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Genetic Parameters, Multivariate Analysis and Tolerance Indices of Rice Genotypes under Normal and Drought Stress Environments

E. F. El-Hashash[1*], R. Y. A. EL-Agoury[2], K. M. El-Absy[3] and S. M. I. Sakr[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.
[3]Department of Biology, Faculty of Science, Tabuk University,Tayma Branch,Tabuk, Saudi Arabia.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

In order to evaluate genetic parameters and drought tolerance indices using multivariate analysis, seventeen genotypes of rice were evaluated under normal and drought conditions. The combined analysis of variance indicated highly significant effects of genotype on all studied traits under normal and drought conditions. Most studied genotypes were better than the grand mean during normal and drought conditions. Drought stress reduced the studied traits while other was tolerant to drought, suggesting genetic variability in these genotypes for drought tolerance. The environmental and genetic variances and heritability showed highly significant for all studied traits under normal and drought conditions. The maximum values of genetic variance were found for all studied traits followed by the environmental and genotypes × season variances at normal and drought conditions. High heritability coupled with high genetic advance as percent of the mean was observed for most studied traits under normal and drought conditions. The differences between phenotypic coefficients of variation (PCV%) were higher than the values of genotypic coefficients of variation (GCV%) for all

**Corresponding author: E-mail: dressamelhashash@yahoo.com;*

studied traits under normal and drought conditions. The moderate to low values of GCV% and PCV% were recorded for studied characteristics during drought condition. The values of the relative coefficient of variation were higher than the unity for all studied traits at normal and drought conditions. Hence, these genetic parameters can be used as direct selection criteria for rice improvement under drought stress conditions. The first two PCs with eigen values >1 contributed 99.74% of the variability amongst genotypes. PC1 accounted for about 73.25% of the variation in drought tolerance indices and PC2 for 26.49%. According to tolerance indices, correlation and principle component analysis, indices including STI, MP, GMP, YI and HM under Yp and Ys as well as YI, YSI and DI under Ys could properly distinguish drought tolerant rice genotypes with high yield performance. Therefore, these indices were considered as a better predictor of Ys and Yp than TOL and SSI. The former other indices were independent of SSI and TOL. Screening drought tolerant genotypes using mean performances, drought tolerance indices and multivariate analysis, discriminated genotypes G3, G16, G7 and G2 as the most drought tolerant (Group A) and we recommend them for using in a breeding program for high yielding of rice under normal and drought conditions in Egypt.

Keywords: Genetic parameters; multivariate analysis; drought tolerance indices; rice.

1. 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 the 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.

Drought is the main environmental constraint, which occurs in many parts of the world every year, often having devastating effects on crop productivity. Hence, improving drought-tolerant varieties is a major objective in dryland plant breeding programs [5]. Drought resistance is defined as the relative yield of genotype compared to other genotypes subjected to the same drought stress [6]. 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].

The main goal in plant breeding is looking and selection 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 [7]. Therefore, selection of rice genotypes should be adapted to drought stress. In addition, drought tolerance mechanism should be identified during the development of new cultivars in order to increase the productivity [8]. The development of high yielding varieties requires detailed knowledge of the genetic variability presents in the germplasm of the crop, the association among yield components, inputs requirements, cultural practices [9]. 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. 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 [10]. Selection based on seed yield and its components should be based on genotypic variance and the proportion of the genetic gain and heritability for each trait [11].

The genetic advance is yet another important selection parameter that aids breeder in a selection program [12].

The ability of crop cultivars to perform reasonably well in drought-stressed environments is paramount for the stability of production. The relative yield performance of genotypes in drought-stressed and non-stressed environments can be used as an indicator to identify drought-resistant varieties in breeding for drought-prone environments. Several drought indices have been suggested on the basis of a mathematical relationship between yield under drought conditions and non-stressed conditions. These indices are based on either drought resistance or drought susceptibility of genotypes [13].

Fischer and Maurer [14] 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 [15] introduced a tolerance index (TOL) based on the differences in yields measured under non-stress (Yp) and stress (Ys) conditions. Rosielle and Hamblin [15] 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 [15, 16]. Fernandez [16] 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. [17], yield stability index (YSI) suggested by Bouslama and Schapaugh [18], drought resistance Index (DI) by Lan [19] and harmonic mean (HM) by Chakherchaman et al., [20] in order to evaluation the stability of genotypes in the both stress and non-stress conditions.

Principal component analysis (PCA) is one of the most successful techniques for reducing the multiple dimensions of the observed variables to a smaller intrinsic dimensionality of independent variables [21]. Therefore, PCA has used for selection based on a combination of stress tolerance indices. The present study was conducted to 1) estimate the genetic parameters, 2) evaluate the effectiveness of several drought tolerance indices and comparison between them using correlation and PCA and 3) drought tolerant genotypes of rice during normal and drought stress conditions in Egypt.

2. MATERIALS AND METHODS

2.1 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 are used in this study; the namely and the origin, pedigree, type of these parental genotypes are 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 each irrigation for normal and drought plots was 90 m^3 in each season. The amounts of irrigation for the normal and drought experiments were 6378 and 4586 m^3/fed. Respectively during both crop seasons, respectively. Submerged flow orifice with fixed dimension was used to convey and measure the irrigation water applied and calculated according to Michael [22]. 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 x 20 distances between rows and hills. All the recommended cultural practices of rice production in the area were done as usual.

2.2 Traits Measurement

The data on heading date (days), plant height (cm), flag leaf area (cm^2), number of panicles/plant, panicle length (cm), fertility (%) and grain yield/plant traits were recorded as recommended by Standard Evaluation System for Rice [23].

