

Article

# Comparison of Different Multivariate Statistical Methods for Screening the Drought Tolerant Genotypes of Pearl Millet (*Pennisetum americanum* L.) and Sorghum (*Sorghum bicolor* L.)

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**Abstract:** Drought is the main limiting factor of crops production in major regions of the world. Forage plants such as pearl millet and sorghum are drought tolerant and suitable for arid regions to grow. In this study, for selecting and introducing the best drought tolerant genotypes, seven pearl millet and five sorghum genotypes in three locations (Kerman, Jiroft, and Bardsir in Kerman Province) were studied with different climatic conditions. The experiments were conducted for three consecutive years of cultivation (2016, 2017, and 2018) under regularly irrigated conditions and the 100% ( $I_{100}$ , full irrigation) plant water requirement and under water deficiency, (50%) plant water requirement ( $I_{50}$ ) in two randomized complete block designs in triplicate separately at each location. Eight drought tolerance/susceptibility indices were used. Multivariate factor analysis (FA) and stress tolerance score (STS) methods were employed to compare the most drought tolerant genotypes in each region. The STS method was more efficient and effective than the FA method for detecting the most drought tolerant genotype with any number of used genotypes. Based on the results of drought tolerance indices and STS, the IP13150 and IP13151 genotypes of pearl millet and speed feed genotype of sorghum in Kerman, Jiroft, and Bardsir respectively, were introduced as the most drought tolerant genotypes for three consecutive years of cultivation.

**Keywords:** drought tolerance; factor analysis; pearl millet; sorghum; stress tolerance score; tolerance indices

## 1. Introduction

Drought stress is the most important factor limiting the growth of plants all over the world; hence, reduced growth due to drought stress is more than other environmental stresses significantly [1].

Pearl millet (*Pennisetum americanum* L.) and forage sorghum (*Sorghum bicolor* L.) are adapted to hot arid climates [2] and drought stress, which are appropriate for regions with irrigation water shortage is the main cause of limitation in crop production [3,4]. Due to its low water requirement, low dependence on the soil type as well as high yield and quality of forage, pearl millet can be considered as a suitable strategy for feeding livestock [5]. Different mechanisms have been proposed for drought

tolerance in pearl millet and sorghum, including strategies against drought stress, improving drought tolerance, and premature plants. It is important to know how each genotype tolerates drought stress. Researches have revealed that millet can escape from the impacts of drought stress through early flowering and lack of synchronicity in tillers development [6,7].

Bruck et al. (2000) [8] reported the low crop harvest index in pearl millet due to drought stress. Different indexes have been reported for identifying the tolerance and response of cultivars to stress based on yield. Some researchers have suggested the tolerance (TOL) and the mean productivity (MP) indexes. High values of TOL indicate the relative sensitivity of genotypes to stress [9]. MP index is also defined as the total yield of a genotype under stress and non-stress conditions. The stress tolerance index (STI) is considered as a criterion for selecting drought tolerant cultivars; high values of STI indicate high tolerance and high yield potential [10].

Geometric mean productivity (GMP) is another index having more potential than MP for separation of cultivars [10]. The stress susceptibility index (SSI) is another selection index. Researchers believe that genotypes with lower SSI than unit tolerate drought more. Hence, reduction in their yield under drought conditions is less than the reduced average yield of total genotypes [11]. The yield stability index (YSI) assesses the yield of a cultivar under stress conditions compared to its yield under non-stress conditions and it can be a suitable index for identifying varieties tolerant of drought stress. Consequently, it is believed that cultivars with higher YSI have better yield under both conditions [12]. The yield index (YI) only categorizes the cultivars based on yield and under stress conditions, thus, it does not detect cultivars with high yield under both stress and non-stress conditions [13]. Ouk et al. [14] have reported that the yield under drought stress is associated with three factors, including yield potential, drought tolerance, and appropriate phenology. Drought tolerance is one of the traits controlled by many genes and it is one of the quantitative traits. The main problem is to identify a standard assessment test for selecting drought tolerant genotypes [15]. The aim of this study was selecting drought tolerant genotypes in regions with different climates using all drought tolerance/susceptibility indexes under stress and non-stress conditions simultaneously.

Ghollamin et al. (2010) [16] in a study stated that on durum wheat properties under drought stress and without drought stress 82.58% of its total yield variability was justified by factor analysis [16]. Abdulshahi et al. (2012) selected drought resistant genotypes from 40 different wheat genotypes using the STS method [17].

## 2. Materials and Methods

### 2.1. Treatments

The treatments were performed to determine drought resistant genotypes, among the pearl millet cultivars including HHVBC, IP22269, HYB-1, HYB-2, ICMVO-O5222, IP13150, and IP13151 and different sorghum genotypes including S<sub>35</sub>, ICSV-112, SPEED FEED, ICSV-14001, and Pegah were selected in three regions almost different alternate in climate, including: Kerman, Jiroft, and Bardsir, whose geographical features and other characteristics are given in Table 1.

**Table 1.** Geographical characteristics of the study sites in different regions.

|                             | <b>Kerman</b>      | <b>Jiroft</b>     | <b>Bardsir</b>        |
|-----------------------------|--------------------|-------------------|-----------------------|
| Above sea level             | 1756 m             | 680 m             | 2047 m                |
| Longitude                   | 30°29′             | 28°40′            | 29°55′                |
| Latitude                    | 57°6′              | 57°44′            | 56°34′                |
| Average rainfall in 10 year | 122.7 mm           | 180 mm            | 92.5 mm               |
| Soil type                   | L-S                | L                 | L-S                   |
| Growth season               | 20 June–31 October | 20 March–2 August | 30 April–11 September |

Water treatments including 100% ( $I_{100}$ , full irrigation) plant water requirement and 50% plant water requirement ( $I_{50}$ ) were used respectively, as regularly irrigated and drought stress condition ( $I_{100}$ ,  $I_{50}$ ).

## 2.2. The Characteristics of Experimental Farms

The first field experiment site was conducted at the Research Farm in Faculty of Agriculture, Shahid Bahonar University of Kerman and had a hot arid climate. The second field experiment site for the study was located in the Research Farm, Faculty of Agriculture, Islamic Azad University of Jiroft and had a hot arid climate. The third field experiment site located in the Research Farm of Agriculture Organization Office of Bardsir had a temperate semi-arid. The temperature range of the three regions is given in Figure 1. This experiment was conducted in the mentioned regions during the 2016, 2017, and 2018 crop years. The soil properties of the tested sites are also given in Table 2.

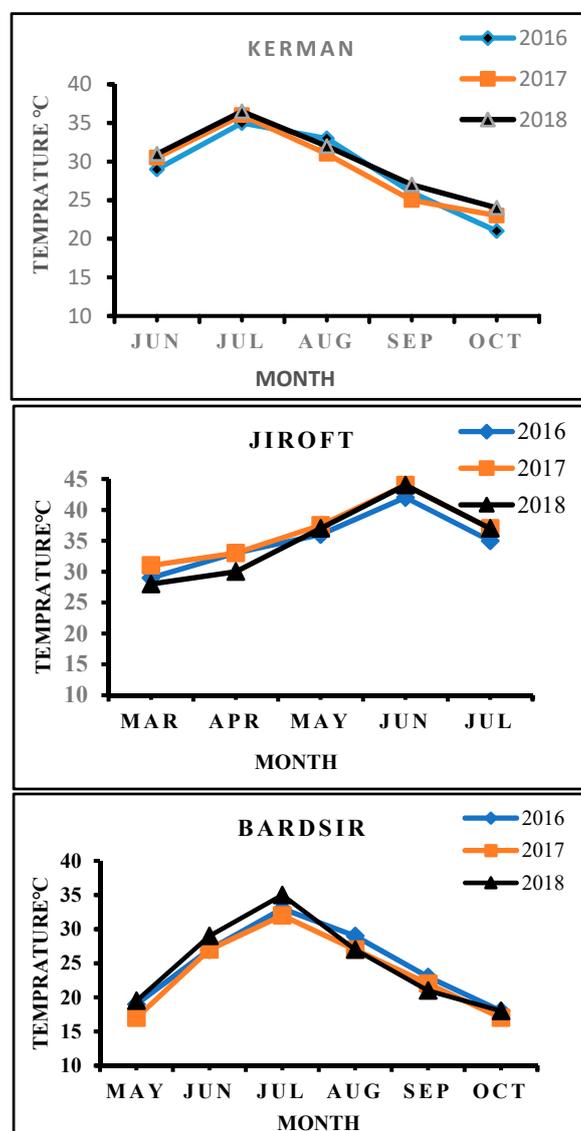


Figure 1. The temperature In Kerman, Jiroft, and Bardsir in three years.

