the most sensitive inbred lines under drought stress condition.

These results are supported by other reports (El-Sabagh, Barutçular, Hossain, & Islam, 2018; Farshadfar, Poursiahbidi, & Pour Aboughadareh, 2012; Khalili, Reza Naghavi, Pour Aboughadareh, & Javad Talebzadeh, 2012; Shafiq, Akram, & Ashraf, 2019). Results in the ranking method showed that inbred lines with the highest yield in Non-stress conditions are: MCH87002/19-1, MSG9002/96-1, MPA90010/51-1, MCH9001/76-1, MCH9001/82-1 And, in drought stress condition: MCH90011/82-1, MPA90010/51-1, MCH87002/19-1, MCH87022/28-3, MCH87011/25-1. And also, in both conditions: MPA90010/51-1, MCH9001/76-1, MCH90011/82-1, MSG9002/96-1 and MCH87002/19-1.
Table 4. Analyze of variation of super sweet maize inbred lines traits under Non-Stress and Drought-Stress conditions

| Variable | DF | Rep. | Genotype | Error | Mean | % C.V. | Rep. | Genotype | Error | Mean | % C.V. |
|----------|----|------|----------|-------|------|--------|------|----------|-------|------|--------|
| GY       | 23 | 42952| 2265200**| 27960 | 2332 | 7.1    | 30822| 2084636**| 97427 | 1944 | 16     |
| KN       | 23 | 10.51| 191**    | 4.7   | 24.6 | 8.8    | 19.9*| 90.2**   | 5.1   | 21.7 | 10     |
| RN       | 23 | 0.07 | 10.4**   | 0.1   | 14.4 | 2.5    | 1.8* | 3.7**    | 0.5   | 13.4 | 5.5    |
| EL       | 23 | 0.55 | 8.4**    | 0.2   | 13   | 4      | 2.1**| 6.9**    | 0.4   | 12    | 5.8    |
| ED       | 23 | 0.08 | 0.4**    | 0.03  | 3.5  | 5.4    | 0.06 | 0.2**    | 0.04  | 3.3   | 6.3    |
| PH       | 23 | 174**| 936**    | 42    | 120  | 5.3    | 14.1 | 1166.8**| 43.1  | 108   | 6      |

Remarks: ** = significant at 0.01 probability level,  * = significant at 0.05 probability level, GY = Grain Yield, KN = Kernel No., RN = Rows No., EL = Ear Length, ED = Ear Diameter, PH = Plant Height

Table 5. Pearson correlation coefficient between morphological traits of 24 super sweet maize inbred lines under irrigation and drought stress conditions

| Variable | GY | KN | RN | EL | ED | PH |
|----------|----|----|----|----|----|----|
| GY       | 0.71**| 0.4 | 0.37| 0.68**| 0.28|
| KN       | 0.51**| 0.61**| 0.55**| 0.53**| 0.44|
| RN       | 0.27 | 0.39| 0.44| 0.38 | 0.43|
| EL       | 0.34 | 0.17 ns| 0.09 ns| 0.26 | 0.46|
| ED       | 0.31 | 0.36| 0.15 ns| 0.01 ns| 0.03 ns|
| PH       | 0.42 | 0.33| 0.33| 0.33 | -0.22|