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

Code	Name	Origin	Pedigree	Type
G1	Giza 177	Egypt	Giza 171 / yomji No. 1 // Pi No. 4	Japonica
G2	Giza 178	Egypt	Giza175 / Milyang 49	Indica /Japonica
G3	Giza 179	Egypt	GZ 1368-5-5-4 / GZ 6296-12-1-2-1-1	Indica /Japonica
G4	Sakha 101	Egypt	Giza 176 / Milyang 79	Japonica
G5	Sakha 102	Egypt	GZ 4096-7-1 / (Giza 177) GZ 4120-2-5-2	Japonica
G6	Sakha 103	Egypt	Giza 177 / Suweon 349	Japonica
G7	Sakha 104	Egypt	GZ 4096-8-1 / GZ 4100-9-1	Japonica
G8	Sakha 105	Egypt	GZ 5581-46-3 / GZ 4316-7-1-1	Japonica
G9	Sakha 106	Egypt	Giza 177 / Hexi 30	Japonica
G10	Egyptian Yasmine	Egypt	IR 262-43-8-1 / NAHNG SARN	Indica
G11	Giza 182	Egypt	Giza 181 / IR39422-161-1-3 // Giza 181	Indica
G12	GZ1368	Egypt	IR 1615-31 / BG 94-2349	Indica
G13	IET1444	India	TN 1 X CO 29	Indica
G14	IRAT170	Côte d'Ivoire	IRAT13 / Palawan	Japonica
G15	WAB 880-1-32-1-2- P1-HB	Africa Rice Center	WAB 56 / CG 14	Indica
G16	IR 47545-510-3-2-2-3	IRRI	IRRI	Indica
G17	Hybrid 1	Egypt	IR69625 A / Giza 178	Indica

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)	$\frac{1-(Y_s/Y_p)}{1-(\bar{Y}_s/\bar{Y}_p)}$	Fischer and Maurer [14]
2	Stress tolerance index (TOL)	$Y_p - Y_s$	Rosielle and Hamblin [15]
3	Mean productivity index (MP)	$\frac{Y_p + Y_s}{2}$	Rosielle and Hamblin [15]
4	Geometric mean productivity (GMP)	$\sqrt{Y_p x Y_s}$	Fernandez [16]
5	Stress tolerance index (STI)	$\frac{Y_p x Y_s}{(\bar{Y}_p)^2}$	Fernandez [16]
6	Yield index (YI)	$\frac{Y_s}{\bar{Y}_s}$	Gavuzzi et al. [17]
7	Yield stability index (YSI)	$\frac{Y_s}{Y_p}$	Bouslama and Schapaugh [18]
8	Drought resistance Index (DI)	$\frac{Y_s x(Y_s/Y_p)}{\bar{Y}_s}$	Lan [19]
9	Harmonic mean (HM)	$\frac{2(Y_p x Y_s)}{Y_p + Y_s}$	Chakherchaman et al. [20]

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

2.3 Estimation of Drought Tolerance Indices

Grain yield/plant was calculated as the mean of all the plants across replications in the two years. Drought resistance indices based on grain yield/plant for non-stress (Yp) and drought stress (Ys) conditions for each genotype were calculated using the formulas cited in Table 2 to discriminate genotypes on the basis of drought response in terms of grain yield/plant.

2.4 Statistical Analysis

A combined analysis of variance was performed to determine the effect of genotype (G), season (S) and G × S interaction on phenotypic data from three trials in two years and computed according to the method of Gomez and Gomez [24]. The environmental (σ_E^2), genotypic (σ_G^2) and genotype x season interaction (σ_{GS}^2) variances were estimated with analysis of variance (ANOVA) by Searle et al. [25]. Heritability in broad sense (BSH) was estimated from method given by Fehr [26]. The extent of genetic advance to be expected by selecting ten percent of the superior progeny was calculated according to Robinson et al. [27]. Genotypic (GCV%), phenotypic (PCV%) and error (ECV%) coefficients of variation were calculated according to Burton [28]. The heritability estimates were categorized as suggested by Robinson et al. [27] (0-30% = low; 31-60% = moderate; above 60% = high). Standard errors (SE) of variance components and heritability were calculated according to Lothrop et al. [29]. Cluster analysis and principal component analysis were done using a computer software program PAST version 2.17c.

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance

Genotypes and years were two distinct factors to access the significant differences among genotypes (G) and seasons (S) under normal and drought conditions (Table 3). The two factor factorial analysis of variance revealed highly significant differences among genotypes for all studied traits. While, years factor showed significant and highly significant in their effects on heading date and plant height traits at normal and drought conditions, respectively. The G x S interaction (GEI) exhibited non-significantly different from each other for all studied traits. A large proportion of total variation were caused by the genotypes, while the lowest proportion was due to the years and GEI, these indicating that there were substantial differences in genotypes responses across seasons for all studied traits during normal and drought conditions. These results indicates the existence of a high degree of genetic variability (or diversity) in the studied genotypes to be exploited in breeding program in rice, and that also reflected the broad ranges observed for each trait. Also, the magnitude of differences in genotypes was sufficient to provide some scope for selecting the pest genotypes to improve drought tolerance of rice in Egypt. Sangaré et al. [30] reported that analysis of variance showed highly significant differences among genotypes for all traits studied excepted grain yield. Genotype × year interaction was significant only for days to flowering. The combined analysis of variance indicated significant effects of environment, genotype and genotype × environment (GE) interactions on grain yield [31,32]. During the Table 3, the highest values of experimental coefficient of variation (CV%) were recorded for number of panicles/plant and hundred grain weight traits during normal and drought stress conditions. These results displayed the large influence of environment for these traits through different water stress severities. The magnitude of CV% indicated that the genotypes had exploitable genetic variability for the studied traits during drought stress condition. The other studies showed the higher CV% for grain yield by Kole and Hasib [33] and Sangaré et al. [30], while lower CV% for days to flowering and plant height traits by Sangaré et al. [30].

