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Comparison of Grain Yield-Based Drought Tolerance Indices under Normal and Stress Conditions of Rice in Egypt

E.F El-Hashash[1*], R.Y.A EL-Agoury[2]

[1]Department of Agronomy, Faculty of Agriculture, Al-Azhar University, Cairo, Egypt
[2]Rice Research and Training Center (RRTC), Field Crops Research Institute, Agricultural Research Center, Egypt

***Corresponding author:** E.F El-Hashash
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Abstract **Original Research Article**

The objective of this study was to evaluate the ability of several indices to identify drought resistant genotypes of rice under normal and stress conditions in Egypt. Thirteen drought tolerance indices including stress susceptibility index (SSI), tolerance index (TOL), mean productivity index (MP), geometric mean productivity (GMP), stress tolerance index (STI), yield index (YI), yield stability index (YSI), drought resistance Index (DI), yield reduction ratio (YR), abiotic tolerance index (ATI), stress susceptibility percentage index (SSPI), harmonic mean (HM) and golden mean (GOL) were calculated based on grain yield under normal (Yp) and stress (Ys) conditions. Combined analysis of variance for grain yield showed highly significant differences among Irrigations regimes (I), genotypes (G) and G × I interaction. Highly significant differences among genotypes were obtained for grain yields (Yp and Ys) and all drought tolerance indices. A high broad sense heritability (h^2) and genetic advance as percent of mean (GAM%) estimates were observed for Yp, Ys and all studied indices. Moderate to high genotypic and phenotypic coefficients of variation were observed for Ys and all drought tolerance indices except Yp, MP and GMP indices. According to correlation and multivariate analysis, MP, GMP, STI, HM and YI drought tolerance indices can be used as parameter in breeding programs to increase grain yield under normal and stress conditions, and SSI, TOL, YSI, DI, YR, ATI, SSPI and GOL under stress conditions. During screening drought tolerant genotypes using mean performances, drought tolerance indices and multivariate analysis, the genotypes G3, G16, G7 and G2 (Group A) in normal and stress conditions as well as the genotypes G14, G12 and G13 in stress conditions were the most drought tolerant genotypes. Based on ranking method, the genotypes G16, G13, G12 and G2 (Group A) appeared as the most droughts tolerant. Therefore, they are recommended to be used as parents in hybridization programs for improvement of drought tolerance for other cultivars rice in Egypt. Also, MP, GMP, STI, HM and YI seem to be useful yield-based drought tolerance indices to be employed in plant breeding programs for rice in Egypt.
Keywords: Comparison, Genetic parameters, multivariate analysis, drought tolerance indices, rice.

Introduction

Rice is arguably the most important staple food that feeds more than half of the world population [1]. Global rice production in 2017/18 is projected at 484.3 million tons (milled basis), down 0.4 million tons from the previous forecast but 0.5 percent below the year-earlier record [2]. USDA recently estimated Egypt's MY 2017-2018 rice production. Milled rice production is estimated at 3.3 million tons, which is down significantly from an estimated 4.8 million tons in MY 2016-2017. The decline is attributed to a decrease in planting area. The USDA estimates Egypt's MY 2017-2018 rice planting area at around 588,000 hectares, down from 850,000 hectares in MY 2016-2017 [3].

Rice is a profligate user of water, and it alone receives about 35% of the global surface water irrigation [4]. Erratic rainfall patterns due to the current and imminent environmental instabilities will increase the scarcity of water in arid and semi-arid regions and also are a great threat to the quality of water, where available, for crop use. To ensure the food security and reduce the water shortage in Egypt, development of acceptable yield, drought tolerant and water-saving rice varieties has become increasingly important.

Yield is more or less affected by several biotic and abiotic stresses such as drought, pre-harvest sprouting, diseases, pests *etc*. Among these, drought and pre-harvest sprouting are major abiotic stresses causing grain loss. Drought is a major problem that limits the adoption of high-yielding rice varieties in drought-prone rainfed rice environments, where high sensitivity to even short periods of water deficit constitutes a risk that farmers cannot afford to take [5]. In rice, moderate stress can be broadly characterized by a 31 to 64% loss in grain yield as compared with non-stress conditions [6]. Drought resistance is defined as the relative yield of genotype compared to other genotypes subjected to the same drought stress [7]. Drought resistance is a complex phenomenon, which is the manifestation of both drought tolerance (tissue tolerance, maintenance of photosystem, *etc*.) and drought avoidance (deep root, leaf rolling, *etc*.) traits that are governed by multiple genes [1]. Drought tolerance selection is not easy due to many strong interactions between genotypes and the environment and restricted knowledge about the function and the role of tolerance mechanisms. Hence, improving drought tolerance of varieties is a major objective in dry land plant breeding programs [8]. Breeding for drought tolerance is usually performed by selecting genotypes for high yield under water limited conditions [9].

The main goal in plant breeding is looking and selecting the genotypes with high seed yield and quality. Drought stress tolerance is a complex trait that is obstructed by low heritability and deficiency of successful selection approaches [10]. Therefore, selection of rice genotypes should be adapted to drought stress conditions. In addition, drought tolerance mechanism should be identified during the development of new cultivars in order to increase the productivity [11]. The development of high yielding varieties requires detailed knowledge of the genetic variability present in the germplasm of the crop, the association among yield components, input requirements and culture practices [12]. Genetic parameters, such as genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) are useful in detecting the amount of variability present in the germplasm. Moreover, knowledge of heritability is essential for selection as it indicates the extent of transmissibility of a character into future generations and the quality of phenotype data in multilocation trials [13]. Heritability coupled with high genetic advance would be more useful in predicting the resultant effect in the selection of the best genotypes for yield and its attributing traits. It helps in determining the influence of environment on the expression and reliability of characters [14]. The genetic advance is yet another important selection parameter that aids breeder in a selection program [15].

The ability of crop cultivars to perform reasonably well in drought-stressed environments is paramount for stability of production. The relative yield performance of genotypes in drought stressed and more favorable environments seems to be a common starting point in the identification of traits related to drought tolerance and the selection of genotypes for use in breeding for dry environments [16]. To differentiate drought resistant genotypes, several drought indices have been suggested basis on a mathematical relationship between yield under drought and non-stressed conditions. These indices are based on either drought resistance or drought susceptibility of genotypes [17, 18]. Fischer and Maurer [19] suggested the stress susceptibility index (SSI) for measurement of yield stability that apprehended the changes in both potential and actual yields in variable environments. Rosielle and Hamblin [20]) introduced a tolerance index (TOL) based on the differences in yields measured under non-stress (Yp) and stress (Ys) conditions. They defined mean productivity index (MP) as the average of Yp and Ys. But MP has an upward bias when there are larger differences between Yp and Ys. The geometric mean productivity (GMP), which is less sensitive to extreme values, is a better indicator than MP for separating superior genotypes in both stress and non-stress environments [20, 21]. Fernandez [21] defined a stress tolerance index (STI), which can be used to identify genotypes which produce high yields under both stress and non-stress conditions. The yield index (YI) suggested by Gavuzzi *et al*. [22], yield stability index (YSI) suggested by Bouslama and Schapaugh [23], drought resistance Index (DI) by Lan [10], Yield reduction ratio (YR) by Golestani–Araghi and Assad [24], harmonic mean (HM) by Hossain *et al*. [25] and Golden mean (GOL) by Moradi *et al*. [26] in order to evaluate the stability of genotypes in both stress and non-stress conditions. Moosavi *et al*. [27] introduced Abiotic tolerance index (ATI) and stress susceptibility percentage index (SSPI) for screening drought tolerant genotypes in stress and non-stress conditions.

