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Performance of Some Wheat (*Triticum aestivum* L.) Genotypes and their Drought Tolerance Indices under Normal and Water Stress

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WATER drought stress is a major environmental stress limiting wheat productivity worldwide. The aim of this study was to assess and compare various stress tolerance indices in order to identify the most drought-tolerant wheat genotypes for the future wheat breeding programs. For this purpose, 28 bread wheat genotypes (7 parents and their 21 hybrids) were evaluated in two separate experiments under water-deficit (two irrigations) and well-watered (five irrigations). The drought tolerance indices were calculated based on grain yield under normal (Yp) and stress (Ys) conditions. Highly significant differences were detected among the tested genotypes for all the studied traits, under normal and water stress conditions. Water-deficit stress substantially declined the means of all the studied traits. Water stress caused reductions in days to 50 % heading, plant height, spike length, number of kernels / spike, 1000-kernel weight and grain yield / plant traits by 5.19, 11.15, 16.39, 16.90, 10.67 and 8.98 % respectively. Based on tolerance index (TO L) and stress tolerance index (SSI), the two parents Misr 2 and Line 117, as well as, the crosses Sids14 x Sakha 95, Sids14 x Line 117 and Misr 2 x Line 136 were identified as the suitable genotypes under water stress conditions due to lower values of these indices. Moreover, these genotypes expressed the highest yield under stress conditions. Therefore, the parental genotypes Sids 14 and Sakha 95, as well as the hybrids Sakha 95 x Misr 2 and Sakha 95 x line 115, were identified as highly drought-tolerant genotypes. Accordingly, these genotypes could be used in the future wheat breeding for improving grain yield under water deficit conditions.

Keywords: Wheat, yield and yield components, Water stress, stress indices.

1. Introduction

Wheat (*Triticum aestivum* L.) is a strategic cereal crop globally. In Egypt, it is probably the most important one; there is a gap between production and consumption **(**Farid *et al*., 2023**)**, where its production is insufficient for meeting a growing population's demands. Egypt's annual consumption of wheat grains is approximately 20 million tons, whereas local production reaches around 9.62 million tons (E.A.S., 2021/2022). Water scarcity is a significant environmental stress that has negative effects on wheat growth and production (Cosgrove and Rijsberman, 2000; Jinmenag *et al* 2018).

Thus, there is an actual need to increase its productivity. Drought stress is a major abiotic stress, which has adverse effects on crops. In Egypt, water shortage has become a significant limiting factor for agricultural production in new lands (Ali *et al*., 2019). As plants are the main source of food for most humans, increases in drought will increase human hunger, and this will be exacerbated by population growth. Moreover, increases in drought with global climate change will decrease plant growth, thereby decreasing food production in both natural ecosystems and agricultural systems. (El-Shafei *et al*., 2023).

The importance of breeding drought-tolerant and high-yielding wheat genotypes has grown. This is crucial to maintain wheat production and ensure global food security in the face of a growing population.

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The initial step involves selecting potential germplasm that exhibits genotypic variations in drought tolerance (Baenziger, 2016). To achieve successful breeding of drought-tolerant bread wheat genotypes through conventional methods, breeders must have essential information about the breeding material. This includes significant variability in genotypic responses to water stress and an understanding of the genetic control of different traits. Understanding plant responses to drought is crucial for developing stress-tolerant crops (Farshadfar et al., 2013).

The development of genotypes which need less water and are more tolerant to drought is the main goal of wheat breeders to decrease the gap between national production and consumption. For successful breeding of bread wheat genotypes tolerant to drought through conventional approach, basic information about the breeding material must be available to the breeders. There must be significant variability in genotypic response to water stress, also, knowledge and understanding the type of gene action controlling the inheritance of different traits is important. Understanding plant responses to drought is of great importance and also a fundamental part of making crops stress tolerant (Farshadfar *et al* 2013).

Several drought indices have been used for screening drought tolerant genotypes based on yield under normal and drought stress conditions. Such as : Tolerance index (TOL) (Rosielle and Hamblin, 1981), mean productivity (MP) (Rosielle and Hamblin, 1981), geometric mean productivity (GMP) (Fernandez, 1992),harmonic mean (HM) (Bidinger and Mahalakshmi, 1987),stress susceptibility index (SSI)(Fischer and Maurer, 1978), stress tolerance index (STI) (Fernandez, 1992), yield index (YI) (Gavuzzi *et al*., 1997), yield stability index (YSI) (Bouslam and Schapaugh, 1984) and Relative stress index (RSI) (Bouslam and Schapaugh, 1984). The objectives of this study were to assess and compare various stress tolerance indices in order to identify the most drought-tolerant wheat genotypes for the future wheat breeding programs.