3.2 Mean performances

The combined means mean performance of the studied traits of rice genotypes under normal and drought conditions over the two seasons are presented in Table 4. Based on each agronomic trait the response of genotypes at each condition differed. The studied traits in the all studied genotypes have been observed to be affected by drought stress to a considerable extent. These genotypes produced the best values of the studied traits during the normal condition but some genotypes could perform well under drought stress conditions, suggesting genetic variability in these genotypes for drought tolerance. Most studied genotypes were better than the grand means for all studied traits during normal and drought conditions. The lowest mean of heading date was found for G6 at normal and drought conditions followed by G11, G3 and G1 at normal condition and followed by G3, G9 and G1 at drought condition. As for plant height, the genotype G3 had recorded the lowest mean under normal and drought conditions, followed by G4, G11, G1 and G6 under normal condition and followed by G1, G10, G8 and G11 under drought condition. During normal and drought conditions the highest flag leaf area values were observed for the genotypes G10, G15 and G16. Highest number of panicles/plant had observed in G17, G2, G4 and G9 as well as in G12, G14, G13 and G2 under normal and drought conditions, respectively. In respect to panicle length, the genotype G16 was recorded the highest mean, followed by G13, G14, G15 and G17 but with different order in normal and drought conditions. The genotype G15 was registered highest values for hundred grain weight at normal and drought conditions, followed by G7, G9 and G1 as well as followed by G14, G10 and G3 at normal and drought conditions, respectively. Beneath normal condition the highest fertility % values were observed for G3, G16, G4 and G2, while the highest fertility % values were observed for G13, G12, G14 and G2 under drought condition. Among all genotypes, G3, G17, G9 and G7 were the highest grain yield/plant values at normal condition, while G16, G13, G3, G12 and 14 showed the highest values under drought condition. Using mean performance as an indicator of adaptation, the genotypes G3, G13, G14 and G16 appears to be broadly adapted and relatively drought tolerant under stress conditions, although its yield potential may be less than that of genotypes adapted to the normal condition. The ranking of genotypes according to grain yield in each year was different indicating different responses of genotypes to different levels of drought. This finding justified the utilization of stress tolerance index to describe the behavior of genotypes under stress and normal conditions [34]. Selection based on just yield cannot be effective but selection through yield and its components has more efficiency. The possibility of selecting individual genetically different from the mean of a segregating population is obviously of great interest to the plant breeder. To evaluate such a possibility, heritability is considered together with genetic advance.

Table 3. Analysis of variance for studied traits of rice genotypes under normal and drought stress environments over the two seasons in Egypt

Environment	S.O.V	df	HD (day)	PH (cm)	FLA (cm^2)	NP/P	PL (cm)	HGW (g)	F%	GY/P (g)
Normal	Year (Y)	1	6.13*	0.04ns	0.03ns	0.25ns	0.04ns	0.00ns	0.03ns	0.36ns
	Reps within Year	4	1.08ns	0.63ns	0.37ns	0.04ns	0.16ns	0.01ns	0.15ns	0.35ns
	Genotypes (G)	16	353.33**	751.29**	303.93**	29.94**	12.63**	0.23**	18.40**	131.69**
	Y x G (GEI)	16	1.27ns	1.37ns	0.68ns	0.83ns	0.14ns	0.01ns	0.34ns	0.52ns
	Pooled Error	64	0.89	0.88	0.93	0.80	0.20	0.01	0.63	0.88
	GEI/G		0.004	0.002	0.002	0.028	0.011	0.052	0.019	0.004
	CV%		0.94	0.87	3.23	4.21	1.95	3.67	0.87	2.21
Drought	Year (Y)		0.16ns	14.16**	0.00ns	1.19ns	0.03ns	0.01ns	0.01ns	0.01ns
	Reps within Year		0.43ns	1.08ns	0.48ns	0.40ns	0.07ns	0.01ns	0.01ns	0.01ns
	Genotypes (G)		598.17**	593.54**	145.07**	32.82**	21.91**	0.12**	307.14**	164.96**
	Y x G (GEI)		0.28	0.74	0.48	0.71	0.04ns	0.01ns	0.04	0.02ns
	Pooled Error		1.13	1.00	0.31	0.74	0.06	0.01	0.02	0.01
	GEI/G		0.001	0.001	0.003	0.022	0.002	0.074	0.0001	0.0001
	CV%		1.11	1.07	2.57	6.96	1.25	4.20	0.18	0.43

HD = heading date; PH = plant height; FLA = flag leaf area; NP/P = number of panicles/plant; PL = panicle length; HGW = hundred grain weight; F% = fertility; GY = grain yield

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

Table 4. Mean comparison of various traits in rice genotypes under normal and drought stress environments over the two growing seasons

Genotypes	Environment	Traits							
		HD (day)	PH (cm)	FLA (cm^2)	NP/P	PL (cm)	HGW (g)	F %	GY/P (g)
Giza 177	Normal	93.50	99.67	27.90	18.33	21.17	2.83	92.53	42.73
	Drought	85.17	84.67	19.66	8.17	16.23	2.31	66.31	17.65
Giza 178	Normal	104.67	103.50	36.14	24.00	23.43	2.69	92.70	43.28
	Drought	98.00	88.33	20.06	14.33	19.43	2.31	85.37	27.88
Giza 179	Normal	92.67	90.50	28.47	21.67	23.37	2.78	94.19	52.86
	Drought	80.33	80.83	20.88	12.33	20.18	2.45	77.47	29.64
Sakha 101	Normal	109.33	94.50	24.49	24.00	21.95	2.63	92.99	44.54
	Drought	99.83	90.83	21.00	12.50	19.52	2.32	83.36	20.31
Sakha 102	Normal	95.50	107.83	22.98	19.83	22.67	2.74	91.07	42.09
	Drought	89.00	87.67	17.54	9.67	18.45	2.19	66.71	17.98
Sakha 103	Normal	91.33	100.67	20.77	20.67	20.25	2.62	90.34	39.55
	Drought	79.17	90.83	16.61	9.67	17.40	2.17	81.61	17.16
Sakha 104	Normal	102.33	106.50	24.51	20.50	22.68	2.84	92.43	46.67
	Drought	95.83	89.67	19.02	12.33	19.02	2.40	72.60	26.42
Sakha 105	Normal	94.50	102.00	22.51	23.00	21.87	2.58	91.32	43.10
	Drought	88.17	86.67	16.90	10.00	17.98	2.19	75.11	18.28
Sakha 106	Normal	96.00	106.00	25.20	22.83	22.73	2.84	91.54	46.71
	Drought	85.00	90.17	19.61	8.67	17.43	2.27	67.24	17.98
E.Yasmine	Normal	119.50	106.83	47.21	22.17	23.85	2.57	89.23	35.23
	Drought	101.50	86.17	25.58	13.00	18.47	2.46	82.74	18.28
Giza 182	Normal	91.50	97.50	29.28	21.17	22.38	2.72	91.74	40.98
	Drought	90.67	87.00	19.01	13.33	17.50	2.37	83.70	20.03
GZ1368	Normal	103.00	112.17	26.30	19.67	22.77	2.48	90.28	38.59
	Drought	100.33	96.83	20.02	16.50	19.95	2.30	86.14	29.59
IET1444	Normal	104.33	106.17	30.27	18.83	23.88	2.50	91.69	38.84
	Drought	104.17	99.50	23.18	14.50	21.00	2.40	88.66	29.83
IRAT170	Normal	103.17	126.17	31.31	18.17	24.35	2.60	90.43	34.57
	Drought	110.17	111.67	22.92	14.67	21.33	2.49	85.73	28.35
WAB880	Normal	95.33	128.50	41.26	19.17	24.27	3.26	88.74	40.68
	Drought	104.00	115.17	35.12	12.50	22.15	2.54	78.11	26.03
IR47545	Normal	105.67	129.17	37.06	20.67	26.35	2.44	93.92	44.03
	Drought	112.67	108.67	31.26	13.17	23.62	2.00	83.16	30.86
Hybrid 1	Normal	107.17	105.00	31.85	26.17	24.83	2.55	87.80	49.01
	Drought	100.00	88.33	22.59	14.17	20.05	2.13	79.17	22.45
Grand mean	Normal	100.56	107.22	29.85	21.23	23.11	2.68	91.35	42.56
	Drought	95.53	93.12	21.82	12.32	19.40	2.31	70.01	23.45