Remarks: Upper-right = Non-Stress condition, Down-left = Drought-Stress condition, ** = significant at 0.01 probability level, ns = non significant,  GY = Grain Yield, KN = Kernel No., RN = Rows No., EL = Ear Length, ED = Ear Diameter, PH = Plant Height
| INDEX | Ypi | Ysi | TOL | MP   | GMP | STI | SSI | HARM | MRP | REI | MSTIk1 | MSTIk2 | YI  | SDI | RDY | DI  | GM  | ATI | SSPI | SNPI | RDY | DTE |
|-------|-----|-----|-----|------|-----|-----|-----|------|-----|-----|--------|--------|-----|-----|-----|-----|-----|-----|------|------|-----|-----|-----|
| Ypi   | .47** |     |     |      |     |     |     |      |     |     |        |        |     |     |     |     |     |     |      |      |     |     |     |
| Ysi   | .47** | .47** |     |      |     |     |     |      |     |     |        |        |     |     |     |     |     |     |      |      |     |     |     |
| TOL   | .51** | .51** | .37** | .37** | .37** | .37** | .37** | .37** | .37** | .37** | .37** | .37** | .37** | .37** | .37** | .37** | .37** | .37** | .37** | .37** | .37** |
| MP    | .85** | .85** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** |
| GMP   | .96** | .96** | .96** | .96** | .96** | .96** | .96** | .96** | .96** | .96** | .96** | .96** | .96** | .96** | .96** | .96** | .96** | .96** | .96** | .96** | .96** |
| STI   | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** |
| SSI   | .95** | .95** | .95** | .95** | .95** | .95** | .95** | .95** | .95** | .95** | .95** | .95** | .95** | .95** | .95** | .95** | .95** | .95** | .95** | .95** | .95** |
| HARM  | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** |
| MRP   | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** | .82** |
| REI   | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  | .8**  |
| MSTIk1| .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** |
| MSTIk2| .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** |
| Y    | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** | .99** |
| SDI   | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** |
| RDY   | .98** | .98** | .98** | .98** | .98** | .98** | .98** | .98** | .98** | .98** | .98** | .98** | .98** | .98** | .98** | .98** | .98** | .98** | .98** | .98** | .98** |
| DTE   | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** | .91** |

Remarks: ** = significant at 0.01 probability level, * = significant at 0.05 probability level, ns = non-significant, Ypi = Grain yield in non-stress conditions, Ysi = Grain yield in drought-stress condition, TOL = Tolerance Index, MP = Mean Productivity, GMP = Geometric Mean Productivity, STI = Stress Tolerance Index, SSI = Stress Susceptibility Index, HARM = Harmonic Mean Of Yield, MRP = Mean Relative Performance, REI = Relative Efficiency Index, MSTIk1 = Modified Stress Tolerance Index 1, MSTIk2 = Modified Stress Tolerance Index 2, YI = Yield Index, SDI = Sensitivity Drought Index, RDY = Relative Decrease In Yield, DTE = Drought Tolerance Efficiency (DTE)
Table 7. Rank, rank mean (R) and standard deviation of ranks (SDR) of drought resistance/tolerance indices