2. Materials and methods

The present study was carried out at the Experimental Farm, Faculty of Agriculture, Kafrelsheikh University, Egypt, during the 2020 /2021 and 2021/2022 successive winter growing seasons. Seven bread wheat genotypes (*Tritium aestivum* L.) which differed considerably in their characters (Table 1) were used as parents in this study.

The seven parental genotypes were sown at 15th November 2020 /2021 season, and all possible diallel crosses (excluding reciprocals) were made among them to obtain seeds of 21 F_1 crosses. The seven parents with their crosses were sown at 15th November 2021 /2022 season under two separate irrigation experiment.

Table 1. The code, name and pedigree of the seven bread wheat genotypes used in the present study.

Parent	Name	pedigree	Characterization
P1	Sids4	Bow"S"Vee"S"//Bow"S"/TSI/BaniSewef 1SD293- 1SD-2SD-4SD-OSD.	Moderate tolerant
P2	Sakha95	PASTOR//Site/MO/3/CHEN/AEGILOPSSQUARrOSA(TAUS)//BCN/4/WbLL.CMSA01Y00158S-040P0Y-040M-030ZTM-040SY-26M0Y0SY-0S.	Drought tolerant
P3	Gemmiza11	BOW"S"/KVZ"S"//7C/SER182/3/GIZA168/SAKHA61	Susceptible
P4	Misr2	SKAUZ/BAV92. CMSS96M03611S-1M-010SY-010M-010SY-8M-0Y-0S	Drought tolerant
P5	Line115	CIMMYT/C. 2008/29ESWYT/OCC. 549/Plot134/ Rep1/Block 7/Entry 134	Moderate tolerant
P6	Lime117	CIMMYT/C. 2008/29ESWYT/OCC. 549/Plot141/ Rep1/Block 9/Entry 142	Drought tolerant
P7	Line136	CIMMYT/C. 2008/ 29ESWYT/OCC.549/Plot136/Rep1/Block 8/Entry 136	Drought tolerant

The first experiment (normal irrigation) was irrigated four times after sowing irrigation (five irrigations were given through the whole season). While, the second experiment (water stress condition) was irrigated only one time after sowing irrigation (two irrigations were given through the whole season). The two experiments were designed in a randomized complete block design with three replications. Each genotype was represented by one row per plot within replicate. The plot size was (0.9 m^2) 3.0 m long and spaces between rows were 30 cm with 15 cm between plants. Seeds were sown by hand. Other agricultural wheat practices were applied as recommended by wheat department, **FCRI**, (Field Crop Research Institute) **ARC (**Agriculture Research Center) 2020/2021 season.

The meteorological data of the experimental site was collected from Sakha meteorological station during 2020/2021 and 2021/2022 growing season and presented in Table 2.

Table 2: Climatic data of the cultivated site in 2020/2021 and 2021/2022 winter seasons.

Month	AT °C 2020/2021		AT °C 2021/2022		RH %		Rainfall (mm)	
	Max.	Min.	Max.	Min.	2020/21	2021/22	2020/21	2021/22
November	28.4	25.1	16.7	15.7	62.5	65.8	3.2	0.0
December	22.8	20.1	12.0	11.5	67.7	70.5	0.0	2.8
January	21.6	17.0	10.4	7.40	68.1	72.7	0.0	2.2
February	21.8	20.1	10.0	8.70	68.4	63.4	0.0	0.2
March	22.3	20.7	10.7	9.00	67.1	60.3	0.0	0.4
April	28.2	31.0	13.7	12.0	60.3	51.9	0.0	0.0
May	35.8	33.0	17.9	17.0	50.0	52.5	0.0	0.2

AT: Actual Temperature RH: Relative Humidity

Table 3: Physical and chemical analysis of soil at the experimental site in 2020/2021 and 2021/2022 seasons.

Soil Properties	2020/2021	2021/2022
Particle size distribution (%)		
Sand	17.1	16.2
Silt	37.0	36.3
Clay	45.9	47.5
Chemical analysis		
pH (1:2.5, soil: water suspension)	8.5	8.2
EC (soil past, dS m^{-1})	2.1	2.4
Organic matter, %	1.5	1.3
Soluble anions (cmolc kg^{-1} soil)		
Na^+	14.4	14.8
K^+	0.3	0.5
Ca^{++}	4.6	5.3
Mg^{++}	2.5	2.0
CO_3^{--}	0.0	0.0
HCO_3^-	5.5	3.8
CL^-	10.1	15.0
SO_4^{--}	6.2	3.8
$CaCO_3$, %	2.7	2.3

The studied characters were days to 50 % heading (day) spike length (cm), No. of kernels/spike, 1000-kerneles weight (g) and grain yield/plant (g). Data were measured on ten guarded plants per plot under two experiments at harvest.