3.3 Genetic Parameters

Genetic parameters for studied traits under normal and drought conditions in rice genotypes are presented in Table 5. The error (σ^2_E) and genetic (σ^2_G) variances showed highly significant, while the genotypes × season variances (σ^2_{GS}) were non-significant for all studied traits under normal and during conditions. Highly significant indicates that the variances values were double the standard error values. The highest values of σ^2_G followed by σ^2_E and σ^2_{GS} were recorded for all studied traits under normal and drought conditions. The σ^2_{GS} was equal zero for most studied traits, because their values were negative. These results provided the evidence that yield and yield related traits are influenced much under normal and drought condition. While, the maximum values of genotypic variance recorded for most studied traits under drought stress conditions. This result convinced that most of studied traits were activated and pronounced their effects when plants faced the drought stress condition. Greater differences between genotypic and experimental variances gave evidence that these traits were greatly influenced by the environment under drought stress. These results are in agreement with those obtained by El-Hashash and Agwa [35] in barley. Blum [7] reported the reduction in genetic variance under severe stress condition.

Table 5. Genetic parameters for different studied traits in rice genotypes under normal and drought stress environments

Traits	Environments	Genetic parameters									
		σ^2_E	σ^2_G	σ^2_{GS}	BSH	GA	GAM%	GCV%	PCV%	ECV%	RCV
Heading date	Normal	0.89±0.16	58.68±20.82	0.13±0.16	1.00±0.35	13.46	13.38	7.62	7.63	0.94	8.11
	Drought	1.13±0.20	99.65±35.25	0.00±0.07	1.00±0.35	17.55	18.37	10.45	10.46	1.11	9.41
plant height	Normal	0.88±0.15	124..99±44.27	0.17±0.17	1.00±0.35	19.66	18.34	10.43	10.44	0.87	11.99
	Drought	1.00±0.17	98.80±34.97	0.00±0.11	1.00±0.35	17.48	18.77	10.67	10.68	1.07	9.97
flag leaf area	Normal	0.93±0.16	50.54±17.91	0.00±0.10	1.00±0.35	12.49	41.85	23.81	23.85	3.23	7.37
	Drought	0.31±0.05	24.10±8.55	0.06±0.06	1.00±0.35	8.63	39.53	22.50	22.53	2.57	8.75
number of panicles/plant	Normal	0.80±0.14	4.85±1.76	0.01±0.11	0.97±0.35	3.87	18.01	10.38	10.52	4.21	2.47
	Drought	0.74±0.13	5.35±1.93	0.00±0.09	0.98±0.35	4.03	32.67	18.77	18.99	6.96	2.70
panicle length	Normal	0.20±0.04	2.08±0.74	0.00±0.02	0.98±0.35	2.52	10.90	6.24	6.29	1.95	3.20
	Drought	0.06±0.01	3.64±1.29	0.00±0.01	1.00±0.35	3.36	17.30	9.84	9.86	1.25	7.87
hundred grain weight	Normal	0.01±0.00	0.04±0.01	0.00±0.00	0.95±0.35	0.32	12.07	7.04	7.23	3.67	1.92
	Drought	0.01±0.00	0.02±0.01	0.00±0.00	0.93±0.35	0.23	10.00	5.91	6.14	4.20	1.41
fertility	Normal	0.63±0.11	3.01±1.08	0.00±0.06	0.97±0.35	3.00	3.29	1.90	1.93	0.87	2.18
	Drought	0.02±0.00	51.18±18.10	0.01±0.00	1.00±0.35	12.59	15.94	9.05	9.06	0.18	50.28
grain yield/plant	Normal	0.88±0.15	21.86±7.76	0.00±0.08	0.99±0.35	8.20	19.27	10.99	11.02	2.21	4.97
	Drought	0.01±0.00	27.49±9.72	0.00±0.00	1.00±0.35	9.23	39.34	22.36	22.36	0.43	52.00

σ^2_E, σ^2_G and σ^2_{GS}= error, genetic and genotypes × season variances, respectively; BSH = 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.

Heritability is a measure of the magnitude of the phenotypic variation caused by the action of genes. Heritability plays a predictive role in breeding programme, showing the reliability of phenotypes as a guide to its breeding value. The broad sense heritability (BSH) across two years was showed highly significant for all studied traits during normal and drought. The highly significant is due to the heritability values were twice the values of standard error. According to Robinson et al. [27], the BSH had recorded the highest values (BSH > 0.60) for all studied traits through the normal and drought conditions. The highest values of broad sense heritability 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. Superior heritability values indicates the greater effectiveness of selection and improvement to be expected for these studied traits in future breeding programmes as the genetic variance is mostly due to the additive gene action or a few major genes under drought stress conditions. Similar results were previously reported by Megha et al. [36] for grain yield per plant, flag leaf width and plant height; by Sangaré et al. [30] for days to 50% flowering, plant height, thousand kernels weight; by Mamata et al. [37] for plant height, spikelet fertility and grain yield/plant traits and by Kumar et al. [38] for days to 50% flowering, plant height, panicle length, fertility and1000-grain weight traits.