**Table 2.** Soil properties of the study sites in Kerman, Jiroft, and Bardsir during the growing season.

|         | N%  | P<br>(mg<br>kg <sup>-1</sup> ) | K<br>(mg<br>kg <sup>-1</sup> ) | pH  | EC<br>(dsm <sup>-1</sup> ) | OC% | Fe<br>(mg<br>kg <sup>-1</sup> ) | Zn<br>(mg<br>kg <sup>-1</sup> ) |
|---------|-----|--------------------------------|--------------------------------|-----|----------------------------|-----|---------------------------------|---------------------------------|
| Kerman  | 0.4 | 9                              | 470                            | 7.5 | 4.2                        | 1.2 | 8                               | 1                               |
| Jiroft  | 0.5 | 11                             | 440                            | 7.5 | 4.6                        | 1.1 | 6.2                             | 1.2                             |
| Bardsir | 0.3 | 8.8                            | 460                            | 7.5 | 4.1                        | 1.4 | 6.8                             | 0.8                             |

### 2.3. The Stages of Implementation

At the first step, the studied farms were plowed and leveled using a land leveler so that the slope of the ground became almost nearly zero and the runoff problem was eliminated. Fifty kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> fertilizer and 70 kg ha<sup>-1</sup> of urea fertilizer were added to the soils in three farms before implantation. In this experiment, two randomized complete block designs were used in each area (each with three replications). Each replicate consisted of 12 experimental units (plots) assigned to each genotype. Therefore, each randomized complete block design consisted of 36 experimental units and a total of 72 experimental units in total.

Each block design was irrigated with water treatment. The amount of irrigation water was determined by two separate weighing lysimeters embedded on the periphery of the farm (one for pearl millet and another for sorghum). The irrigation water was transferred to the test site through a poly vinyl chloride (PVC) pipe (75 mm) using an electric pump from the water source and the required water was given to each plot by a water volume meter. Table 3 shows the number of irrigation in the growing season and the amount of water consumed in each area.

**Table 3.** The number of cut and irrigation and amount of water consumed per plant and irrigation treatment in Kerman, Jiroft, and Bardsir.

|                  | Plant        | Cut | Number of<br>Irrigation | Total Amount of<br>Applied Water (m <sup>3</sup><br>ha <sup>-1</sup> ) |
|------------------|--------------|-----|-------------------------|--|
| <i>Kerman</i>    |              |     |                         |  |
| I <sub>100</sub> | Pearl millet | 2   | 15.28                   | 6744.51  |
|                  | Sorghum      | 2   | 15.28                   | 7495.91  |
| I <sub>50</sub>  | Pearl millet | 2   | 15.28                   | 3372.26  |
|                  | Sorghum      | 2   | 15.28                   | 3747.95  |
| <i>Jiroft</i>    |              |     |                         |  |
| I <sub>100</sub> | Pearl millet | 3   | 27.75                   | 7726.8   |
|                  | Sorghum      | 3   | 27.75                   | 8731.28  |
| I <sub>50</sub>  | Pearl millet | 3   | 27.75                   | 3863.4   |
|                  | Sorghum      | 3   | 27.75                   | 4365.64  |
| <i>Bardsir</i>   |              |     |                         |  |
| I <sub>100</sub> | Pearl millet | 2   | 15.28                   | 6455.44  |
|                  | Sorghum      | 2   | 15.28                   | 7423.75  |
| I <sub>50</sub>  | Pearl millet | 2   | 15.28                   | 3227.72  |
|                  | Sorghum      | 2   | 15.28                   | 3711.72  |

Water treatments were applied when the plant was well established (four-leaf stage). Five lines were implanted in each experiment unit. Plants were cut from 10 cm height of soil surface for harvesting. After harvesting, the fresh forage was weighed. The growing season was considered 135 days from

planting date to final harvesting with the same period for all three years. In some areas, such as Jiroft with high temperatures, three crops were harvested (first crop: 72 days after planting, the second: 120 days, and the third: 135 days after planting), and in Kerman and Bardsir regions only two crops were harvested (first crop: 84 days after planting and the second crop: 135 days after planting).

#### 2.4. Calculation of Drought Tolerance/Susceptibility Indices

$I_{100}$  (full irrigation) and  $I_{50}$  treatments were considered as water treatments under regularly irrigated and water deficiency conditions. Fresh yield in regularly irrigated conditions was ( $Y_p$ ) and in water stress conditions, it was ( $Y_s$ ). The tolerance/susceptibility indices for each plant genotype were obtained using the following equations [16].

$$SSI = \frac{1 - \frac{Y_s}{Y_p}}{1 - \frac{\bar{Y}_s}{\bar{Y}_p}} \quad (1)$$

where  $Y_s$  is the wet forage yield under water deficiency and  $Y_p$  is the wet forage yield under regularly irrigated condition,  $\bar{Y}_s$  and  $\bar{Y}_p$  are the mean yield ( $t ha^{-1}$ ) of all genotypes under water deficiency and regularly irrigated conditions, respectively.

$$MP = \frac{Y_s + Y_p}{2} (t ha^{-1}) \quad (2)$$

$$TOL = Y_p - Y_s (t ha^{-1}) \quad (3)$$

$$GMP = \sqrt{Y_p \times Y_s} (t ha^{-1}) \quad (4)$$

$$STI = \frac{Y_p + Y_s}{(\bar{Y}_p)^2} \quad (5)$$

$$YI = \frac{Y_s}{\bar{Y}_s} \quad (6)$$

$$YSI = \frac{Y_s}{Y_p} \quad (7)$$

$$(\beta) \quad (8)$$

$\beta$  is the coefficient linear regression of yield of each genotype in each condition of the environmental index.

The new stress tolerance score (STS) method was used to apply these indices. This method is easier than the factor analysis (FA) method and could be applied to any number of genotypes, which is calculated by the following equation.

$$STS = MP + STI + GMP + YI + YSI - SSI - TOL - \beta \quad (9)$$

As it is deduced from the tolerance/susceptibility indices equations, high values are related to MP, STI and GMP, YI, and YSI indices and low values are related to SSI, Tol, and  $\beta$  indices, that are indicated higher resistance to drought stress. Therefore, MP, STI, GMP, YI, and YSI have a positive sign and coefficient, while SSI, Tol, and  $\beta$  have a negative coefficient [17]. Raw data cannot be used for calculating STS; hence, these indices must be first standardized and then used; the data are standardized using the following equation.

$$Z_{ij} = \frac{X_{ij} - \bar{X}_i}{S_i} \quad (10)$$

where  $Z_{ij}$  is the standard score for  $j$ th genotype  $i$ th index.  $X_{ij}$  is the raw data of  $j$ th genotype in  $i$ th index, and  $S_i$  is the standard deviation of  $i$ th index.

### 2.5. Statistical Analysis

ANOVA, simple correlation, and mean comparisons with LSD were performed by SAS 9.4 statistical software (SAS Institute Inc. Cary, NC, USA). The FA was used by means of MINITAB 19 software (State College, PA, USA).

### 3. Results

The results of ANOVA are shown that  $Y_p$  and  $Y_s$  were significant in all indices at all three sites in the tested years. Comparison of means indicated that IP13151 and IP13150 genotypes of pearl millet in Kerman and Jiroft, respectively and the speed feed genotype of sorghum in the Bardsir area had the highest yield under stress and non-stress conditions. According to Tables 4–6, there was a significant positive correlation between the yields ( $Y_p$ ) and ( $Y_s$ ), so that in Kerman ( $r = 0.76^{**}$ ,  $r = 0.98^{**}$ , and  $r = 0.99^{**}$ ) and in Jiroft ( $r = 0.98^{**}$ ,  $r = 0.98^{**}$ , and  $r = 0.99^{**}$ ).