The best indices are those which have high correlation with grain yield in both conditions and would be able to identify potential upper yielding and drought tolerant genotypes [21, 28]. According to their comparative yield performance in stress and non-stress environments genotypes have been categorized in four groups by Fernandez [21] as genotypes with relatively uniform performance in both stress and non-stress conditions (group A), genotypes with high yield in non-stress conditions (group B), genotypes with high yield in stress conditions (group C) and genotypes with low yield in both stress and non-stress conditions (group D). Many statistical procedures have been used by plant breeders to evaluate the effectiveness of several drought resistance indices for screening and identification of drought tolerant genotypes. For selection based on a combination of indices, some researchers for different crops as well as Kumar *et al*. [9] by Rahimi *et al*. [29] and Baghyalakshmi *et al.* [30] for rice have used correlation coefficient and principal component analysis (PCA). Biplot is an exploratory data visualization technique to display the multivariate data into a two-dimensional scatter plot. The concept of biplot was first developed by Gabriel [31]. Ranking methods have been used for screening drought tolerant cultivars by Khalili *et al*. [32] in canola, Farshadfar and Elyasi [33] in wheat and Abd El-Mohsen *et al*. [34] in bread wheat. The present study was carried out to 1) estimate the genetic parameters, 2) evaluate the effectiveness of several drought tolerance indices and comparison between them using correlation, PCA and cluster analysis, 3) determine the best indices for increase and improvement of cultivars yield in stress and non-stress condition and 4) identifying drought tolerant genotypes of rice during normal and drought stress conditions in Egypt.

MATERIALS AND METHODS

Genetic Material and Field Procedure

This investigation was conducted at the farm of Rice Research and Training Center (RRTC) Sakha, Kafr El- Sheikh, Egypt during two successive seasons 2015 and 2016. Seventeen rice genotypes used in this study; the name, origin, pedigree, and type of these parental genotypes is presented in Table 1. In 2015 and 2016 seasons, the genotypes were planted in two adjacent experiments, the first experiment was normally irrigated (4 days as irrigation intervals) and the second experiment was irrigated under drought stress condition (12 days irrigation intervals). The amount of each irrigation for normal and drought plots was 90 m^3 in each season. The total irrigation was 6378 and 4586 m^3/fed in normal and drought experiments during both crop seasons periods, respectively. Submerged flow orifice with fixed dimension was used to convey and measure the irrigation water applied and calculated according to Michael [19]. The water treatment was applied after 10 days of transplanting. The date of sowing was May 1st and transplanted one seedling / hill at June 1st in the two experiments. Each experiment was designed in a randomized complete block design (RCBD) with three replicates. Each replicate consisted of 3 rows of genotype. Each row was five meters long with 20 cm x 20 cm distance between rows and hills. All the recommended cultural practices of rice production in the area were done as usual.

Table-1: List of seventeen genotypes of rice used for drought tolerance assessment

Code	Name	Origin	Pedigree	Type
G_1	Giza 177	Egypt	Giza 171 / yomji No. 1 // Pi No. 4	Japonica
G_2	Giza 178	Egypt	Giza175 / Milyang 49	Indica /Japonica
G_3	Giza 179	Egypt	GZ 1368-5-5-4 / GZ 6296-12-1-2-1-1	Indica /Japonica
G_4	Sakha 101	Egypt	Giza 176 / Milyang 79	Japonica
G_5	Sakha 102	Egypt	GZ 4096-7-1 / (Giza 177) GZ 4120-2-5-2	Japonica
G_6	Sakha 103	Egypt	Giza 177 / Suweon 349	Japonica
G_7	Sakha 104	Egypt	GZ 4096-8-1 / GZ 4100-9-1	Japonica
G_8	Sakha 105	Egypt	GZ 5581-46-3 / GZ 4316-7-1-1	Japonica
G_9	Sakha 106	Egypt	Giza 177 / Hexi 30	Japonica
G_{10}	Egyptian Yasmine	Egypt	IR 262-43-8-1 / NAHNG SARN	Indica
G_{11}	Giza 182	Egypt	Giza 181 / IR39422-161-1-3 // Giza 181	Indica
G_{12}	GZ1368	Egypt	IR 1615-31 / BG 94-2349	Indica
G_{13}	IET1444	India	TN 1 X CO 29	Indica
G_{14}	IRAT170	Côte d'Ivoire	IRAT13 / Palawan	Japonica
G_{15}	WAB 880-1-32-1-2- P1-HB	Africa Rice Center	WAB 56 / CG 14	Indica
G_{16}	IR 47545-510-3-2-2-3	IRRI	IRRI	Indica
G_{17}	Hybrid 1	Egypt	IR69625 A / Giza 178	Indica

Estimation of Drought Tolerance Indices:

All panicles from each plot were harvested at physiological maturity, dried to about 14% of moisture content, shelled and measured. The weighted plot yield was then used to estimate grain yield (ton/fed.). Drought resistance indices based on grain yield (ton/ fed.) for normal (Yp) and drought stress (Ys) conditions for each genotype were calculated using the formulas cited in Table 2 to discriminate genotypes based on drought response in terms of grain yield (ton/ fed).