It has been emphasized that without genetic advance, the heritability values would not be of practical importance in selection based on phenotypic appearance. So, genetic advance should be considered along with heritability in coherent selection breeding program. Moderate and high genetic advance values coupled with high heritability were recorded for some traits under normal and drought conditions. This indicated the additive nature of genetic variation was transmitted from the parents to the progeny. Also, these traits can easily be fixed in the genotypes by progeny selection or any modified selection procedures aiming to exploit the additive gene effects in early generations during drought stress conditions. The genetic advance will be less when the BSH had mainly due to non-additive affects (dominance and / or epistasis) and which need to be improved by cyclic hybridization, heterosis breeding, diallel selective mating system and biparental mating system duly adopting standard selection procedures. High heritability coupled with high or moderate genetic advance as percent of the mean (GAM%) was noticed for grain yield/plant and most studied traits meantime normal and drought conditions indicating the preponderance of additive gene action. The highest values of GAM% were registered for flag leaf area, number of panicles/plant and grain yield/plant traits during normal and drought condition. High heritability along with high GAM% was observed for the grain yield per plant, flag leaf width and plant height by Megha et al. [36] and for plant height, spikelet fertility and grain yield/plant by Mamata et al. [37], indicating traits were less influenced with the environment variance in the inheritance of these traits. While, low heritability along with low genetic gain was recorded for grain yield indicating that the dominance/epistasis effect is very important in the expression of these characters [30].

The values for phenotypic coefficients of variation (PCV%) were higher than their corresponding genotypic coefficients of variation (GCV%) for all studied traits during normal and drought conditions except grain yield/plant at drought condition. Dutta and Borua [39], Sangaré et al. [30], Kumar et al. [38] and Mamata et al. [37] mentioned that grain yield and all studied traits had showed high PCV% than their corresponding GCV%. These differences between the values were generally low and which indicate that the phenotype was close to the genotype, and environmental influence was less on these traits. Since the broad sense heritability was high for this trait, hence this also means that greater proportion of variability was due to a genetic factor. The small difference observed between GCV% and PCV% indicates the presence of high genetic variability for the traits which may facilitate selection [37]. The moderate values of GCV% and PCV% were recorded for flag leaf area during normal and drought conditions as well as for number of panicles/plant and grain yield/plant under drought condition, indicating that all these characters are amenable for further improvement. While the other traits displayed low values of PCV% and GCV% during normal and drought stress conditions. This may be attributed to the presence of both positives and negative alleles in the genotypes studied [30]. Similar results were reported by Kumar et al. [38] for grain yield/plant, by Mamata et al. [37] for thousand grain weight and panicle length as well as by Sangaré et al. [30] for days to 50% flowering, plant height, thousand kernels weight and grain yield. On the other hand, the high PCV% and GCV% values were obtained for grain yield/plant by Megha et al. [36] and Mamata et al. [37]. These results indicate that the least variability for GCV% and PCV% corresponded to high heritability in drought stress conditions. Hence, these traits can be used as indirect selection criteria under drought stress conditions.

The lowest values of error coefficients of variation (ECV%) were observed for grain yield/plant and most studied traits at normal and drought conditions. From previously results, the values of the relative coefficient of variation (RCV= GCV%/ECV%) were higher than the unity for all studied traits during normal and drought conditions. The highest values of RCV (RCV >1) indicate that environmental variation among the genotypes was lower than the genetic variation from the average during drought stress conditions for the all studied traits as noticed by El-Hashash and Agwa [35] in barley. 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. These genetic parameters can be used for defining which direct selection criteria, breeding methods, and experimental designs are more suitable to obtain rice genetic gains for drought tolerance. Under drought conditions, grain yield of rice showed high estimates of PCV%, GCV%, heritability and genetic advance in percent of the mean [40]. The results revealed that the estimates GCV%, PCV%, heritability and genetic advance were higher in drought conditions as compared to normal conditions for most studied traits. The adverse drought conditions appeared to unfurl greater degree of variability and transmissibility in the yield as well as other studied traits. Therefore, the greater possibility of improvement in biochemical traits through selection appears in drought condition than control condition [40].

3.4 Cluster Analysis

Cluster analysis showed that the genotypes based on the studied traits under normal and drought conditions divided into six clusters with 1, 2, 1, 6, 1 and 6 genotypes, respectively (Fig. 1). The first (I), third (III) and fifth (V) clusters comprised of genotypes G15, G3 and G10, respectively. The second cluster (II) including genotypes G14 and G16. The fourth cluster (IV) consists of genotypes G1, G5, G9, G8, G11 and G6. The sixth cluster (VI) consisted of G4, G2, G17, G7, G12 and G13 genotypes. The genotypes of the first, second and third clusters were recorded the best values for grain yield and most studied traits during normal and drought conditions, which exhibited a desirable resistance to drought for most studied traits. While, the genotypes in the sixth cluster were showed the lowest values for the most studied traits during normal and drought conditions, which were the lowest resistance to drought based on most studied traits. Other clusters (4 and 5) were moderate, which were a desirable resistance to drought; also these clusters were the moderate values for most studied traits under normal and drought conditions. Cluster analysis based on studied traits discriminated the genotypes G3, G14, G15 and G16 as the most drought tolerant. Therefore they are recommended to be used as parents for improvement of drought tolerance in other cultivars in rice. Ul-Qamar et al. [41], Kumar et al. [42] and Iqbal et al. [43] mentioned that the cluster analysis grouped the 50, 134 and 14 rice genotypes into six, five and four different clusters, respectively. This indicates the presence of high to moderate diversity among the tested genotypes.