**Table 4.** Simple correlation coefficients between  $Y_p$ ,  $Y_s$ , and drought tolerance/susceptibility indices of genotypes in Kerman in three years.

| 2016    | $Y_p$    | $Y_s$    | SSI      | MP       | TOL      | STI     | GMP     | YI      | YSI     | $\beta$ |
|---------|----------|----------|----------|----------|----------|---------|---------|---------|---------|---------|
| $Y_p$   | 1        |          |          |          |          |         |         |         |         |         |
| $Y_s$   | 0.76 **  | 1        |          |          |          |         |         |         |         |         |
| SSI     | 0.71 *   | 0.08     | 1        |          |          |         |         |         |         |         |
| MP      | 0.98 **  | 0.84 **  | 0.59     | 1        |          |         |         |         |         |         |
| TOL     | 0.97 **  | -0.58 ** | 0.85 **  | 0.92 **  | 1        |         |         |         |         |         |
| STI     | 0.96 **  | 0.89 **  | 0.51     | 0.99 **  | 0.88 **  | 1       |         |         |         |         |
| GMP     | 0.96 **  | 0.90 **  | 0.50     | 0.99 **  | 0.87 **  | 0.99 ** | 1       |         |         |         |
| YI      | 0.76 **  | 0.99 **  | 0.09     | 0.85 **  | 0.59 *   | 0.89 ** | 0.90 ** | 1       |         |         |
| YSI     | -0.68    | -0.05    | -0.99 ** | -0.57    | -0.83 ** | -0.48   | -0.47   | -0.06   | 1       |         |
| $\beta$ | -0.69 ** | 0.08     | -0.97 ** | -0.58 ** | -0.82 ** | -0.50 * | 0.48    | 0.09    | -0.97 * | 1       |
| 2017    | $Y_p$    | $Y_s$    | SSI      | MP       | TOL      | STI     | GMP     | YI      | YSI     | $\beta$ |
| $Y_p$   | 1        |          |          |          |          |         |         |         |         |         |
| $Y_s$   | 0.98 **  | 1        |          |          |          |         |         |         |         |         |
| SSI     | -0.11    | -0.26    | 1        |          |          |         |         |         |         |         |
| MP      | 0.99 **  | 0.99 **  | -0.84 ** | 1        |          |         |         |         |         |         |
| TOL     | 0.99 **  | 0.39     | -0.82 ** | 0.99 **  | 1        |         |         |         |         |         |
| STI     | 0.99 **  | 0.99 **  | -0.85 ** | 0.99 **  | 0.99 **  | 1       |         |         |         |         |
| GMP     | 0.99 **  | 0.99 **  | -0.85 ** | 0.99 **  | 0.99 **  | 0.99 ** | 1       |         |         |         |
| YI      | 0.98 **  | 0.99 **  | -0.86 ** | 0.99 **  | 0.99 **  | 0.99 ** | 0.99 ** | 1       |         |         |
| YSI     | 0.23 **  | 0.38 **  | -0.78 ** | 0.80 **  | 0.78 **  | 0.81 ** | 0.80 ** | 0.81 ** | 1       |         |
| $\beta$ | 0.12     | -0.03    | 0.48     | -0.06    | -0.01    | -0.09   | -0.07   | -0.1    | -0.41   | 1       |
| 2018    | $Y_p$    | $Y_s$    | SSI      | MP       | TOL      | STI     | GMP     | YI      | YSI     | $\beta$ |
| $Y_p$   | 1        |          |          |          |          |         |         |         |         |         |
| $Y_s$   | 0.99 **  | 1        |          |          |          |         |         |         |         |         |
| SSI     | -0.22 ** | -0.29 ** | 1        |          |          |         |         |         |         |         |
| MP      | 0.99 **  | 0.99 **  | -0.23 ** | 1        |          |         |         |         |         |         |
| TOL     | 0.99 **  | -0.43 *  | -0.18    | 0.99 **  | 1        |         |         |         |         |         |
| STI     | 0.99 **  | 0.99 **  | -0.25    | 0.99 **  | 0.99 **  | 1       |         |         |         |         |
| GMP     | 0.99 **  | 0.99 **  | -0.25    | 0.99 **  | 0.99 **  | 0.99 ** | 1       |         |         |         |
| YI      | 0.99 **  | 0.99 **  | -0.29    | 0.99 **  | 0.99 **  | 0.99 ** | 0.99 ** | 1       |         |         |
| YSI     | -0.08 ** | -0.01 ** | -0.76 ** | -0.06    | 0.11     | 0.06    | -0.04   | -0.009  | 1       |         |
| $\beta$ | 0.16     | 0.08     | -0.87 ** | 0.14     | 0.20     | 0.12    | 0.12    | 0.08    | -0.8 ** | 1       |

Significant at the \* 0.05 and \*\* 0.01 probability level.



Table 6. Cont.

|                |                |                |       |         |         |         |         |         |      |   |
|----------------|----------------|----------------|-------|---------|---------|---------|---------|---------|------|---|
| SSI            | −0.52          | −0.59          | 1     |         |         |         |         |         |      |   |
| MP             | 0.99 **        | 0.99 **        | −0.54 | 1       |         |         |         |         |      |   |
| TOL            | 0.99 **        | 0.38           | −0.47 | 0.99 ** | 1       |         |         |         |      |   |
| STI            | 0.99 **        | 0.99 **        | −0.56 | 0.99 ** | 0.99 ** | 1       |         |         |      |   |
| GMP            | 0.99 **        | 0.99 **        | −0.56 | 0.99 ** | 0.99 ** | 0.99 ** | 1       |         |      |   |
| YI             | 0.85 **        | 0.86 **        | −0.6  | 0.85 ** | 0.84 ** | 0.85 ** | 0.86 ** | 1       |      |   |
| YSI            | 0.52           | 0.59           | −1    | 0.54    | 0.47    | 0.56    | 0.56    | 0.60 *  | 1    |   |
| β              | 0.98 **        | −0.96 **       | −0.41 | 0.97 ** | 0.99 ** | 0.97 ** | 0.97 ** | 0.80 ** | 0.41 | 1 |
| 2018           | Y <sub>p</sub> | Y <sub>s</sub> | SSI   | MP      | TOL     | STI     | GMP     | YI      | YSI  | β |
| Y <sub>p</sub> | 1              |                |       |         |         |         |         |         |      |   |
| Y <sub>s</sub> | 0.99 **        | 1              |       |         |         |         |         |         |      |   |
| SSI            | −0.46          | −0.41          | 1     |         |         |         |         |         |      |   |
| MP             | 0.99 **        | 0.99 **        | −0.45 | 1       |         |         |         |         |      |   |
| TOL            | 0.98 **        | −0.48 *        | −0.48 | 0.99 ** | 1       |         |         |         |      |   |
| STI            | 0.99 **        | 0.99 **        | −0.43 | 0.99 ** | 0.99 ** | 1       |         |         |      |   |
| GMP            | 0.99 **        | 0.99 **        | −0.43 | 0.99 ** | 0.99 ** | 0.99 ** | 1       |         |      |   |
| YI             | 0.99 **        | 0.99 **        | −0.41 | 0.99 ** | 0.98 ** | 0.99 ** | 0.99 ** | 1       |      |   |
| YSI            | −0.19          | −0.11          | 0.23  | −0.17   | −0.24   | −0.16   | −0.15   | −0.1    | 1    |   |
| β              | 0.26           | −0.16          | −0.57 | 0.24    | 0.32    | 0.22    | 0.21    | 0.16    | −0.8 | 1 |

Significant at the \* 0.05 and \*\* 0.01 probability level.

This correlation implies that by using normal conditions it could perform a direct selection for stress conditions, and this role indicates the yield potential under drought stress conditions [18]. However, Si-o-seh Mardeh et al. (2006) [19] reported a negative correlation between yields in stress and non-stress conditions, which was inconsistent with the results of the present study. Eight drought tolerance/susceptibility indices (SSI, MP, TOL, GMP, STI, YI, YSI, and β) were used for selecting the favorable genotypes with acceptable yield in different climatic conditions.

According to the Tables 4–6, four indices MP, GMP, STI, and YI had positive and strong correlations with Y<sub>p</sub> and Y<sub>s</sub>. This was also reported by Ilker et al. (2011) [20] that high-yielding genotypes could be assessed by MP, GMP, and STI indices under stress and non-stress conditions; while Jafari (2009) [21] introduced the STI index for this selection. According to the results of the present study, MP, GMP, STI, and YI were the most appropriate and effective indices. On the other hand, three indices of SSI, TOL, and β correlated negatively with yield under stress conditions.

According to Table 7, the first two factors were calculated using the FA method with varimax rotation in 2016, 2017, and 2018, and there was a high factor loading among MP, TOL, GMP, and YI in Kerman, Bardsir, and Jiroft regarding the first factor (FA1) for every three years. These indices had positive coefficients for FA1. There was a high factor loading between the SSI and YSI indices for the second factor (FA2) with a positive coefficient. However, these two indices had negative coefficients in Jiroft and Bardsir in the second year. However, FA1 and FA2 were considered as drought tolerant factors. Higher FA1 + FA2 score shows higher drought tolerance and lower genotypic susceptibility scores indicate the susceptibility to drought.