Table-2: Drought tolerance indices used for the evaluation of rice genotypes to drought conditions

No.	Drought tolerance indices	Equation	Reference
1	Stress susceptibility index (SSI)	$[1-(Y_s/Y_p)]/[1-(\bar{Y}_s/\bar{Y}_p)]$	Fischer and Maurer [19]
2	Stress tolerance index (TOL)	$Y_p - Y_s$	Rosielle and Hamblin [20]
3	Mean productivity index (MP)	$(Y_p + Y_s)/2$	Rosielle and Hamblin [20]
4	Geometric mean productivity (GMP)	$(Y_p x Y_s)^{1/2}$	Fernandez [21]
5	Stress tolerance index (STI)	$(Y_p x Y_s)/(\bar{Y}_p)^2$	Fernandez [21]
6	Yield index (YI)	$Y_s/\bar{Y}_s$	Gavuzzi *et al.* [22]
7	Yield stability index (YSI)	Y_s/Y_p	Bouslama and Schapaugh [23]
8	Drought resistance Index (DI)	$[Y_s x(Y_s/Y_p)]/\bar{Y}_s$	Lan [10]
9	Yield reduction ratio (YR)	$1-(Y_s/Y_p)$	Golestani–Araghi and Assad [24]
10	Abiotic tolerance index (ATI)	$[(Y_p - Y_s)/(\bar{Y}_p - \bar{Y}_s)]x[\sqrt{Y_p x Y_s}$	Moosavi *et al.* [27]
11	Stress susceptibility percentage index (SSPI)	$[(Y_p - Y_s)/2(\bar{Y}_p)]x100$	Moosavi *et al.* [27]
12	Harmonic mean (HM)	$[2(Y_p x Y_s)]/(Y_p + Y_s)$	Hossain *et al.* [25]
13	Golden mean (GOL)	$(Y_p + Y_s)/(Y_p - Y_s)$	Moradi *et al.* [26]

Y_p and Y_s: grain yield of each genotype under non-stress and stress conditions, respectively.
$\bar{Y}_p$and $\bar{Y}_s$: mean grain yield of all genotypes in non-stress and stress conditions, respectively.

Statistical Analysis

For grain yield, the combined three-way ANOVA was performed considering the effect of years, irrigations regimes and genotypes, and using the PBSTAT SOFTWARE. For grain yield (Yp and Ys) and drought tolerance indices, the combined two-way ANOVA was performed considering the effects of years and genotypes, and computed according to the method of Gomez and Gomez [62]. Heritability in broad sense (BSH) was estimated from method given by Fehr [61]. The extent of genetic advance to be expected by selecting ten percent of the superior progeny was calculated according to Robinson *et al.* [30]. Genotypic (GCV%), phenotypic (PCV%) and error (ECV%) coefficients of variation were calculated according to Burton [35]. Standard error (SE) of BSH was calculated according to Lothrop *et al.* [36]. Rank sum (RS) = Rank mean ($\bar{R}$) + Standard deviation of rank (SDR) and SDR= $(S_i^2)^{0.5}$ [37]. Correlation coefficient, principal component analysis and cluster analysis were performed for better understanding of the relationships among all possible pair-wise comparisons of Yp, Ys and different drought tolerance indices. Correlation coefficient, principal component analysis and cluster analysis were done using a computer software program PAST version 2.17c.

RESULTS AND DISCUSSION

Analysis of variance

The results of the combined analysis of variance for grain yield (ton/fed.) are presented in Table 3. The mean square due to genotypes, irrigation regimes and their interaction (G x I) were highly significant for grain yield (ton/fed.). While, the other sources of variation were not significant. A large proportion of sums of squares (TSS) were caused by the irrigation regimes (79.30%), followed by the genotypes (10.74%) and G x I interaction (9.18%), respectively. These results indicated that there were substantial differences in genotypes responses across seasons under normal and drought conditions for grain yield in rice, which enabled us to screen drought tolerant genotypes. Also, highly significant difference between grain yield in normal and drought conditions indicates existence of genetic variation and possibility of selection for favorable genotypes in both conditions to improve drought tolerance of rice in Egypt. The combined analysis of variance indicated significant effects of environment, genotype and genotype × environment (GE) interactions on grain yield [38, 39].

Table-3: Combined analysis of variance for grain yield of seventeen rice genotypes

Source of variation	Degree of freedom	Mean square	Percentage relative to total sum of squares (TSS%)
Years (Y)	1	0.0043	0.0016
Irrigations regimes (I)	1	208.7068**	79.3035
Y x I	1	0.0001	0.0000
Replications x Y x I	8	0.0119	0.0361
Genotypes (G)	16	1.7668**	10.7417
G x Y	16	0.0144	0.0878
G x I	16	1.5105**	9.1833
G x Y x I	16	0.0075	0.0457
Error	128	0.0123	0.6002
CV%	3.22		

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

According to combined ANOVA analysis of normal (Yp) and stress (Ys) conditions as well as drought tolerance indices (Table 4), grain yield (Yp and Ys) and all drought tolerance indices exhibited highly significant between genotypes (G). Similar results were previously reported by Yagdi & Sozen [40] and Anwar *et al*. [41] in wheat. Those results demonstrated that almost all indices revealed an important genetic diversity and were able to discriminate between the genotypes under normal and stress conditions. Also, these results indicated that genotypes differed for genes controlling yield and drought tolerance indices [42]. However, the efficient indices also should be able to select the genotypes combining high yield and drought tolerance [28]. There were significant genotypic differences in TOL, GMP, MP, STI, HM and YI indicating the heritability of drought tolerance indices, and therefore potentially their usefulness for screening drought tolerant genotypes in breeding programmes [43].

The highest values of genotype variance were recorded for SSPI index followed by GOL and ATI and TOL indices. There were no significant differences between the years and G x Y interaction for grain yield (Yp and Ys) and tolerance indices. Therefore, those drought tolerance indices were not influenced mainly by year effect. Bahrami *et al*. [44] reported that a highly significant variation was observed in seed yield and tolerance indices among the genotypes in safflower, while, there were no significant differences between the two study years in terms of seed yield and tolerance indices. Saad *et al*. [45] mentioned that significant differences were observed between years and genotypes for most studied drought indices. They added that the interaction genotype × year was significant only for SSI and ATI. Thus, those indices ranked differently the genotypes depending on the variation of stress intensity between years.

Presented in Table 4, the values of the CVs varied between 2.08% (MP) and 11.19% (GOL). Based on maximum and minimum values, it was possible to observe the great magnitude between and within the grain yield (Yp and Ys) and drought tolerance indices, which indicates influence of different factors in its measurements [46]. These results displayed the low influence of environment for the all indices traits different except the index GOL which was medium influenced. The magnitude of CV% indicated that the genotypes had exploitable genetic variability for the studied drought tolerance indices. The other studies showed higher CV% for grain yield in rice by Kole and Hasib [47]; Sangaré *et al*. [48].