3.5 Drought Tolerance Indices

Drought tolerance indices were calculated on the basis of grain yield/plant for understanding genotypic response under normal and drought conditions (Table 6). Selection based on a combination of indices may provide a more useful criterion for improving drought resistance of rice. Accordingly, high levels indicators STI, MP, GMP, YI, YSI, DI and HM values and low index of SSI and TOL indicator of resistance to stress conditions were figured. Grain yield/plant of seventeen genotypes under normal condition had an increasing value of 45% than yields under drought condition over two growing seasons. Drought stress in this study could be considered moderate stress, therefore this results provides a good indication of genotypic differences under random drought stress [30]. The lowest values by SSI and TOL as well as the highest values by YSI and DI were calculated for G14, G13, G12, G16, G2 and G15, indicating these genotypes had a lower grain yield reduction in stress condition and the highest drought tolerance. Whilst, the highest values by SSI and TOL as well as the lowest values by YSI and DI were found for G9, followed by G1 and G8, indicate that these genotypes had a greater grain yield

Table 6. Drought tolerance indices of rice genotypes based on grain yield under normal (YP) and drought stress (YS) environments. The numbers in the parentheses are the genotype ranks for each index

Indices / Genotypes	Y_p	Y_s	SSI	TOL	STI	MP	GMP	YI	YSI	DI	HM
G1	42.73(9)	17.65(14)	1.31(13)	25.08(15)	0.42(14)	30.19(14)	27.46(15)	0.75(13)	0.41(12)	0.31(16)	24.98(15)
G2	43.28(7)	27.88(6)	0.79(4)	15.4(6)	0.67(4)	35.58(5)	34.74(4)	1.19(5)	0.64(4)	0.77(5)	33.91(3)
G3	52.86(1)	29.64(3)	0.98(7)	23.22(11)	0.87(1)	41.25(1)	39.58(1)	1.26(3)	0.56(6)	0.71(6)	37.98(1)
G4	44.54(5)	20.31(10)	1.21(10)	24.23(13)	0.50(10)	32.43(9)	30.08(10)	0.87(9)	0.46(9)	0.39(12)	27.90(10)
G5	42.09(10)	17.98(13)	1.28(12)	24.11(12)	0.42(14)	30.04(15)	27.51(14)	0.77(12)	0.43(10)	0.33(13)	25.20(14)
G6	39.55(13)	17.16(15)	1.26(11)	22.39(10)	0.37(15)	28.36(16)	26.05(16)	0.73(14)	0.43(10)	0.32(15)	23.94(17)
G7	46.67(4)	26.42(7)	0.97(6)	20.25(8)	0.68(3)	36.55(3)	35.11(3)	1.13(6)	0.57(5)	0.64(8)	33.74(5)
G8	43.1(8)	18.28(12)	1.28(12)	24.82(14)	0.44(13)	30.69(12)	28.07(13)	0.78(11)	0.42(11)	0.33(13)	25.67(13)
G9	46.71(3)	17.98(13)	1.37(14)	28.73(17)	0.46(11)	32.35(10)	28.98(11)	0.77(12)	0.38(13)	0.30(17)	25.97(12)
G10	35.23(16)	18.28(12)	1.07(8)	16.95(7)	0.36(16)	26.76(17)	25.38(17)	0.78(11)	0.52(7)	0.40(11)	24.07(16)
G11	40.98(11)	20.03(11)	1.14(9)	20.95(9)	0.45(12)	30.51(13)	28.65(12)	0.85(10)	0.49(8)	0.42(10)	26.91(11)
G12	38.59(15)	29.59(4)	0.52(2)	9.00(2)	0.63(6)	34.09(7)	33.79(6)	1.26(3)	0.77(2)	0.97(3)	33.50(6)
G13	38.84(14)	29.83(2)	0.52(2)	9.01(3)	0.64(5)	34.34(6)	34.04(5)	1.27(2)	0.77(2)	0.98(2)	33.74(4)
G14	34.57(17)	28.35(5)	0.40(1)	6.22(1)	0.54(9)	31.46(11)	31.31(9)	1.21(4)	0.82(1)	0.99(1)	31.15(8)
G15	40.68(12)	26.03(8)	0.80(5)	14.65(5)	0.58(8)	33.36(8)	32.54(8)	1.11(7)	0.64(4)	0.71(6)	31.75(7)
G16	44.03(6)	30.86(1)	0.67(3)	13.17(4)	0.75(2)	37.45(2)	36.86(2)	1.32(1)	0.70(3)	0.92(4)	36.29(2)
G17	49.01(2)	22.45(9)	1.21(10)	26.56(16)	0.61(7)	35.73(4)	33.17(7)	0.96(8)	0.46(9)	0.44(9)	30.79(9)
Mean	42.56	23.45	0.99	19.10	0.42	33.01	31.37	1.00	0.56	0.58	29.85

Y_p: yield under non-stress; Y_s: yield under stress; SSI: susceptibility stress index; TOL: tolerance index; STI: stress tolerance index; MP: mean productivity; GMP: geometric mean productivity; YI: yield index; YSI: yield stability index; DI: drought resistance index; HM: Harmonic mean.

reduction under drought stress condition and the least relative drought tolerant. The other genotypes were identified as semi-tolerance or semi-sensitive to drought stress. The greater the SSI and TOL values, the larger the yield reduction under stress condition and the higher the drought sensitivity. Based on the STI, MP, GMP and HM indices, the genotypes including G3, G16, G7, G2 and G13 had the high values and considered as drought tolerance with high yield stability in the normal and drought conditions. On the other side, the genotypes G10, G6, G5 and G1 with the lowest values of STI, MP, GMP and DI indices were considered as susceptible. The other genotypes were identified as semi-tolerance or semi-sensitive to drought stress. These results exhibited that the MP, GMP and HM indices in selection of genotypes were similar to STI index. Also, according to YI selected the genotypes G16, G13, G3, G12, G14, G2 and G7 as the most relatively tolerant cultivars while for YI the genotypes G6, G1, G5 and G10 were the least relative tolerant. Similar ranks for the genotypes were observed between STI, MP, GMP and HM parameters and between SSI and TOL, which suggests that these parameters are equal for selecting genotypes. These findings were in line with Baghyalakshmi et al. [44]. The indices that are able to distinguish genotypes in region A from other, are desirable and the genotypes that are located in this region have high yield in both conditions [16]. These results are in agreement with those obtained by Khan and Dhurve [45] for the drought indices STI, MP, GMP and YI as well as by Garg and Bhattacharya [46] 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 [45,46] as well as TOL and SSI [47] can be used to screen drought resistant.