| Inbred line       | Ypi | Ysi | TOL | GMG | STI | SSI | HARM | MRP | REI | MSTk1 | MSTk2 | Y1 | SDI | RDI | DI | GM | ATI | SSPI | SNPI | RDY | DTE |
|-------------------|-----|-----|-----|-----|-----|-----|------|-----|-----|-------|-------|----|-----|-----|----|----|-----|------|------|-----|-----|
| MCH87002/ 19-1    | 16  | 24  | 4   | 4   | 4   | 23  | 4    | 4   | 3   | 8     | 13    | 23  | 23  | 19  | 16 | 24 | 24  | 6   | 4   | 23  | 1   | 1   | 15  |
| MSG9002/ 96-1     | 14  | 24  | 4   | 4   | 4   | 23  | 4    | 4   | 3   | 8     | 13    | 23  | 23  | 19  | 16 | 24 | 24  | 6   | 4   | 23  | 1   | 1   | 15  |
| MPA90001/ 51-1    | 23  | 12  | 10  | 10  | 10  | 13  | 8    | 10  | 9   | 10    | 12    | 13  | 13  | 12  | 6  | 15 | 15  | 4   | 10  | 13  |     |     |     |
| MSN90001/ 87-1    | 12  | 11  | 6   | 6   | 6   | 6   | 5    | 6   | 6   | 5     | 6     | 5   | 5   | 23  | 6  | 5   | 18  | 6   | 5   |     |     |     |
| MSG90019/ 89      | 12  | 7   | 9   | 7   | 7   | 8   | 7    | 8   | 8   | 4     | 10    | 9   | 12  | 7   | 8  |    |     |     |     |     |     |     |
| MSG90012/ 124-1   | 13  | 16  | 16  | 14  | 13  | 18  | 14   | 14  | 13  | 16    | 16    | 18  | 18  | 14  | 12| 17 | 16  | 7   | 13  | 18  |     |     |     |
| MBA87001/ 18-1    | 14  | 11  | 12  | 11  | 12  | 11  | 12   | 11  | 12  | 10    | 12    | 10  | 12  | 10  | 12| 11 | 12  | 11  |     |     |     |     |     |
| MPA90004/ 49-2    | 16  | 10  | 7   | 16  | 14  | 14  | 7    | 13  | 15  | 14    | 15    | 13  | 10  | 7   | 9  | 24 | 8   | 7   | 20  | 14  |     |     |     |
| MCH87019/ 19-1    | 17  | 18  | 14  | 19  | 19  | 19  | 16   | 18  | 19  | 17    | 18    | 16  | 16  | 17  | 8  | 13 | 14  | 10  | 19  | 16  |     |     |     |
| MBA87003/ 4-1     | 18  | 19  | 13  | 20  | 20  | 20  | 19   | 20  | 20  | 19    | 19    | 14  | 14  | 18  | 7  | 12 | 13  | 9   | 20  | 14  |     |     |     |
| MCH87000/ 22-3    | 19  | 4   | 1   | 8   | 8   | 8   | 2    | 9   | 8   | 4     | 16    | 4   | 2   | 2   | 21| 1   | 22  | 8   | 2    |     |     |     |     |
| MBA87001/ 3-2     | 20  | 8   | 4   | 17  | 17  | 17  | 4    | 16  | 8   | 11    | 4     | 4   | 5   | 10  | 4  | 4   | 19  | 17  | 4    |     |     |     |     |
| MCH87011/ 25-1    | 21  | 5   | 2   | 15  | 16  | 1   | 17   | 13  | 16  | 20    | 9     | 5   | 1   | 3   | 19| 3   | 2   | 21  | 16  |     |     |     |     |
| MSG90017/ 124-2   | 22  | 20  | 11  | 22  | 22  | 22  | 10   | 22  | 22  | 22    | 22    | 20  | 10  | 10  | 16| 18 | 11  | 11  | 17  | 22  | 10   |     |     |     |
| MCH8701/ 23-3     | 23  | 22  | 10  | 23  | 23  | 23  | 11   | 23  | 23  | 23    | 23    | 22  | 11  | 20  | 3  | 9   | 10  | 14  | 23  | 11   |     |     |     |
| MCH87004/ 23-1    | 24  | 24  | 8   | 24  | 24  | 24  | 9    | 24  | 24  | 24    | 24    | 24  | 24  | 22  | 1 | 7   | 8   | 11  | 24  | 9    |     |     |     |
| Mean              | 2323| 1944| 388 | 2138| 2095| 0.8 | 0.7 | 2055| 2    | 1.05| 1.28 | 1.44 | 0.9 | 0.12| 1.04| 0.95| 0.92| 656913| 8.3| 1354| -47916| 87   |     |     |     |
| Standard deviation| 755 | 759 | 778 | 649 | 644 | 0.5 | 1.9 | 644 | 0.6 | 0.6 | 1.6  | 2    | 0.3 | 0.3 | 0.3 | 0.69| 0.40| 1545522 | 16 | 5124| 29861 | 33   |     |     |     |

R-square 0.96 0.87 0.94 0.93 0.83 0.93 0.96 0.88 0.87 0.83 0.83 0.79 0.86 0.85 0.93 0.83