Table-4: Analysis of variance of grain yield under normal (Yp), drought (Ys) conditions and different drought tolerance indices in rice genotypes over the two growing seasons

S.O.V Indices	Year (Y)	Reps within Year	Genotypes (G)	G x Y interaction	Polled error	CV%
D.F.	1	4	16	16	64	
Yp	0.002	0.006	1.452**	0.005	0.009	2.149
Ys	0.016	0.012	1.846**	0.010	0.010	4.165
SSI	0.000	0.000	0.590**	0.003	0.003	5.848
TOL	0.007	0.008	3.059**	0.013	0.018	6.731
MP	0.007	0.007	0.884**	0.004	0.005	2.084
GMP	0.013	0.012	1.107**	0.008	0.009	2.821
STI	0.000	0.000	0.125**	0.001	0.001	4.640
YI	0.000	0.000	0.309**	0.002	0.002	4.309
YSI	0.000	0.000	0.121**	0.001	0.001	4.837
DI	0.000	0.000	0.428**	0.001	0.001	6.261
YR	0.000	0.000	0.121**	0.001	0.001	6.011
ATI	0.019	0.029	7.565**	0.019	0.037	5.958
SSPI	1.352	1.113	384.340**	1.620	2.330	6.755
HM	0.018	0.017	1.414**	0.012	0.012	3.570
GOL	0.106	0.068	32.229**	0.415	0.216	11.189

* and **: significant at 5% and 1% levels of probability, respectively. Yp: yield under non-stress; Ys: yield under stress; SSI: susceptibility stress index; TOL: tolerance index; MP: mean productivity; GMP: geometric mean productivity; STI: stress tolerance index; YI: yield index; YSI: yield stability index; DI: drought resistance index; YR: yield reduction ratio; ATI: abiotic tolerance index; SSPI: stress susceptibility percentage index; HM: harmonic mean; GOL: golden mean.

Genetic Parameters

Table 5 shows the values of the genetic parameters for grain yield (Yp and Ys) and drought tolerance indices. The broad sense heritability (h^2) across two years showed highly significant for grain yield (Yp and Ys) and all drought tolerance indices. It has been emphasized that without a genetic advance, the heritability values would not be of a practical importance for selection based on phenotypic appearance. So, genetic advance should be considered along with heritability in coherent selection breeding program. High values of h^2 (≥ 0.99) coupled with high genetic advance as percent of mean (GAM%) were noticed for grain yield (Yp and Ys) and drought tolerance indices. The highest values of h^2 revealed that greater proportion of the entire variance was due to the greater genotypic variance influenced less by environmental factors and the less contribution of the experimental error in the total phenotypic variability, therefore having high heritable variations. The genetic variance is mostly due to the additive gene action or a few major genes under drought stress conditions. Therefore, the role of additive variance was higher than that of dominant variance for these drought tolerance indices [37]. The highest values of GAM% were registered for GOL index followed by DI, TOL, SSPI and ATI indices. Therefore, in this study, it seems that selection for drought resistance or tolerance based on most studied indices will be fruitful under drought-prone conditions [42, 37]. Saba *et al*. [42] and Darvishzadeh *et al*. [43] mentioned that h^2 estimates were low for SSI and TOL, while, moderate for MP, GMP, HM, STI and YI. On the other hand, the highest values of h^2 and GAM% were recorded for Yp, Ys, TOL, MP, HM, SSI, GMP, STI, YI and YSI by Anwar *et al*. [41]. Based on the heritability and genetic advance estimates, selection for drought resistance based on GMP, MP and STI [42, GMP, STI, HM and YI [43] as well as STI [37] will be more fruitful than based on the other studied indices.

Table-5: Genetic parameters of Yp, Ys and different drought tolerance indices in rice

Indices	Genetic Parameters						
	h^2	GA	GAM%	GCV%	PCV%	ECV%	RCV
Yp	1.00±0.35	1.01	22.64	11.01	11.03	2.15	5.12
Ys	0.99±0.35	1.14	46.49	22.63	22.69	4.17	5.43
SSI	0.99±0.35	0.64	65.16	31.71	31.79	5.85	5.42
TOL	1.00±0.35	1.46	72.66	35.35	35.42	6.73	5.25
MP	1.00±0.35	0.79	22.80	11.09	11.12	2.08	5.33
GMP	0.99±0.35	0.88	26.80	13.06	13.11	2.82	4.63
STI	0.99±0.35	0.30	53.84	26.20	26.27	4.64	5.65
YI	0.99±0.35	0.46	46.49	22.64	22.70	4.31	5.25
YSI	0.99±0.35	0.29	52.44	25.53	25.59	4.84	5.27
DI	1.00±0.35	0.55	94.36	45.87	45.94	6.26	7.33
YR	0.99±0.35	0.29	65.17	31.72	31.80	6.01	5.28
ATI	1.00±0.35	2.31	71.51	34.76	34.80	5.96	5.83
SSPI	1.00±0.35	16.42	72.66	35.35	35.42	6.76	5.23
HM	0.99±0.35	0.99	31.82	15.51	15.58	3.57	4.34
GOL	0.99±0.35	4.71	113.34	55.38	55.74	11.19	4.95

h^2: broad sense heritability; GA: genetic advance; GAM%: genetic advance as percent of mean; GCV%: genotypic coefficients of variation; PCV%: phenotypic coefficients of variation; ECV%: error coefficients of variation; RCV: relative coefficient of variation.

The values of coefficients of phenotypic variation (PCV%) were higher than their corresponding coefficients of genotypic variation (GCV%) for grain yield (Yp and Ys) and drought tolerance indices, but the differences between the values were generally low, indicating that the phenotype was close to the genotype, and environmental influence was less for Yp, Ys and drought tolerance indices. The highest values of the GCV% and PCV% were recorded for GOL index followed by DI, TOL, SSPI, ATI, YR and SSI indices; while, there were moderate values for Ys as well as STI, YSI, YI and HM indices, indicating that all these indices are amenable for further improvement. In contrast to that, the lowest values for the GCV% and PCV% were observed for Yp as well as Mp and GMP indices. These findings were supported by Anwar *et al*. [41] in wheat who also reported high GCV% for Yp, Ys, TOL, MP, HM, SSI, GMP, STI, YI and YSI. The values of error coefficients of variation (ECV%) varied from 2.08% to11.19% (Table 5). The GOL index had the highest ECV%, followed by SSPI, TOL, DI and YR indices, while MP index showed the lowest value. From previous published results, the values of the relative coefficient of variation (RCV= GCV%/ECV %) were higher than unity for grain yield (Yp and Ys) and drought tolerance indices. The highest values of RCV (RCV >1) indicate that environmental variation among the genotypes was lower than the genetic variation for grain yield (Yp and Ys) and drought tolerance indices. From these results the differences between genotypic values may increase or decrease from one environment to another which might cause genotypes to even rank differently between environments [49].

Drought tolerance indices

To assess drought tolerance of seventeen rice genotypes, SSI, TOL, MP, GMP, STI, YI, YSI, DI, YR, ATI, SSPI, HM and GOL were calculated based on grain yield under normal (Yp) and stress (Ys) conditions (Table 6). Grain yield (ton/fed.) of seventeen rice genotypes under normal condition had an increasing value about 45% than yields under drought condition over two growing seasons. Drought stress in this study could be considered moderate stress; therefore this result provides a good indication of genotypic differences under random drought stress [48]. According to Fernandez [21] the best measure for selection under drought conditions could separate genotypes which have desirable and similar yield under stress and normal conditions from other groups and also, the best indices are those which have high correlation with grain yield under both conditions. Selection based on a combination of indices may provide a more useful criterion for improving drought resistance of rice. Genotypes with low tolerance indices (SSI, TOL, YR, ATI and SSPI) and genotypes with high tolerance indices (Yp, Ys, MP, GMP, STI, YI, YSI, DI, HM and GOL) would be more tolerant.