3.6 Correlation Analysis

Correlation analysis between grain yield and drought tolerance indices can be a good criterion for determining the best genotypes and drought tolerance indices used (Table 7). The relationship between yields under both normal (Yp) and drought (Ys) conditions was found to be non-significant, indicating that high potential yield under normal conditions does not necessarily result in improved yield in a drought-prone environment. For example, the genotypes G17, G7 and G9 produced the highest yield under normal condition but failed to produce high yields in the drought condition. Therefore, indirect selection for such conditions based on the results of normal condition will not be efficient. The indices SSI and TOL were consistently associated ($P<0.01$) with each other, indicating that they are identical in screening drought resistant genotypes. SSI and TOL had highly significant and negatively correlation with Ys, while they had positive correlation with Yp. Hence, as for the positive correlation between SSI and TOL with Yp and a negative correlation between SSI and TOL with Ys suggested that selection based on SSI and TOL will result in increased yield under Yp [48]. Regarding SSI was significantly or high significantly and negatively correlated with STI, MP, GMP, YI, YSI, DI and HM. No significant correlation of TOL with STI, MP and GMP were found, whereas it has significantly and negatively correlation with YI, YSI, DI and HM. These results were earlier corroborated by Rahimi et al. [49].

Table 7. Correlation coefficients of drought tolerance indices with mean grain yield/plant of rice under normal and drought conditions over two seasons

Indices	Yp	Ys	SSI	TOL	STI	MP	GMP	YI	YSI	DI
Ys	0.03									
SSI	0.40	-0.87**								
TOL	0.64*	-0.68**	0.93**							
STI	0.43*	0.88**	-0.64*	-0.38						
MP	0.57*	0.80**	-0.50*	-0.21	0.97**					
GMP	0.42*	0.88**	-0.64*	-0.38	1.00**	0.97**				
YI	0.02	1.00**	-0.88**	-0.69**	0.88**	0.80**	0.88**			
YSI	-0.40	0.87**	-1.00**	-0.93**	0.63*	0.49*	0.63*	0.88**		
DI	-0.28	0.92**	-0.97**	-0.85**	0.71**	0.59*	0.72**	0.93**	0.98**	
HM	0.32	0.93**	-0.71**	-0.49*	0.98**	0.93**	0.98**	0.92**	0.71**	0.78**

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

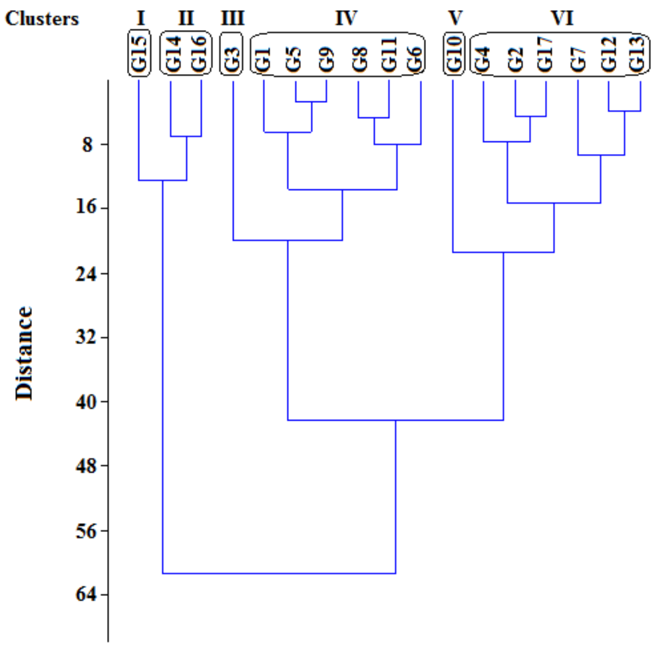

Fig. 1. Dendrogram using Ward method between groups showing classification of genotypes based on studied traits during normal and drought conditions.

The drought tolerance indices STI, MP, GMP, YI, YSI, DI and HM were exhibited positive and significant correlations with Ys at 1% probability (P<0.01). A positive and significant correlation was noted between Yp and the yield-based indices STI, MP and GMP. These results showing that they are ranking the genotypes in similar fashions and also indicating that these criteria were more effective in identifying high yielding cultivars under different moisture conditions. Therefore these indices were able to discriminate group (A) genotypes from other genotypes. The drought tolerance indices including STI, MP, GMP, YI, YSI, DI and HM were significantly or high significantly and positively correlated with each other. The observed relations were consistent with those reported by Rahimi et al. [49] and Baghyalakshmi et al. [44]. Based on correlation analysis of grain yield in both conditions and for both years, STI, MP, GMP, YI, YSI, DI and HM indices were recognized to be the best criteria to identify the tolerant genotypes to drought stress in rice. A similar trend of results was found by Rahimi et al. [49] stated that STI, MP, GMP, YI, YSI and HM indices had highly significant correlations with grain yield under normal and drought stress conditions and were identified as suitable indices to select the high-yielding genotypes in applied rice breeding programs. On the other hand, Baghyalakshmi et al. [44] reported that DI, STI, GMP, HM, MPI, YSI, and YI had recorded high and significant positive correlation with yield under stress. Similarly among susceptibility indices, SSI had significantly negative correlation with grain yield.

3.7 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 condenses the eight indices to only two components (PCA1 and PCA2). The first two main PCAs extracted had eigen value more than one (Eigen value >1). However, the other PCAs have recorded eigenvalues less than one (Eigen value < 1). The eigenvalues for PC1 and PC2 were 8.06 and 2.91, respectively (Table 8). The cumulative variance of PCA1 and PCA2 explained 99.74% of the total variation between drought stress indices. These results are corroborated with the findings of Rahimi et al. [49] and Baghyalakshmi et al. [44] in rice. First principal component analysis (PCA) contributed 73.25% of the total variation with Yp, Ys, STI, MP, GMP, YI, DI and HM. Thus the first component can be named as the yield potential and drought tolerance while second PCA explained 26.49% of the total variability. Rahimi et al. [49] and Baghyalakshmi et al. [44] mentioned that the first two components explained 81.39% and 81.01% as well as 18.26% 13.23% of total variation, respectively.