**Table 7.** Factor analysis (FA) for drought tolerance/susceptibility indices of genotypes in Kerman, Jiroft, and Bardsir in three years.

| <i>Kerman</i>  |                |        | <i>2016</i> |                |        | <i>2017</i> |                |        | <i>2018</i> |  |  |
|----------------|----------------|--------|-------------|----------------|--------|-------------|----------------|--------|-------------|--|--|
| <b>Index</b>   | Factor loading |        | Com.        | Factor loading |        | Com.        | Factor loading |        | Com.        |  |  |
|                | FA1            | FA2    |             | FA1            | FA2    |             | FA1            | FA2    |             |  |  |
| <b>SSI</b>     | −0.293         | 0.955  | 0.996       | −0.164         | 0.986  | 0.997       | −0.054         | 0.998  | 0.99        |  |  |
| <b>MP</b>      | 0.960          | −0.276 | 1           | 0.999          | −0.038 | 1           | 0.999          | 0.012  | 1           |  |  |
| <b>TOL</b>     | 0.992          | −0.123 | 0.996       | 0.991          | 0.121  | 1           | 0.992          | 0.117  | 0.999       |  |  |
| <b>STI</b>     | 0.952          | −0.301 | 0.998       | 0.992          | −0.101 | 0.994       | 0.997          | −0.026 | 0.998       |  |  |
| <b>GMP</b>     | 0.946          | −0.321 | 1           | 0.995          | −0.093 | 1           | 0.999          | −0.026 | 1           |  |  |
| <b>YI</b>      | 0.918          | −0.394 | 0.997       | 0.981          | −0.191 | 1           | 0.994          | −0.101 | 1           |  |  |
| <b>YSI</b>     | 0.290          | 0.956  | 0.996       | 0.167          | 0.985  | 0.997       | 0.054          | 0.998  | 0.997       |  |  |
| <b>B</b>       | −0.221         | 0.974  | 0.97        | 0.152          | 0.987  | 0.995       | 0.095          | 0.994  | 0.998       |  |  |
| <b>%Var</b>    | 0.517          | 0.477  | 0.994       | 0.71           | 0.287  | 0.998       | 0.574          | 0.424  | 0.998       |  |  |
| <i>Jiroft</i>  |                |        | <i>2016</i> |                |        | <i>2017</i> |                |        | <i>2018</i> |  |  |
| <b>Index</b>   | Factor loading |        | Com.        | Factor loading |        | Com.        | Factor loading |        | Com.        |  |  |
|                | FA1            | FA2    |             | FA1            | FA2    |             | FA1            | FA2    |             |  |  |
| <b>SSI</b>     | −0.207         | −0.977 | 0.948       | 0.044          | 0.998  | 1           | 0.230          | 0.931  | 1           |  |  |
| <b>MP</b>      | 0.918          | 0.395  | 0.998       | 0.999          | 0.039  | 1           | 0.998          | −0.056 | 1           |  |  |
| <b>TOL</b>     | 0.984          | 0.174  | 0.992       | 0.985          | 0.170  | 0.999       | 0.994          | −0.095 | 1           |  |  |
| <b>STI</b>     | 0.853          | 0.512  | 0.992       | 0.995          | −0.019 | 0.991       | 0.993          | −0.045 | 0.989       |  |  |
| <b>GMP</b>     | 0.888          | 0.458  | 0.999       | 0.999          | −0.007 | 1           | 0.999          | −0.041 | 1           |  |  |
| <b>YI</b>      | 0.824          | 0.564  | 1           | 0.994          | −0.101 | 1           | 0.999          | −0.012 | 1           |  |  |
| <b>YSI</b>     | 0.207          | 0.977  | 0.976       | −0.046         | −0.998 | 1           | 0.102          | 0.960  | 1           |  |  |
| <b>B</b>       | 0.990          | −0.040 | 0.979       | 0.955          | 0.257  | 0.979       | 0.976          | −0.103 | 0.973       |  |  |
| <b>%Var</b>    | 0.543          | 0.442  | 0.986       | 0.733          | 0.263  | 0.996       | 0.742          | 0.253  | 0.995       |  |  |
| <i>Bardsir</i> |                |        | <i>2016</i> |                |        | <i>2017</i> |                |        | <i>2018</i> |  |  |
| <b>Index</b>   | Factor loading |        | Com.        | Factor loading |        | Com.        | Factor loading |        | Com.        |  |  |
|                | FA1            | FA2    |             | FA1            | FA2    |             | FA1            | FA2    |             |  |  |
| <b>SSI</b>     | 0.085          | 0.996  | 1           | −0.275         | −0.956 | 0.998       | −0.418         | 0.658  | 1           |  |  |
| <b>MP</b>      | 0.985          | 0.167  | 1           | 0.949          | 0.307  | 0.991       | 0.992          | −0.010 | 1           |  |  |
| <b>TOL</b>     | 0.963          | 0.267  | 1           | 0.971          | 0.227  | 0.972       | 0.980          | −0.185 | 0.999       |  |  |
| <b>STI</b>     | 0.992          | 0.118  | 0.998       | 0.935          | 0.343  | 1           | 0.995          | −0.061 | 0.998       |  |  |
| <b>GMP</b>     | 0.989          | 0.140  | 1           | 0.941          | 0.331  | 1           | 0.995          | −0.080 | 0.981       |  |  |
| <b>YI</b>      | 0.996          | 0.076  | 0.997       | 0.798          | 0.428  | 0.968       | 0.998          | −0.029 | 1           |  |  |
| <b>YSI</b>     | −0.082         | 0.996  | 0.996       | 0.261          | −0.960 | 0.947       | 0.161          | 0.966  | 0.997       |  |  |
| <b>B</b>       | 0.312          | 0.949  | 0.97        | 0.981          | 0.144  | 1           | 0.126          | 0.971  | 0.998       |  |  |
| <b>%Var</b>    | 0.621          | 0.378  | 0.994       | 0.669          | 0.308  | 1           | 0.63           | 0.369  | 0.369       |  |  |

Note: Com. = Communality.

#### 4. Discussion

The strong and positive correlation among MP, GMP, STI, and YI indices were shown that they could produce identical results. Selections based on these indices resulted in genotypes with high yield.

In contrast, there was a strong and negative correlation between  $\beta$  and TOL indices with  $Y_s$  (Tables 4–6). Hence, according to Fernandez (1992) [10], low-yield potential genotypes can be selected based on TOL under non-stress conditions and high-yield potential genotypes can be selected under stress conditions. Thus, the idea of selection based on STI, MP, GMP, and YI was employed to select favorable low-yield potential genotypes.

In this study, the IP13151 and TP13150 pearl millet genotypes and speed feed sorghum genotype (with the highest yield under stress conditions) were introduced as the most drought tolerant genotypes in Kerman, Jiroft, and Bardsir in the tested years, respectively (Table 8). Comparison of this result with the result of multivariate statistical methods that can be used the indices simultaneously, such as FA and STS methods are given in this table.

**Table 8.** Mean yield in regularly irrigated ( $Y_p$ ) and water deficiency ( $Y_s$ ) conditions and drought tolerance/susceptibility indices for genotypes in three years.