Table-6: Comparison of different drought tolerance indices for rice genotypes based on grain yield under normal (Yp) and drought (Ys) conditions (averaged over 2 years)

Genotypes	Drought Tolerance Indices													
	Yp	Ys	SSI	TOL	MP	GMP	STI	YI	YSI	DI	YR	ATI	SSPI	HM	GOL
G1	4.48	1.85	1.30	2.63	3.17	2.88	0.42	0.76	0.41	0.31	0.59	3.76	29.51	2.62	2.41
G2	4.54	2.92	0.79	1.63	3.73	3.64	0.67	1.19	0.64	0.77	0.36	2.94	18.23	3.55	4.60
G3	5.55	3.11	0.97	2.44	4.33	4.15	0.87	1.27	0.56	0.71	0.44	5.03	27.37	3.98	3.55
G4	4.67	2.12	1.21	2.55	3.40	3.15	0.50	0.87	0.45	0.39	0.55	3.99	28.59	2.92	2.67
G5	4.36	1.89	1.26	2.48	3.12	2.87	0.41	0.77	0.43	0.33	0.57	3.52	27.74	2.63	2.53
G6	4.15	1.80	1.25	2.35	2.97	2.73	0.37	0.73	0.43	0.32	0.57	3.18	26.36	2.51	2.53
G7	4.90	2.73	0.98	2.17	3.81	3.66	0.67	1.12	0.56	0.62	0.44	3.93	24.29	3.50	3.53
G8	4.52	1.92	1.27	2.60	3.22	2.95	0.44	0.79	0.42	0.33	0.58	3.80	29.16	2.70	2.48
G9	4.90	1.89	1.36	3.01	3.40	3.05	0.47	0.77	0.39	0.30	0.61	4.55	33.74	2.73	2.26
G10	3.70	1.91	1.07	1.78	2.80	2.66	0.36	0.78	0.52	0.41	0.48	2.35	19.97	2.52	3.15
G11	4.30	1.93	1.22	2.37	3.11	2.86	0.42	0.79	0.45	0.37	0.55	3.31	26.57	2.64	2.69
G12	4.05	3.10	0.52	0.95	3.57	3.54	0.63	1.27	0.76	0.97	0.24	1.68	10.69	3.51	7.52
G13	4.08	3.12	0.52	0.95	3.60	3.57	0.64	1.28	0.77	0.98	0.23	1.69	10.69	3.54	7.55
G14	3.62	2.97	0.40	0.66	3.29	3.28	0.54	1.21	0.82	0.99	0.18	1.07	7.38	3.26	10.27
G15	4.27	2.73	0.80	1.54	3.50	3.42	0.59	1.12	0.64	0.72	0.36	2.61	17.22	3.33	4.58
G16	4.62	3.23	0.66	1.39	3.93	3.86	0.75	1.32	0.70	0.93	0.30	2.66	15.54	3.80	5.68
G17	5.13	2.35	1.20	2.77	3.74	3.47	0.61	0.96	0.46	0.44	0.54	4.78	31.09	3.23	2.70
Max.	5.55	3.23	1.36	3.01	4.33	4.15	0.87	1.32	0.82	0.99	0.61	5.03	33.74	3.98	10.27
Min.	3.62	1.80	0.40	0.66	2.8	2.66	0.36	0.73	0.39	0.30	0.18	1.07	7.38	2.51	2.26
Mean	4.46	2.44	0.99	2.02	3.45	3.28	0.55	1.00	0.55	0.58	0.45	3.23	22.60	3.12	4.16

Among rice genotypes, G3, G17, G7 and G9 had a high grain yield under normal condition (Yp) and intermediate yield under stress condition (Ys). The genotypes G16, G13, G3, G12, G14 and G2 had the highest grain yield under Ys and intermediate grain yield under Yp. Generally, the two genotypes G2 and G3 produced the best grain yield under Yp and Ys. The genotypes G14, G13 and G12 had the lowest recorded values for SSI, TOL, YR, ATI and SSPI indices and highest values for YSI, DI and GOL indices. Thus, these genotypes were recognized as the most drought tolerant and desirable under Ys. It seems that these indices had succeeded in selection of genotypes with high yield under Ys but had failed to select genotypes with proper yield under both environments. While, the genotypes G9 and G1 by SSI, YSI, DI, YR and GOL indices, the genotypes G9 and G17 by TOL and SSPI indices and the genotypes G3 and G17 by ATI index were identified as susceptible ones to drought.

According to MP, GMP, STI and HM indices, the genotypes G3 and G16 were found as drought tolerant with highest values of these indices and grain yield under Yp and Ys. In contrast, the genotypes G10 and G6 recorded the lowest values by MP, GMP, STI and HM indices under Yp and Ys conditions, indicating higher sensitivity to drought. In respect to YI index, the genotypes G16, G13, G12, G14 and G3 were recorded the highest values and were identified as drought tolerant genotypes under Ys. The genotypes G6, G1, G5 and G9 with low values of YI index were recognized as a sensitive to drought stress. Thus, under stress conditions, the selection should be done based on high rates of YI. Except of previous genotypes (sensitive and tolerant), the other genotypes were identified as semi-tolerant or semi-sensitive to drought stress by the all drought tolerance indices in this study.

These results exhibited that the MP, GMP, STI and HM indices as well as SSI, TOL, YR, ATI, SSPI, YSI, DI and GOL were similar in selection of genotypes. The STI, MP, GMP and HM indices were convenient parameters to select high yielding rice genotypes under both normal and stress conditions, while relative decrease of yield, SSI, TOL, YR, ATI, SSPI, YSI, DI and GOL values were better to determine drought tolerance levels. These results are in agreement with those obtained by Khan and Dhurve [50] for the drought indices STI, MP, GMP and YI as well as by Garg and Bhattacharya [51] for the drought indices STI and YI, which were superior and indicating that they can be used as alternative for each other to select drought tolerant genotypes. Drought indices SSI, TOL and YSI [50, 51] as well as TOL and SSI [52] can be used to screen drought resistance.