Remarks: Ypi = grain yield in non-stress conditions, Ysi = grain yield in drought-stress condition, TOL = Tolerance Index, MP = Mean Productivity, GMP = Geometric Mean Productivity, STI = Stress Tolerance Index, SSI = Stress Susceptibility Index, HARM = Harmonic Mean Of Yield, MRP = Mean Relative Performance, REI = Relative Efficiency Index, MSTk1 = Modified Stress Tolerance Index 1, MSTk2 = Modified Stress Tolerance Index 2, Y1 = Yield Index, SDI = Sensitivity Drought Index, RDI = Relative Drought Index, DI = Drought Resistance Index, GM = Golden Mean, ATl = Abiotic Tolerance Index, SSPI = Stress Susceptibility Percentage Index, SNPI = Stress/Non-Stress Production Index, RDY = Relative Decrease In Yield, DTE = Drought Tolerance Efficiency (DTE)
Three Dimensional Plots
Three dimensional-plots used to detect groups Fernandez & Kuo (1993) and separate the inbred lines of group A as tolerant inbred lines from the others and also illustrate the advantage of MP, GMP, STI, HARM, TOL and RDY indices. Results showed that inbred lines number 4 (MCH87002/19-1), 15 (MPA90010/51-1), and 18 (MSH90011/82-1) inbred lines were placed in A group with stable GY under both conditions. The inbred lines number 6 (MCH87004/23-1), 7 (MCH87001/23-3), and 24 (MSG90017/124-2) inbred lines placed in D group with poor performance in both conditions (Fig. 1). Results also indicate the importance of STI, GMP and MP parameters for screening the most suitable drought-tolerant inbred lines.

Cluster Analysis
Cluster analysis graph tended into three groups with 3, 7 and 14 inbred lines (Fig. 2) based on drought tolerance indices. The first group (Tolerant) with the highest MP, GMP, STI, HARM, MRP, REI and RDY contain MCH87002/19-1, MPA90010/51-1 and MSH90011/82-1 inbred lines. The second group (Semi-Sensitive/Semi-tolerant) with mean indicators values was stable in non-stress conditions. The third group (Sensitive) was vulnerable to drought and could only use in irrigated and non-stress conditions. These results confirmed by three-dimensional plots. Fig. 2 also clustered inbred lines based on studied traits under both conditions in four separate groups.

Fig. 1. Three dimensional plots among MP, GMP, STI, TOL and RDY vs. Yp and Ys
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Principal Component Analysis (PCA)

Results of Principal Component Analysis (PCA) based on the correlation coefficient matrix showed three PCs with Eigenvalue above 1, explained 96.34 percent variations for drought tolerance indices. The PC1, PC2, and PC3 explained 50.36, 40.08, and 5.89 percent of the observed variations, respectively (Table 8). The extracted PCs were rotated using the orthogonal VARIMAX method to achieve significant components (Table 9) and also we clearly see what traits fall in what factor (highlighted traits). The communality of each variable also calculated, by taking the sum of the squared loadings for that variable.

Results showed the highest correlations of PC1 with Ypi, Ysi, RDY, MP, GMP, STI, HARM, MRP, REI, MSTIK1, and MSTIK2; therefore, the PC1 can be nominated as a potentially stable yield component. Results also indicate the highest relationships of PC2 with DTE, SDI, RDI, DI, TOL, ATI, SSPI, SSI, and SNPI and PC3 with GM, so PC2 and PC3 can be nominated as sensitive to stress component. The efficiency of PCA in the present study was confirmed by Aminpanah, Sharifi, & Ebadi (2018), Basaran, Emre, Karadavut, Balbaloglu, & Bulmus (2012), Farshadfar, Poursiahbidi, & Pour Abooghadareh (2012), Ghaffari, Toorchi, Valizadeh, & Shakiba (2012), Khodarahmpour & Hamidi (2011), Marcelo, Niones, Orbase, & Desamero (2017), and Rahimi, Ebrahimpour, & Khalili (2013).

In Biplot diagram (Fig. 3) results showed the importance of MP, GMP, STI, HARM, MRP, REI, MSTIK1, MSTIK2, and YI indices to find suitable inbred lines such as MCH87002/19-1 (4), MPA90010/51-1 (15), and MSH90011/82-1 (18).