| <i>Kerman</i>    |                         |                         |      |                      |                       |      |                       |      |      |         |              |       |
|------------------|-------------------------|-------------------------|------|----------------------|-----------------------|------|-----------------------|------|------|---------|--------------|-------|
| 2016<br>Genotype | $Y_p$ (t<br>$ha^{-1}$ ) | $Y_s$ (t $ha^{-1}$ )    | SSI  | MP (t<br>$ha^{-1}$ ) | TOL (t<br>$ha^{-1}$ ) | STI  | GMP (t<br>$ha^{-1}$ ) | YI   | YSI  | $\beta$ | FA1 +<br>FA2 | STS   |
| HHVBC            | 67.69                   | 27.32                   | 1.29 | 47.51                | 40.37                 | 0.27 | 43                    | 0.75 | 0.4  | 2.2     | 3.21         | -1.92 |
| IP22269          | 78.86                   | 34.51                   | 1.21 | 56.69                | 44.35                 | 0.4  | 52.15                 | 0.95 | 0.44 | 2.07    | 0.26         | -0.43 |
| HYB-1            | 84.86                   | 36.14                   | 1.24 | 60.5                 | 48.72                 | 0.45 | 55.36                 | 1    | 0.43 | 2.14    | -0.02        | 1.59  |
| HYB-2            | 90.92                   | 37.16                   | 1.28 | 64.04                | 53.76                 | 0.5  | 58.12                 | 1.02 | 0.41 | 2.24    | -0.37        | 2.23  |
| IP13150          | 99.65                   | 39.8                    | 1.3  | 69.73                | 59.85                 | 0.59 | 62.98                 | 1.1  | 0.4  | 2.17    | -0.52        | 4.34  |
| ICM-05222        | 82.81                   | 33.12                   | 1.3  | 57.97                | 49.69                 | 0.41 | 52.37                 | 0.91 | 0.4  | 2.27    | 1.22         | -1.19 |
| IP13151          | 99.96                   | 40.8                    | 1.28 | 70.38                | 59.16                 | 0.61 | 63.86                 | 1.13 | 0.41 | 2.27    | -0.89        | 4.6   |
| S35              | 71.34                   | 36.18                   | 1.06 | 53.76                | 35.16                 | 0.38 | 50.76                 | 1    | 0.51 | 1.76    | 3.89         | -3.88 |
| ICS-112          | 68.7                    | 35.34                   | 1.03 | 52.02                | 33.36                 | 0.36 | 49.16                 | 0.97 | 0.53 | 1.72    | 7.71         | -6.35 |
| SPEEDFEED        | 92.92                   | 37.68                   | 1.29 | 65.3                 | 55.24                 | 0.52 | 59.17                 | 1.04 | 0.41 | 2.1     | -0.27        | 3.01  |
| ICS-14001        | 81.75                   | 36.95                   | 1.18 | 59.35                | 44.8                  | 0.45 | 54.95                 | 1.02 | 0.45 | 2.01    | -0.35        | 1.39  |
| PEGAH            | 66.02                   | 33.86                   | 1.05 | 49.94                | 32.16                 | 0.33 | 47.28                 | 0.93 | 0.51 | 1.73    | -2.43        | 0.52  |
| LSD              | 2.07                    | 3                       | 0.09 | 3.68                 | 6.56                  | 0.05 | 3.38                  | 0.08 | 0.05 | 0.21    |              |       |
| 2017<br>Genotype | $Y_p$ (t<br>$ha^{-1}$ ) | $Y_s$ (t<br>$ha^{-1}$ ) | SSI  | MP (t<br>$ha^{-1}$ ) | TOL (t<br>$ha^{-1}$ ) | STI  | GMP (t<br>$ha^{-1}$ ) | YI   | YSI  | $\beta$ | FA1 +<br>FA2 | STS   |
| HHVBC            | 85.54                   | 27.54                   | 1.04 | 56.28                | 58.53                 | 0.29 | 48.07                 | 0.92 | 0.32 | 2.92    | 0.82         | -6.31 |
| IP22269          | 93.34                   | 30.33                   | 1.03 | 62.84                | 65                    | 0.36 | 53.77                 | 1.03 | 0.32 | 2.92    | 0.37         | -3.49 |
| HYB-1            | 96.46                   | 31.56                   | 1.02 | 56.44                | 64.89                 | 0.38 | 55.17                 | 1.07 | 0.33 | 2.84    | -1.44        | 1.14  |
| HYB-2            | 103.44                  | 33.77                   | 1.02 | 60.23                | 69.68                 | 0.43 | 59.1                  | 1.15 | 0.33 | 2.86    | -1.28        | 2.99  |
| IP13150          | 111.74                  | 37.03                   | 1.01 | 65.1                 | 74.71                 | 0.51 | 64.32                 | 1.26 | 0.33 | 2.83    | -2.28        | 5.95  |
| ICM-05222        | 97.52                   | 30.57                   | 1.04 | 55.08                | 66.95                 | 0.37 | 54.6                  | 1.04 | 0.31 | 2.97    | 1.3          | -0.62 |
| IP13151          | 115.71                  | 38.22                   | 1.03 | 65.08                | 77.5                  | 0.55 | 66.5                  | 1.3  | 0.33 | 2.85    | -2.05        | 8.72  |
| S35              | 72.41                   | 22.58                   | 1.04 | 48.01                | 49.83                 | 0.2  | 40.42                 | 0.77 | 0.31 | 2.91    | 1.61         | -3.17 |
| ICS-112          | 74.63                   | 22.32                   | 1.06 | 46.43                | 52.31                 | 0.21 | 40.81                 | 0.76 | 0.3  | 2.04    | 4.2          | -4.12 |
| SPEEDFEED        | 94.24                   | 31.6                    | 1.01 | 61.71                | 62.64                 | 0.37 | 54.27                 | 1.08 | 0.34 | 2.77    | -3.06        | 5.19  |
| ICS-14001        | 83.62                   | 27.84                   | 1.01 | 54.58                | 55.79                 | 0.29 | 48.25                 | 0.95 | 0.33 | 2.76    | -2.59        | -0.15 |
| PEGAH            | 63.34                   | 21.38                   | 1    | 43.76                | 41.97                 | 0.17 | 36.8                  | 0.73 | 0.34 | 2.64    | -3.50        | -1.28 |
| LSD              | 6.01                    | 3.02                    | 0.09 | 3.55                 | 6.32                  | 0.05 | 3.32                  | 0.08 | 0.05 | 0.2     |              |       |

Table 8. Cont.

| 2018<br>Genotype | Y <sub>p</sub> (t<br>ha <sup>-1</sup> ) | Y <sub>s</sub> (t<br>ha <sup>-1</sup> ) | SSI  | MP (t<br>ha <sup>-1</sup> ) | TOL (t<br>ha <sup>-1</sup> ) | STI  | GMP (t<br>ha <sup>-1</sup> ) | YI   | YSI  | β    | FA1 +<br>FA2 | STS   |
|------------------|---|---|------|-----------------------------|------------------------------|------|------------------------------|------|------|------|--------------|-------|
| HHVBC            | 84.5                                    | 26.63                                   | 1.01 | 55.57                       | 57.87                        | 0.27 | 47.44                        | 0.93 | 0.32 | 3.09 | -1.15        | -0.68 |
| IP22269          | 94.24                                   | 29.84                                   | 1    | 62.04                       | 64.4                         | 0.34 | 53.02                        | 1.04 | 0.32 | 3.08 | -1.51        | 1.71  |
| HYB-1            | 96.03                                   | 30.31                                   | 1.01 | 63.17                       | 65.72                        | 0.35 | 53.95                        | 1.06 | 0.32 | 3.09 | -1.26        | 1.67  |
| HYB-2            | 102.84                                  | 32.04                                   | 1.01 | 67.44                       | 70.8                         | 0.4  | 57.4                         | 1.12 | 0.31 | 3.14 | -0.35        | 1.39  |
| IP13150          | 111.56                                  | 36.32                                   | 1.01 | 73.94                       | 75.25                        | 0.49 | 63.65                        | 1.27 | 0.33 | 3.01 | -0.64        | 4.6   |
| ICM-05222        | 97.19                                   | 30.29                                   | 1.01 | 63.74                       | 66.91                        | 0.36 | 54.25                        | 1.06 | 0.31 | 3.14 | -0.38        | 0.3   |
| IP13151          | 113.77                                  | 36.02                                   | 1    | 74.9                        | 77.75                        | 0.5  | 64.01                        | 1.26 | 0.32 | 3.1  | -2.11        | 6.53  |
| S35              | 71.98                                   | 22.04                                   | 1.02 | 47.01                       | 49.95                        | 0.19 | 39.82                        | 0.77 | 0.31 | 3.17 | 0.86         | -6.29 |
| ICS-112          | 73.95                                   | 22.69                                   | 1.02 | 48.32                       | 51.26                        | 0.2  | 40.96                        | 0.79 | 0.31 | 3.16 | 0.66         | -5.65 |
| SPEEDFEED        | 95.02                                   | 30.32                                   | 1    | 62.67                       | 64.7                         | 0.35 | 53.67                        | 1.06 | 0.32 | 3.06 | -2.03        | 2.78  |
| ICS-14001        | 83.18                                   | 26.61                                   | 1    | 54.9                        | 56.58                        | 0.27 | 47.04                        | 0.93 | 0.32 | 3.04 | -2.20        | 0.85  |
| PEGAH            | 63.07                                   | 20.28                                   | 1    | 41.68                       | 42.78                        | 0.15 | 35.76                        | 0.71 | 0.32 | 3    | -2.62        | -1.98 |
| LSD              | 6.35                                    | 3.09                                    | 0.09 | 3.79                        | 6.51                         | 0.06 | 3.5                          | 0.08 | 0.05 | 0.21 |              |       |
| <i>Jiroft</i>    |   |   |      |                             |                              |      |                              |      |      |      |              |       |
| 2016<br>Genotype | Y <sub>p</sub> (t<br>ha <sup>-1</sup> ) | Y <sub>s</sub> (t<br>ha <sup>-1</sup> ) | SSI  | MP (t<br>ha <sup>-1</sup> ) | TOL (t<br>ha <sup>-1</sup> ) | STI  | GMP (t<br>ha <sup>-1</sup> ) | YI   | YSI  | β    | FA1 +<br>FA2 | STS   |
| HHVBC            | 85.69                                   | 25.31                                   | 1.02 | 55.5                        | 60.38                        | 0.26 | 46.57                        | 0.72 | 0.3  | 1.46 | -4.99        | -2.92 |
| IP22269          | 95.66                                   | 27.74                                   | 1.03 | 61.7                        | 67.92                        | 0.32 | 51.51                        | 0.79 | 0.29 | 1.7  | -1.59        | -2.92 |
| HYB-1            | 96.72                                   | 29.09                                   | 1.01 | 62.91                       | 67.63                        | 0.34 | 53.04                        | 0.83 | 0.3  | 1.65 | 0.75         | -1.06 |
| HYB-2            | 103.1                                   | 32.91                                   | 0.99 | 68.01                       | 70.19                        | 0.41 | 58.23                        | 0.94 | 0.32 | 1.66 | 6.95         | 2.73  |
| IP13150          | 109.98                                  | 38.46                                   | 0.94 | 74.22                       | 71.52                        | 0.51 | 65.01                        | 1.09 | 0.35 | 1.6  | 15.96        | 8.86  |
| ICM-05222        | 97.57                                   | 28.35                                   | 1.03 | 62.96                       | 69.22                        | 0.33 | 52.59                        | 0.81 | 0.29 | 1.73 | -0.66        | -2.65 |
| IP13151          | 116.52                                  | 37.8                                    | 0.98 | 77.16                       | 78.72                        | 0.53 | 66.36                        | 1.07 | 0.32 | 1.8  | 14.39        | 5.45  |
| S35              | 70.82                                   | 21.2                                    | 1.02 | 46.01                       | 49.62                        | 0.18 | 38.74                        | 0.6  | 0.3  | 1.01 | -10.64       | -3.17 |
| ICS-112          | 73.84                                   | 21.41                                   | 1.03 | 47.63                       | 52.43                        | 0.19 | 39.76                        | 0.61 | 0.29 | 1.16 | -10.75       | -4.39 |
| SPEEDFEED        | 94.35                                   | 31.02                                   | 0.97 | 62.69                       | 63.33                        | 0.35 | 54.1                         | 0.88 | 0.33 | 1.47 | 4.51         | 3.21  |
| ICS-14001        | 83.66                                   | 25.47                                   | 1.01 | 54.57                       | 58.18                        | 0.26 | 46.16                        | 0.72 | 0.3  | 1.38 | -4.36        | -1.66 |
| PEGAH            | 63.5                                    | 19.75                                   | 1    | 41.63                       | 43.75                        | 0.15 | 35.4                         | 0.56 | 0.31 | 0.76 | -11.91       | -1.82 |
| LSD              | 8.31                                    | 3.26                                    | 0.09 | 5.54                        | 6.06                         | 0.06 | 4.97                         | 0.09 | 0.02 | 0.24 |              |       |