Correlation Analysis

A suitable index must have a significant correlation with grain yield under both studied conditions [28]. To determine the most desirable drought tolerance indices, the correlation analysis between grain yield in both normal (Yp) and stress (Ys) conditions and each of the drought indices were calculated. The correlation coefficients between different tolerance indices are shown in Table 7. The correlation coefficient between Yp and Ys was negligible, which indicated that high yield potential under normal growth conditions does not anticipate superior yield under stress condition. For example, the genotypes G17, G7 and G9 produced the highest yield under normal conditions but failed to produce high yields under drought conditions. Therefore, indirect selection for stress environments based on the performance of non-stress conditions would not be effective. Grain yields (Yp and Ys) had significant or highly significant and positive correlation with MP, GMP and STI indices, indicating that these indices were more effective in identifying high yielding cultivars under normal and stress conditions. We conclude that MP, GMP and STI are able to discriminate group a cultivars only under moderate drought stress conditions. Also, Yp was significantly and positively corrected with TOL (P<0.05), ATI (P<0.01) and SSPI (P<0.05), while Ys had highly significant and positive correlation with YI, YSI, DI, HM and GOL indices. These relationships were influenced by the drought intensity (difference between Ys and Yp) and indicated that genotypes selected based on these indices were characterized by drought tolerance criteria and will improve yield under stress conditions.

Table-7: Correlation coefficient between drought tolerance indices with grain yield of rice genotypes under normal (Yp) and drought condition (Ys)

Indices	Yp	Ys	SSI	TOL	MP	GMP	STI	YI	YSI	DI	YR	ATI	SSPI	HM
Ys	0.07													
SSI	0.39	-0.88**												
TOL	0.63*	-0.73**	0.96**											
MP	0.70**	0.77**	-0.38	-0.12										
GMP	0.51*	0.90**	-0.58*	-0.35	0.97**									
STI	0.53*	0.88**	-0.56*	-0.32	0.97**	1.00**								
YI	0.07	1.00**	-0.88**	-0.73**	0.77**	0.90**	0.88**							
YSI	-0.39	0.88**	-1.00**	-0.96**	0.38	0.58*	0.56*	0.88**						
DI	-0.22	0.95**	-0.98**	-0.89**	0.55*	0.72**	0.70**	0.95**	0.98**					
YR	0.39	-0.88**	1.00**	0.96**	-0.38	-0.58*	-0.56*	-0.88**	-1.00**	-0.98**				
ATI	0.88**	-0.4	0.77**	0.92**	0.28	0.05	0.07	-0.4	-0.77**	-0.65**	0.77**			
SSPI	0.63*	-0.73**	0.96**	1.00**	-0.12	-0.35	-0.32	-0.73**	-0.96**	-0.89**	0.96**	0.92**		
HM	0.36	0.96**	-0.71**	-0.50*	0.92**	0.99**	0.98**	0.96**	0.71**	0.82**	-0.71**	-0.12	-0.50*	
GOL	-0.50*	0.75**	-0.95**	-0.93**	0.22	0.42	0.39	0.75**	0.95**	0.90**	-0.95**	-0.81**	-0.93**	0.54*

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

SSI, TOL, YR, ATI and SSPI had no significant or highly significant and negative correlation with Ys. Therefore, these indices are suitable factors to identify rice genotypes with low yield and tolerance to drought, because under stress yield decreased with increasing indices. However, SSI, TOL, YR, ATI and SSPI had positive correlation with Yp. Hence, as for the positive correlation between SSI, TOL, YR, ATI and SSPI with Yp and a negative correlation between SSI, TOL, YR, ATI and SSPI with Ys suggested that selection based on SSI and TOL will result in increased yield under Yp [53]. Rizza *et al.* [54], however, showed that a selection based on minimum yield decrease under stress with respect to favorable conditions (TOL) failed to identify the best genotypes. The correlation coefficients between SSI, TOL, YR, ATI and SSPI were positive and highly significant, indicating that they are identical in screening drought resistant genotypes. These results gave the impression that SSI, TOL, YR, ATI and SSPI had same capability in performing tolerance against stress. These results were earlier corroborated by Rahimi *et al*. [29] in rice. Significant or highly significant correlations were observed between MP, GMP, STI, YI, YSI, DI and HM within all subsets, except the correlation coefficient of MP with YSI were not significant. GOL was significantly and positively corrected with YI, YSI and DI (P<0.01) as well as with HM (P<0.05). These results were in agreement with the findings of Rahimi *et al*. [29] and Baghyalakshmi *et al.* [30] in rice; Farshadfar and Parvin Elyasi [33] and Abd El-Mohsen *et al*. [34] in broad wheat, Naghavi *et al.* [55] in corn and Koleva and Dimitrova [56] in cotton.

Principle Component Analysis (PCA)

Principal component analysis simplifies the complex data by transforming the number of correlated variables into a smaller number of variables called principal components. To assess the relationship between rice genotypes and drought tolerance indices, principal component analysis was utilized that condensed the grain yields (Yp and Ys) and thirteen indices to only two components (PCA1 and PCA2). The first two main PCAs extracted had eigenvalues larger than one (Eigen value >1). However, the other PCAs had eigenvalues less than one (Eigen value < 1). The eigenvalues for PC1 and PC2 were 10.60 and 4.27, respectively (Table 8). The PCA1 and PCA2 explained 99.14% of the total variation between drought stress indices, mainly distinguish the indices in different groups. Thus, the PCA1 and PCA2 were employed to draw a biplot. These results are corroborated with the findings of Rahimi *et al*. [29] and Baghyalakshmi *et al*. [30] in rice. Selection of genotypes that have high PCA1 and low PCA2 are suitable for both normal and stress conditions [57, 44]. Thus, the genotypes G14, G13, G12, G16, G2 and G3 are superior genotypes with their high PCA1 and low PCA2 under both normal and stress conditions (Fig. 1). The analysis displayed that the PCA1 contributed in 70.66% of the total variation with Yp, Ys, MP, GMP, STI, YI, DI and HM. Therefore, the PCA1 can be named as the yield potential and drought tolerance. On the other hand, the PCA2 explained 28.48% of the total variability with ATI, SSI, SSPI, YR and TOL. Thus, the PCA2 can be named drought susceptible dimension with high yield in non-stressed and low yield in stressed conditions. Hence, selection of genotypes with high PCA1 and low PCA2 are suitable for both stress and non-stress environments. Rahimi *et al*. [29] and Baghyalakshmi *et al*. [30] mentioned that the first two components explained 81.39% and 81.01% as well as 18.26% 13.23% of total variation, respectively.