Fig. 2. Dendrogram using complete method between groups showing classification of inbred lines based on resistance/tolerance indices, morphological traits in Non stress and Drought stress conditions.
Table 8. Eigenvalue, percentage of variance and cumulative variance for the component derived from drought indices after VARIMAX rotation

| Component | Total | % of Variance | Cumulative % |
|-----------|-------|---------------|--------------|
| PC1       | 11.081| 50.367        | 50.367       |
| PC2       | 8.817 | 40.079        | 90.445       |
| PC3       | 1.298 | 5.899         | 96.344       |

Remarks: PC = Principal Component

Table 9. Principal Component Analysis (VARIMAX rotated component matrix)

| Variable | Component | Communality |
|----------|-----------|-------------|
|          | PC1       | PC2        | PC3        |
| Ypi      | .860      | .482       | -.063      | .975 |
| Ysi      | .853      | -.498      | -.125      | .991 |
| RDY      | -.995     | .044       | .040       | .994 |
| MP       | .987      | .002       | -.107      | .985 |
| GMP      | .988      | -.036      | -.101      | .989 |
| STI      | .995      | -.044      | -.041      | .994 |
| HARM     | .985      | -.070      | -.094      | .984 |
| MRP      | .985      | -.050      | -.112      | .986 |
| REI      | .995      | -.044      | -.040      | .994 |
| MSTIk1   | .920      | .201       | .096       | .897 |
| MSTIk2   | .898      | -.286      | -.030      | .890 |
| YI       | .853      | -.497      | -.127      | .991 |
| DTE      | .080      | -.982      | -.044      | .973 |
| SDI      | -.080     | .982       | .044       | .973 |
| RDI      | .080      | -.982      | -.044      | .973 |
| DI       | .505      | -.838      | -.129      | .974 |
| TOL      | .042      | .986       | .058       | .977 |
| ATI      | .157      | .941       | .116       | .924 |
| SSPI     | .042      | .986       | .058       | .977 |
| SSI      | -.080     | .982       | .044       | .973 |
| SNPI     | -.181     | .725       | .529       | .838 |
| GM       | -.168     | .194       | .938       | .946 |

Var. Explained 11.08 8.81 1.298 96.344

Remarks: Ypi = grain yield in non-stress conditions, Ysi = grain yield in drought-stress condition, RDY = Relative Decrease In Yield, MP = Mean Productivity, GMP = Geometric Mean Productivity, STI = Stress Tolerance Index, HARM = Harmonic Mean Of Yield, MRP = Mean Relative Performance, REI = Relative Efficiency Index, MSTIk1 = Modified Stress Tolerance Index 1, MSTIk2 = Modified Stress Tolerance Index 2, YI = Yield Index, DTE = Drought Tolerance Efficiency, SDI = Sensitivity Drought Index, RDI = Relative Drought Index, DI = Drought Resistance Index, TOL = Tolerance Index, ATI = Abiotic Tolerance Index, SSPI = Stress Susceptibility Percentage Index, SSI = Stress Susceptibility Index, SNPI = Stress/Non-Stress Production Index, GM = Golden Mean
Fig. 3. Biplot of principle component analysis of super sweet maize inbred lines and drought tolerance indices

CONCLUSION

All indices except DI, GM, and SNPI in non-stress and SSI, GM under drought-stress conditions, have high correlation with GY that shows the suitability of those drought tolerance indices for screening the resistant inbred lines. Ranking method, cluster analysis, three-dimensional plots, and principal component analysis (PCA), discriminated MCH87002/19-1, MPA90010/51-1, and MSH90011/82-1 inbred lines as the most drought-tolerant inbred lines so they could be used and recommended as parents for improvement of drought tolerance breeding programs. Results also indicate the importance of MP, GMP, STI, HARM, MRP, REI, MSTIK1, MSTIK2, and YI indices as the most suitable indicators in identifying drought-tolerant super sweet maize inbred lines.

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