Table 8. Cont.

| 2017<br>Genotype | Y <sub>p</sub> (t<br>ha <sup>-1</sup> ) | Y <sub>s</sub> (t<br>ha <sup>-1</sup> ) | SSI  | MP (t<br>ha <sup>-1</sup> ) | TOL (t<br>ha <sup>-1</sup> ) | STI  | GMP (t<br>ha <sup>-1</sup> ) | YI   | YSI  | β    | FA1 +<br>FA2 | STS   |
|------------------|---|---|------|-----------------------------|------------------------------|------|------------------------------|------|------|------|--------------|-------|
| HHVBC            | 85.71                                   | 26.02                                   | 1.03 | 55.87                       | 59.69                        | 0.27 | 47.23                        | 0.89 | 0.3  | 1.42 | 1.64         | -4.03 |
| IP22269          | 95.68                                   | 30.09                                   | 1.01 | 62.89                       | 65.59                        | 0.35 | 53.65                        | 1.03 | 0.31 | 1.57 | 0.53         | -0.74 |
| HYB-1            | 96.75                                   | 31.6                                    | 0.99 | 64.17                       | 65.15                        | 0.37 | 55.29                        | 1.08 | 0.33 | 1.52 | -0.67        | 1.68  |
| HYB-2            | 103.14                                  | 33.01                                   | 1    | 68.07                       | 70.13                        | 0.41 | 58.35                        | 1.12 | 0.32 | 1.65 | 0            | 1.4   |
| IP13150          | 117.18                                  | 37.29                                   | 1    | 77.24                       | 79.9                         | 0.53 | 66.1                         | 1.27 | 0.32 | 1.84 | 0.18         | 3.36  |
| ICM-05222        | 97.77                                   | 30.12                                   | 1.02 | 63.95                       | 67.65                        | 0.35 | 54.27                        | 1.03 | 0.31 | 1.63 | 1.2          | -1.70 |
| IP13151          | 108.58                                  | 35.25                                   | 0.99 | 71.92                       | 73.34                        | 0.46 | 61.96                        | 1.2  | 0.32 | 1.7  | -0.47        | 3.21  |
| S35              | 72.35                                   | 22.98                                   | 1    | 47.67                       | 49.37                        | 0.2  | 40.75                        | 0.78 | 0.32 | 1.03 | 0.05         | -2.65 |
| ICS-112          | 73.93                                   | 22.85                                   | 1.02 | 48.39                       | 51.08                        | 0.21 | 41.09                        | 0.78 | 0.31 | 1.09 | 1.17         | -4.27 |
| SPEEDFEED        | 94.35                                   | 31.57                                   | 0.98 | 62.96                       | 62.41                        | 0.36 | 54.58                        | 1.08 | 0.33 | 1.45 | -1.48        | 2.86  |
| ICS-14001        | 83.66                                   | 28.18                                   | 0.98 | 55.92                       | 55.48                        | 0.28 | 48.55                        | 0.96 | 0.34 | 1.24 | -1.67        | 1.69  |
| PEGAH            | 63.62                                   | 21.4                                    | 0.98 | 42.51                       | 42.22                        | 0.16 | 36.89                        | 0.73 | 0.34 | 0.7  | -1.63        | -0.52 |
| LSD              | 8.31                                    | 1.95                                    | 0.08 | 5.07                        | 6.58                         | 0.04 | 3.99                         | 0.06 | 0.02 | 0.25 |              |       |
| 2018<br>Genotype | Y <sub>p</sub> (t<br>ha <sup>-1</sup> ) | Y <sub>s</sub> (t<br>ha <sup>-1</sup> ) | SSI  | MP (t<br>ha <sup>-1</sup> ) | TOL (t<br>ha <sup>-1</sup> ) | STI  | GMP (t<br>ha <sup>-1</sup> ) | YI   | YSI  | β    | FA1 +<br>FA2 | STS   |
| HHVBC            | 85.32                                   | 26.57                                   | 1    | 55.95                       | 58.74                        | 0.28 | 47.62                        | 0.76 | 0.31 | 1.38 | -0.73        | -1.15 |
| IP22269          | 95.28                                   | 30.09                                   | 1    | 62.69                       | 65.19                        | 0.35 | 53.55                        | 0.86 | 0.32 | 1.55 | 0.56         | 1.54  |
| HYB-1            | 96.1                                    | 30.26                                   | 1    | 63.18                       | 65.84                        | 0.35 | 53.93                        | 0.87 | 0.31 | 1.57 | 0.3          | 1.37  |
| HYB-2            | 102.9                                   | 32.11                                   | 1    | 67.5                        | 70.79                        | 0.4  | 57.48                        | 0.92 | 0.31 | 1.69 | -0.55        | 1.48  |
| IP13150          | 117.05                                  | 36.31                                   | 1    | 77.18                       | 79.74                        | 0.53 | 66.08                        | 1.07 | 0.32 | 1.84 | -0.81        | 4.9   |
| ICM-05222        | 97.88                                   | 30.4                                    | 1    | 64.14                       | 67.48                        | 0.36 | 54.55                        | 0.87 | 0.31 | 1.62 | -0.99        | 0.26  |
| IP13151          | 113.81                                  | 35.58                                   | 1    | 74.7                        | 78.24                        | 0.49 | 63.63                        | 1.02 | 0.31 | 1.83 | -0.40        | 3.43  |
| S35              | 71.13                                   | 22.5                                    | 1    | 46.81                       | 48.63                        | 0.2  | 40                           | 0.64 | 0.32 | 0.97 | 0.9          | -0.98 |
| ICS-112          | 74.02                                   | 22.96                                   | 1.01 | 48.49                       | 51.05                        | 0.21 | 41.23                        | 0.66 | 0.31 | 1.09 | 1.07         | -2.71 |
| SPEEDFEED        | 94.03                                   | 30.15                                   | 0.99 | 62.09                       | 63.88                        | 0.34 | 53.24                        | 0.86 | 0.32 | 1.51 | 0.09         | 2.87  |
| ICS-14001        | 83.33                                   | 26.5                                    | 0.99 | 54.92                       | 56.83                        | 0.27 | 46.99                        | 0.76 | 0.32 | 1.31 | -1.18        | 0.57  |
| PEGAH            | 63.37                                   | 20                                      | 1    | 41.69                       | 43.37                        | 0.15 | 35.6                         | 0.57 | 0.32 | 0.74 | 0.49         | -2.05 |
| LSD              | 7.57                                    | 2.29                                    | 0.01 | 4.89                        | 5.41                         | 0.04 | 4.12                         | 0.07 | 0.01 | 0.22 |              |       |