The relationships (similarities and dissimilarities) among different indices are graphically displayed in a biplot of PCA1 and PCA2 (Fig. 2). According to biplot analysis, STI, MP and GMP were a highly positive correlation with grain yield under Yp and Ys, which means that selection based on these indices will result increasing grain yield in both conditions. While, YI, YSI, DI and HM were highly positive with Ys, therefore the selection based on these indices will result increasing grain yield in drought condition. Perfect positive correlations among drought tolerance indices STI and GMP as well as between Ys and YI were observed, this indicates that they are the same in the ranking of genotypes. A strong positive correlation was found between the SSI and TOL, exhibiting that they are closely associated in the ranking of the genotypes. The SSI and TOL indices were negatively associated with Ys as well as the indices STI, GMP, MP, YI, YSI, DI and HM. Whilst, The SSI and TOL indices were positively associated with Yp.

The angle between Ys, Yp, STI, MP, GMP, YI and HM, between DI and YSI as well as between SSI and TOL is acute angle showing that they rank the genotypes in a similar fashion in these indices. The angle between MP, GMP, STI and HM indices with YI, YSI and DI indices were well below 90 degrees (acute angle) under Yp and Ys. The acute angle was noticed among Ys with YI, DI and YSI. While the obtuse angle between Yp with DI and YSI was observed. No relationships were found between the SSI and TOL indices with Ys, STI, MP, GMP, YI, YSI and DI indices. A close correlation was found between the SSI and TOL, and the angle them had acute.

Table 8. Eigen value, percent of variance and cumulative variance obtained from PCA for normal yield, stress yield and drought tolerance indices of seventeen rice genotypes

Principal component analysis (PCA)	Eigen value	Percent of variance	Cumulative variance
PCA1	8.06	73.25	73.25
PCA2	2.91	26.49	99.74

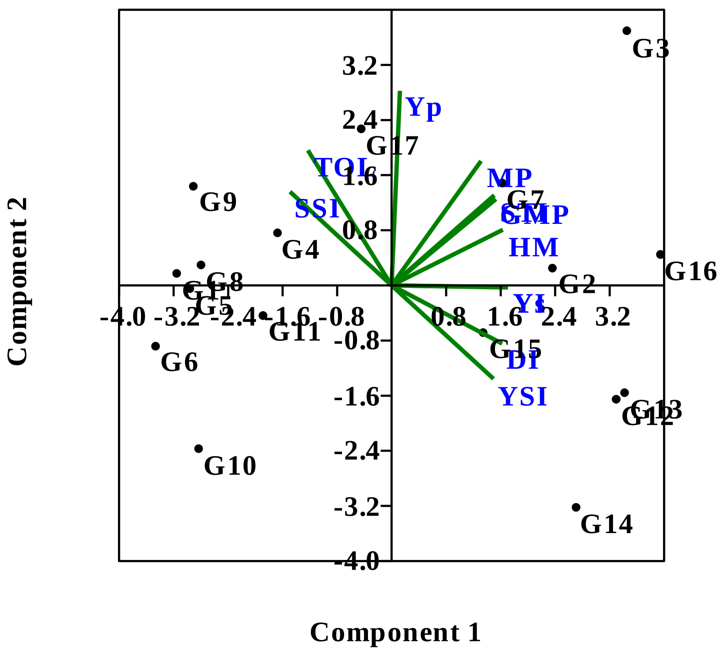

Fig. 2. Biplot diagram of principle components analysis of seventeen rice genotypes according to mean measured of drought tolerance indices under normal and drought conditions

Using the biplot diagram (Fig.1), the genotypes G3, G16, G7 and G2 were located between Yp, Ys and the indices of STI, MP, GMP, YI and HM. The G14, G12 and G13 had considerable correlation with SSI, TOL, DI and YSI. The biplot analysis relationship amongst the above indices revealed that the most appropriate criteria for selecting genotypes are STI, MP, GMP and HM under normal and drought conditions, as well as YI, YSI and DI under stress conditions. The result obtained from principal component through biplot analysis provides valuable information in data analysis and confirms correlation analysis. These findings were similar to the results of Rahimi et al. [49] and Baghyalakshmi et al. [44].

According to Fernandez's classification, the biplot analyses were discriminated that the genotypes G3, G16, G7 and G2 using STI, MP, GMP, YI and HM as well as the genotypes G14, G12 and G13 using SSI, TOL, DI and YSI as the most drought tolerance genotypes (Group A). While, the genotypes G10, G6, G5 and G1 by STI, MP, GMP, YI and HM as well as the genotypes G9, G1 and G8 by SSI, TOL, DI and YSI were detected as sensitive to drought (Group C). The other genotypes identified as moderate drought tolerant genotypes (Group B). Baghyalakshmi et al. [44] obtained the similar results in drought tolerance of rice, where the biplot graph exhibited that YI, MPI, STI, HM and GMP were the best stress indices among all other indices to identify drought tolerant genotypes.

4. CONCLUSIONS

The analysis of variance and genetic parameters indicated the existence of extensive genetic variability in materials used during normal and drought stress conditions. This indicates that the size of differences in genotypes was enough to select from them against drought. More significant differences between genotypic and experimental variances gave evidence that the environment significantly influenced these traits under drought stress. The results revealed that the estimates GCV%, PCV%, heritability and genetic advance were higher in drought conditions as compared to normal conditions for most studied traits. Therefore, the greater possibility of improvement in grain yield and other studied traits of rice through selection appear in drought condition than normal condition. Based on correlation and multivariate analysis it can be concluded that STI, MP, GMP under Yp and Ys as well as YI, YSI, DI and HM under Ys were the best indicators of discriminate drought tolerant genotypes (group A genotypes). During screening drought tolerant genotypes using mean performances, drought tolerance indices and multivariate analysis, the genotypes G3, G16, G7 and G2 were the most drought tolerant genotypes. Therefore they are recommended to be used as parents for improvement of drought tolerance for other cultivars rice in Egypt.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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