Table-8: Results of principal component analysis for grain yield of rice genotypes based on normal, drought conditions and drought tolerance indices

Principal component analysis (PCA)	Eigen value	Percent of variance	Cumulative variance
PCA1	10.60	70.66	70.66
PCA2	4.27	28.48	99.14

The relationships (similarities and dissimilarities) between drought tolerant indices and grain yield in Yp and Ys are graphically displayed in a biplot of PCA1 and PCA2 (Fig. 1). According to biplot analysis, the zero angles (perfect positive correlations) between YS and YI, between SSI and YR, between TOL, and SSPI and between STI and GMP were observed, this indicate that they are the same in ranking of genotypes. MP, GMP, STI and HM were highly positively correlated with grain yield under Yp and Ys (smallest acute angles), showing that they rank the genotypes in a similar fashion in these indices; and this means that selection based on these indices will result in an increasing grain yield in both conditions. Also, DI, YSI and GOL were highly positively correlated with Ys, MP, GMP, STI and HM, as well as the angles between them were less than 90 degrees (acute angle); therefore, the selection based on these indices will result in an increasing grain yield in drought stress conditions. A strong positive correlation was found between SSI, TOL, ATI, SSPI and YR (acute angles), exhibiting that they are closely associated in ranking of the genotypes. The SSI, TOL, YR and SPPI indices were negatively associated with Ys as well as the indices YSI, DI, GOL, YI, HM, GMP, STI, and MP. However, SSI, TOL, ATI, SSPI and YR indices were positively associated with Yp (acute angle). The angles between DI, YSI and GOL with Yp and Ys were obtuse and acute, respectively.

Using the biplot diagram (Fig.1), the genotypes G3, G16, G7 and G2 were located between Yp, Ys and the indices of MP, GMP, STI, HM and YI. The G14, G12 and G13 had considerable correlation with other drought tolerance indices. The biplot analysis of the relationship between the above indices revealed that the most appropriate indices for selecting genotypes are MP, GMP, STI, HM and YI under normal and drought conditions, as well as SSI, TOL, YSI, DI, YR, ATI, SSPI and GOL under stress conditions. The result obtained from principal component analyses using biplos provides valuable information from the data analysis and confirms the correlation analysis. These findings were similar with the results of Rahimi *et al*. [29] and Baghyalakshmi *et al*. [30] in rice, as well as the findings of Farshadfar and Elyasi [33] and Amiri *et al*. [44] in wheat.

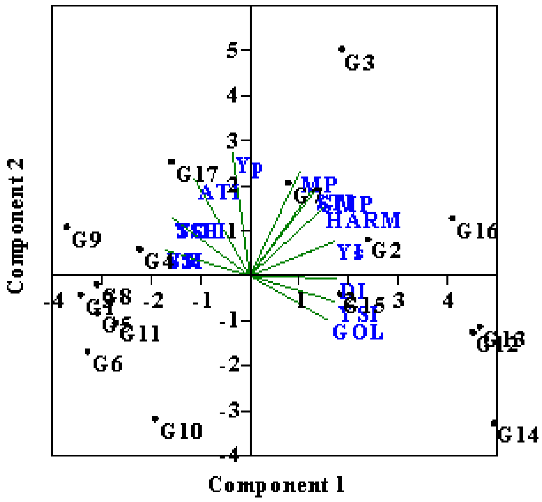

Fig-1: Biplot diagram based on first two principal component axes of seventeen rice genotypes according to mean measured of drought tolerance indices under normal and drought conditions

According to Fernandez's classification, studied genotypes were divided into four categories based on their performance in stressed and irrigated conditions using biplot analyses. The genotypes G3, G16, G7 and G2 using STI, MP, GMP and HM presented high yield under both stress and non-stress (group A). The group B consisted of the genotypes G17, G9 and G4 which having high yield response in normal condition. The genotypes G14, G12 and G13 using SSI, TOL, YSI, DI, YR, ATI, SSPI and GOL produced high yield under stress condition and were included into Group C. Genotypes G6, G10 and G11 based on most studied indices had low grain yield performance in both conditions (Group D).

Cluster analysis

In order to determine the variation among different genotypes and determination of the genotypes far or nearness, the cluster analysis was applied to place the similar genotypes in one group. Cluster analysis with Ward method was performed on the basis of Yp, Ys, GMP, and STI indices to classify the genotypes into four clusters. Each cluster contained genotypes that were highly similar (Fig. 2). According to the dendrogram, 24% of genotypes located in clusters 1 and 3, 35% situated in cluster 2 and 18% in cluster 4 under drought stress condition. Therefore, there was considerable variation among the studied genotypes for drought tolerance in rice. Hybridization/crossing between any distantly related populations is expected to yield more heterosis and vigorous plants. The first cluster (I) comprised of genotypes G3, G7, G17 and G4. The genotypes G3 and G7 were high MP, GMP and STI values, thus they considered to be the most desirable genotypes under normal and stress conditions (Tolerant group), but the genotypes G17 and G4 were identified as semi-tolerant genotypes. The second cluster (II) consisted of genotypes G16, G2, G15, G13, G12, G14. The mean values of MP, GMP, STI and HM were recorded for the genotypes G16, G2 and G15 (Tolerant or Semi- tolerant), while the genotypes G13, G12 and G14 had the highest SSI, TOL, YSI, DI, YR, ATI, SSPI and GOL, and thus were considered to be the most desirable cluster under stress condition (Tolerant group). The genotypes G11, G5, G6 and G10 were classified as the third cluster (III). These genotypes had lowest values of MP, GMP, STI and HM. In the fourth cluster (IV), the genotypes G9, G8 and G1 had high values of SSI, TOL, YR and SSPI, and had low values of YSI, DI and GOL. Therefore, the genotypes in the third and fourth clusters were susceptible to drought and only suitable for both the conditions and for stress condition, respectively.