Table 8. Cont.

| <i>Bardsir</i>   |   |   |      |                             |                              |      |                              |      |      |      |              |       |
|------------------|---|---|------|-----------------------------|------------------------------|------|------------------------------|------|------|------|--------------|-------|
| 2016<br>Genotype | Y <sub>p</sub> (t<br>ha <sup>-1</sup> ) | Y <sub>s</sub> (t<br>ha <sup>-1</sup> ) | SSI  | MP (t<br>ha <sup>-1</sup> ) | TOL (t<br>ha <sup>-1</sup> ) | STI  | GMP (t<br>ha <sup>-1</sup> ) | YI   | YSI  | β    | FA1 +<br>FA2 | STS   |
| HHVBC            | 75.69                                   | 27.15                                   | 1.01 | 51.42                       | 48.54                        | 0.29 | 45.33                        | 0.89 | 0.36 | 2.69 | 0.26         | -4.00 |
| IP22269          | 79.21                                   | 28.54                                   | 1    | 53.88                       | 50.67                        | 0.32 | 47.55                        | 0.94 | 0.36 | 2.68 | -0.07        | -2.24 |
| HYB-1            | 81.75                                   | 29.56                                   | 1    | 55.66                       | 52.18                        | 0.34 | 49.16                        | 0.97 | 0.36 | 2.67 | -0.33        | -0.89 |
| HYB-2            | 92.49                                   | 32.89                                   | 1.01 | 62.69                       | 59.6                         | 0.43 | 55.16                        | 1.08 | 0.36 | 2.73 | 0.9          | -0.36 |
| IP13150          | 95.67                                   | 34.37                                   | 1.01 | 65.02                       | 61.3                         | 0.47 | 57.34                        | 1.13 | 0.36 | 2.71 | 0.14         | 2.39  |
| ICM-05222        | 81.4                                    | 29.18                                   | 1.01 | 55.29                       | 52.22                        | 0.34 | 48.73                        | 0.96 | 0.36 | 2.7  | 0.32         | -2.44 |
| IP13151          | 96.02                                   | 34.76                                   | 1    | 65.39                       | 61.26                        | 0.48 | 57.77                        | 1.14 | 0.36 | 2.68 | -0.40        | 3.79  |
| S35              | 77.13                                   | 28.83                                   | 0.98 | 52.98                       | 48.3                         | 0.32 | 47.15                        | 0.95 | 0.37 | 2.58 | -2.71        | 3     |
| ICS-112          | 77.81                                   | 28.15                                   | 1    | 52.98                       | 49.65                        | 0.31 | 46.8                         | 0.93 | 0.36 | 2.67 | -0.37        | -1.98 |
| SPEEDFEED        | 97.33                                   | 35.81                                   | 0.99 | 66.57                       | 61.51                        | 0.5  | 59.03                        | 1.18 | 0.37 | 2.64 | -1.60        | 6.95  |
| ICS-14001        | 82.7                                    | 30.37                                   | 0.99 | 56.53                       | 52.33                        | 0.36 | 50.11                        | 1    | 0.37 | 2.63 | -1.44        | 1.89  |
| PEGAH            | 67.89                                   | 25.05                                   | 0.99 | 46.47                       | 42.85                        | 0.24 | 41.24                        | 0.82 | 0.37 | 2.6  | -1.78        | -1.79 |
| LSD              | 4.39                                    | 2.1                                     | 0.02 | 3.19                        | 2.58                         | 0.04 | 3.01                         | 0.08 | 0.01 | 0.07 |              |       |
| 2017<br>Genotype | Y <sub>p</sub> (t<br>ha <sup>-1</sup> ) | Y <sub>s</sub> (t<br>ha <sup>-1</sup> ) | SSI  | MP (t<br>ha <sup>-1</sup> ) | TOL (t<br>ha <sup>-1</sup> ) | STI  | GMP (t<br>ha <sup>-1</sup> ) | YI   | YSI  | β    | FA1 +<br>FA2 | STS   |
| HHVBC            | 75.68                                   | 27.46                                   | 1.01 | 51.57                       | 48.22                        | 0.3  | 45.58                        | 0.75 | 0.36 | 1.27 | -2.25        | -2.66 |
| IP22269          | 79.08                                   | 28.79                                   | 1.01 | 53.94                       | 50.3                         | 0.33 | 47.71                        | 0.56 | 0.36 | 1.33 | -1.86        | -3.35 |
| HYB-1            | 81.57                                   | 29.65                                   | 1.01 | 55.61                       | 51.92                        | 0.35 | 49.18                        | 0.81 | 0.36 | 1.37 | -2.05        | -1.76 |
| HYB-2            | 92.32                                   | 33.49                                   | 1.01 | 62.91                       | 58.83                        | 0.44 | 55.6                         | 0.91 | 0.36 | 1.54 | -2.36        | -0.27 |
| IP13150          | 95.49                                   | 35.51                                   | 1    | 65.5                        | 59.98                        | 0.48 | 58.23                        | 0.97 | 0.37 | 1.54 | 0.6          | 2.68  |
| ICM-05222        | 81.22                                   | 30.01                                   | 1    | 55.61                       | 51.21                        | 0.35 | 49.37                        | 0.82 | 0.37 | 1.35 | -0.17        | -0.36 |
| IP13151          | 95.99                                   | 35.76                                   | 1    | 65.87                       | 60.23                        | 0.49 | 58.59                        | 0.97 | 0.37 | 1.54 | 0.82         | 2.95  |
| S35              | 76.94                                   | 28.54                                   | 1    | 52.74                       | 48.41                        | 0.31 | 46.86                        | 0.78 | 0.37 | 1.26 | 0.28         | -0.56 |
| ICS-112          | 77.62                                   | 28.78                                   | 1    | 53.2                        | 48.84                        | 0.32 | 47.27                        | 0.78 | 0.37 | 1.28 | 0.26         | -0.54 |
| SPEEDFEED        | 97.4                                    | 36.6                                    | 0.99 | 67                          | 60.8                         | 0.51 | 59.71                        | 1    | 0.38 | 1.55 | 1.84         | 4.07  |
| ICS-14001        | 82.77                                   | 30.09                                   | 1.01 | 56.43                       | 52.68                        | 0.36 | 49.9                         | 0.82 | 0.36 | 1.39 | -2.02        | -1.54 |
| PEGAH            | 68.17                                   | 24.79                                   | 1.01 | 46.48                       | 43.38                        | 0.24 | 41.1                         | 0.68 | 0.36 | 1.1  | -2.01        | -3.20 |
| LSD              | 4.48                                    | 1.92                                    | 0.02 | 3.07                        | 3.1                          | 2.07 | 2.81                         | 0.19 | 0.01 | 0.09 |              |       |

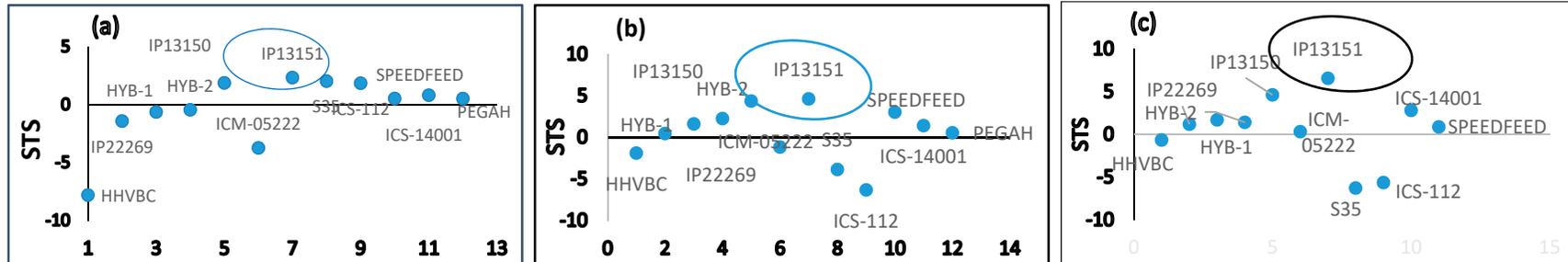
Table 8. Cont.

| 2018 Genotype | Y <sub>p</sub> (t ha <sup>-1</sup> ) | Y <sub>s</sub> (t ha <sup>-1</sup> ) | SSI  | MP (t ha <sup>-1</sup> ) | TOL (t ha <sup>-1</sup> ) | STI  | GMP (t ha <sup>-1</sup> ) | YI   | YSI  | β    | FA1 + FA2 | STS   |
|---------------|--------------------------------------|--------------------------------------|------|--------------------------|---------------------------|------|---------------------------|------|------|------|-----------|-------|
| HHVBC         | 75.67                                | 26.47                                | 1    | 51.07                    | 49.2                      | 0.29 | 44.75                     | 0.9  | 0.35 | 2.76 | -1.51     | -0.98 |
| IP22269       | 79.07                                | 27.36                                | 1.01 | 53.22                    | 51.72                     | 0.31 | 46.51                     | 0.93 | 0.35 | 2.79 | -2.84     | -0.80 |
| HYB-1         | 81.56                                | 27.96                                | 1.01 | 54.76                    | 53.61                     | 0.33 | 47.75                     | 0.95 | 0.34 | 2.82 | -3.97     | -2.39 |
| HYB-2         | 91.94                                | 32.44                                | 1    | 62.19                    | 59.5                      | 0.43 | 54.62                     | 1.1  | 0.35 | 2.75 | -1.18     | 4.38  |
| IP13150       | 95.11                                | 33.59                                | 1    | 64.35                    | 61.52                     | 0.46 | 56.52                     | 1.14 | 0.35 | 2.75 | -1.18     | 5.51  |
| ICM-05222     | 80.87                                | 28.28                                | 1    | 54.57                    | 52.59                     | 0.33 | 47.82                     | 0.96 | 0.35 | 2.76 | -1.70     | -1.02 |
| IP13151       | 94.47                                | 33.48                                | 0.99 | 64.88                    | 61.83                     | 0.46 | 57.04                     | 1.15 | 0.35 | 2.74 | -0.78     | 5.08  |
| S35           | 76.7                                 | 27.38                                | 0.99 | 52.04                    | 49.31                     | 0.3  | 45.83                     | 0.93 | 0.36 | 2.7  | 0.78      | 0.64  |
| ICS-112       | 78.11                                | 27.85                                | 0.99 | 52.98                    | 50.25                     | 0.31 | 46.64                     | 0.95 | 0.36 | 2.71 | 0.57      | 0.26  |
| SPEEDFEED     | 98                                   | 34.4                                 | 0.8  | 66.2                     | 63.6                      | 0.48 | 58.07                     | 1.17 | 0.35 | 2.77 | -1.95     | 5.74  |
| ICS-14001     | 83.25                                | 29.51                                | 0.99 | 56.38                    | 53.75                     | 0.35 | 49.56                     | 1    | 0.35 | 2.73 | -0.36     | 1.91  |
| PEGAH         | 68.05                                | 24.11                                | 0.99 | 46.08                    | 43.95                     | 0.23 | 40.5                      | 0.82 | 0.35 | 2.71 | 0.41      | -4.01 |
| LSD           | 4.78                                 | 1.91                                 | 0.01 | 3.3                      | 3.07                      | 0.04 | 2.98                      | 0.06 | 0.01 | 0.07 |           |       |

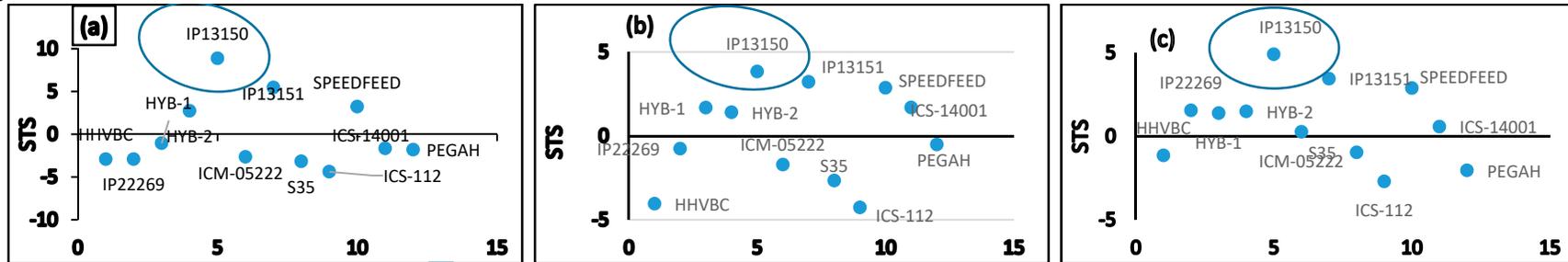
Based on the first two factors (FA1 + FA2), for example, in Kerman, in the three consecutive crop years, the ICSV-112 genotype with a score of 7.71 in the first year, and a score of 4.20 in the second year was the most resistant genotype, respectively. However, in the third year, the highest FA score was for S35 genotype of pearl millet with the value of 0.86, which was contradictory to previous result, which introduced the IP13151 genotype as the highest potential yield. In Jiroft, genotypes IP13150 (15.96), HHVBC (1.64), and ICSV-112 (1.07) were also, respectively, introduced based on FA rankings. This result was contradictory to the previous result. HYB-2 (0.90), speed feed (1.84), and S35 (0.78) genotypes were also introduced as the drought tolerant genotypes in Bardsir for three consecutive years, respectively.

The other statistical multivariate method that can use all the indices simultaneously, is the STS method; it is very easy to use and is calculated according to Equation (9). It is observed from the STS result (Table 8), in Kerman, that the STS scores were 4.60, 8.72, and 6.53 for the IP13151 genotype in the three consecutive crop years, respectively, that was introduced similar to results previously obtained based on the indices. Furthermore, in Jiroft, the obtained STS results of IP13150 genotype, with the scores 8.86, 3.36, and 4.90, respectively, were presented as the genotype with an acceptable yield in these climatic conditions under drought stress conditions. In Bardsir, the highest STS scores were related to the speed feed genotype of sorghum that were 6.95, 4.07, and 5.74, respectively. STS biplot graphs indicating the resistant genotypes in each region and year are presented in Figure 2.

Kerman:



Jiroft:



Bardsir:

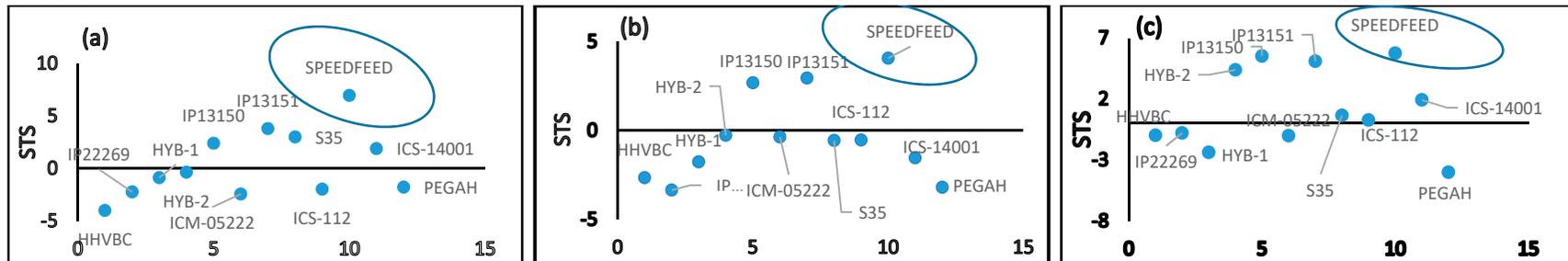


Figure 2. Bi-plot based on the stress tolerance score (STS) in genotypes pearl millet and sorghum in three years. (a) 2016, (b) 2017, and (c) 2018.

## 5. Conclusions

The multivariate statistics such as FA and STS that simultaneously applies all drought tolerance/susceptibility indices can be helpful for selecting drought tolerant genotypes. The multivariate STS method is a simpler, more understandable, and more efficient method than the FA method. Contrary to the FA method, STS could be employed to select and introduce the most tolerant and susceptible genotype even with a small number of genotypes. FA is a complex method and it usually leads to errors in selecting genotypes with a small number of genotypes. In this study, it was tried to select the most tolerant genotype to drought stress using STS in different climatic conditions and the results were compared with the results of the FA.

Finally, based on the new stress tolerance score (STS) method, the best genotype was identified, hence this method can be recommended to use by other researchers.

**Author Contributions:** Collected the data and wrote the first draft of manuscript, M.N.; Planned, supervised the project and reviewed the final manuscript, E.T.-N. and G.K.-N.; Provided the plant materials, selected the experimental locations and genetic consultant, B.N.; Conduct data analysis, G.M.-N.

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