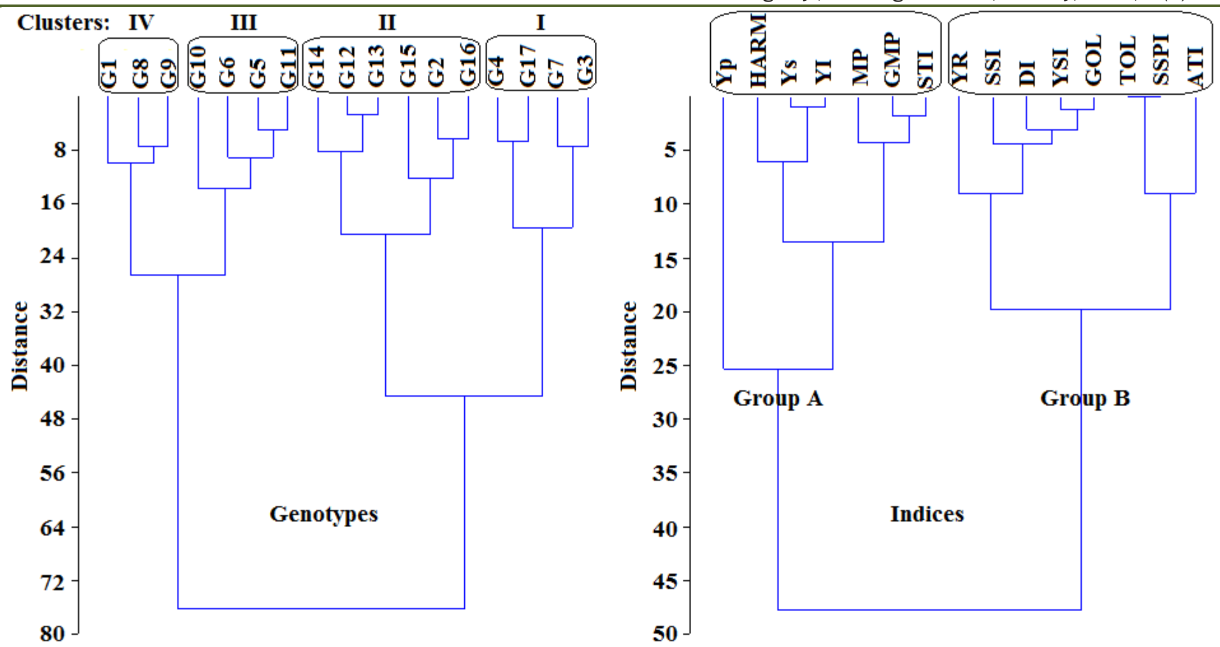

Fig-2: Dendrogram between groups showing classification of genotypes and Yp, Ys and drought tolerance indices using Ward method

In Fig. 2, the cluster analysis for grain yields (Yp and Ys) based on the genotypes under normal and stress conditions tended to group into groups (A and B). The group A consisted of Yp, Ys, MP, GMP, STI, YI and HM indices. While, the group B comprised of SSI, TOL, YSI, DI, YR, ATI, SSPI and GOL. The tree diagram detected minimum distance or dissimilarity between the indices inside each group. While, the highest distance were found among indices of the two groups. These results indicated that each cluster contained drought tolerance indices which were highly similar. While, the results indicated differences existing between the two clusters. Cluster analysis has been used in drought tolerance studies also by other researchers. Based on results of Naghavi *et al*. [55] in corn; Bahrami *et al*. [44] in safflower and Gholinezhad *et al*. [58] in sunflower regarded to cluster analysis, the genotypes were divided into three groups resistant, semi-resistant and susceptible using drought tolerance indices. In rice, Ul-Qamar *et al*. [59]; Kumar *et al*. [6] and Iqbal *et al*. [60,63] mentioned that, the cluster analysis grouped 50, 134 and 14 rice genotypes into six, five and four different clusters, respectively.

Ranking method

The ranks of genotypes for YSI, YR and GOL; for TOL and SSPI as well as for Ys and YI were identical. Also, almost similar ranks for the genotypes were observed between STI, MP, GMP and HM and between SSI, DI and ATI with other indices, which suggest that these parameters are equal for selecting genotypes. These findings were in line with Baghyalakshmi *et al*. [30] in rice and other crops by Farshadfar and Elyasi [33], Naghavi *et al*. [55], Amiri *et al*. [44] and Abd El-Mohsen *et al*. [4]. In Table 9, the estimates indicators of drought tolerance displayed that the identification of drought tolerant genotypes based on a single criterion was contradictory. Different indices introduced different genotypes as drought tolerant. For example, the genotype G3 had drought tolerant by STI, while it was sensitive to drought by ATI. To determine the most desirable drought tolerant genotypes according to the all indices, the mean rank and standard deviation of ranks of all drought tolerance criteria were calculated. Based on rank method and the all drought tolerance indices, the genotype G16 followed by the genotypes G13, G12 and G2 showed the best rank mean almost low standard deviation and rank sum of rank. Thus, these genotypes were identified as the most drought tolerant genotypes. Further, the genotypes G6, G9 and G1 were as the most susceptible under drought stress condition. Other cultivars were identified as semi-tolerant or semi-sensitive to drought stress. Ranking method has been used for screening drought tolerant cultivars by Baghyalakshmi *et al*. [30] in rice and also other crops by Naghavi *et al*. [55] in corn, Farshadfar and Elyasi [33] and Abd El-Mohsen *et al*. [34] in bread wheat.

Table-9: Rank, rank mean (R̄), standard deviation of ranks (SDR) and rank sum (RS) of drought tolerance indices

Genotypes	Drought Tolerance Indices															Rank method		
	Yp	Ys	SSI	TOL	MP	GMP	STI	YI	YSI	DI	YR	ATI	SSPI	HM	GOL	R̄	SDR	RS
G1	8	14	15	14	13	13	12	12	12	15	12	11	14	15	15	13.00	1.93	14.93
G2	6	6	4	5	5	4	3	5	5	5	5	7	5	3	5	4.87	1.06	5.93
G3	1	3	6	10	1	1	1	3	6	7	6	17	10	1	7	5.33	4.56	9.90
G4	4	9	10	12	9	10	9	8	9	11	9	14	12	10	12	9.87	2.29	12.16
G5	9	13	13	11	14	14	13	11	10	13	10	10	11	14	13	11.93	1.71	13.64
G6	12	15	12	8	16	16	14	13	10	14	10	8	8	17	13	12.40	3.04	15.44
G7	3	7	7	7	3	3	3	6	6	8	6	13	7	6	8	6.20	2.62	8.82
G8	7	11	14	13	12	12	11	9	11	13	11	12	13	12	14	11.67	1.84	13.51
G9	3	13	16	16	9	11	10	11	13	16	13	15	16	11	16	12.60	3.62	16.22
G10	15	12	8	6	17	17	15	10	7	10	7	4	6	16	9	10.60	4.42	15.02
G11	10	10	11	9	15	15	12	9	9	12	9	9	9	13	11	10.87	2.13	13.00
G12	14	4	2	2	7	6	5	3	3	3	3	2	2	5	3	4.27	3.10	7.37
G13	13	2	2	2	6	5	4	2	2	2	2	3	2	4	2	3.53	2.92	6.46
G14	16	5	1	1	11	9	8	4	1	1	1	1	1	8	1	4.60	4.76	9.36
G15	11	7	5	4	8	8	7	6	5	6	5	5	4	7	6	6.27	1.83	8.10
G16	5	1	3	3	2	2	2	1	4	4	4	6	3	2	4	3.07	1.44	4.50
G17	2	8	9	15	4	7	6	7	8	9	8	16	15	9	10	8.87	3.93	12.79

Conclusions

There were significant differences among genotypes for all indices, which indicated that genotypes differed for genes controlling yield and drought tolerance indices. The grain yields (Yp and Ys) and all drought tolerance indices were highly h^2 and GAM%, and are usually able to select high yielding genotypes under drought condition. In general, the results of this study based on correlation coefficients, multivariate analysis and ranking method showed that among all drought tolerance indices MP, GMP, STI, HM and YI can be used as the most suitable indicators for screening drought tolerant genotypes and the genotypes G16, G13 and G12 were characterized by the highest tolerance to drought under climate conditions of Egypt. Therefore, they are recommended to be used as parents for improvement of drought tolerance of rice in hybridization programs in Egypt.

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