*2.1. **Statistical Analyses***

All the data collected were subjected to analysis of variance according to Snedecor and Cochran (1989). Treatment means were compared by LSD test. All statistical analysis was performed using analysis of variance technique utilizing "COSTAT" computer soft war package. Drought Tolerance Indices were calculated to identify drought-tolerant genotypes as follows: Tolerance index (TOL) = Yp - Ys (Rosielle and Hamblin, 1981).Mean productivity (MP) = (Ys + Yp)/2 (Rosielle and Hamblin, 1980).Geometric mean productivity (GMP) = $\sqrt{Ys \times Yp}$ (Fernandez, 1992). Harmonic mean (HM) =2(Ys×Yp)/Ys+Yp (Bidinger and Mahalakshmi, 1987).Stress susceptibility index (SSI) = [(1-(Ys/Yp)] / 1- ($\bar{Y}s/\bar{Y}p$)] (Fischer and Maurer, 1978).Stress tolerance index (STI) = $(Y_s \times Y_p)/(\bar{Y}_p)^2$ (Fernandez, 1992).Yield index (YI) = Ys/Ȳs(Gavuzzi et al., 1997).Yield stability index (YSI) = Ys/Yp (Bouslam and Schapaugh, 1984) and Relative stress index (RSI) = $Y_s/Y_p/Y_{ms}/Y_{mp}$ (Bouslam and Schapaugh,1984). where; Ys, is the grain yield of genotypes under stress condition, Yp, the grain yield of genotypes under normal conditions, Ȳs and Ȳp are the mean yields of all genotypes under stress and normal conditions, respectively.

3. Results

3.1. Analysis of variance

The analysis of variance (Table 4) revealed that genotypes exhibited significant differences for all the studied traits under normal irrigation and drought stress condition, indicating the presence of considerable genetic variations among the tested genotypes.

Table 4: Analysis of variance for 28 genotypes for all the studied traits under normal and drought stress conditions.

S.O.V.	D	Days to 50% heading (day)		Plant height (cm)		Spike length (cm)		No. of kernel / spike		1000-kernel weight (g)		Grain yield / plant (g)	
		N	D	N	D	N	D	N	D	N	D	N	D
Reps	2	2.04	8.82	1.39	0.15	0.00	0.43	0.23	1.29	0.23	0.05	0.14	0.44
Genotypes	27	38.48 **	41.60 **	59.95 **	79.13 **	2.61 **	2.37 **	58.16 **	60.15 **	10.45 **	7.56 **	19.15 **	21.86 **
Error	54	2.02	3.02	5.23	8.55	0.46	0.43	2.34	4.29	2.34	1.95	8.06	6.81

*, ** Significant at 0.05 and 0.01 levels of probability; respectively

Abbreviations: Drought (D), normal (N)

3.2. Mean performance and reduction percentage

Mean performance and reduction percentage of the seven parental genotypes and their 21 F_1 crosses under normal and stress conditions for all the studied traits are shown in Table 5. The results revealed that wheat genotypes significantly differed in their responses under both conditions for all the studied traits as shown in Table 3. Means of days to 50% heading %, plant height (cm) and spike length (cm) were 97.82 and 92.72 days, 116.00 and 103.00 cm, and 13.51 and 11.30 cm under normal irrigation and drought stress, respectively.

For days to heading, among parents the parental cultivar Sakha 95 and line 136 were the earliest parents with values of 93.33 and 88.00 days under normal and drought stress respectively. The cross Line 117 x Line days under normal and drought stress respectively.

Regarding plant height, the tallest parents were Misr2 and line 117, with values of, 124.33 and 136 was the earliest with values of 93.67 and 88.00 110.00 cm under normal and drought stress, respectively. The two crosses Misr2 x Line115 and Line 115 x Line 117 exhibited the highest mean values of plant height under both conditions, thus these genotypes could improve plant height. The decrease in plant height due to water stress may be attributed to the reduction in internode length, because of the deficiency of soil moisture. Concerning spike length, the parental Gemmiza 11 and Line 115 gave the highest mean values under both conditions.

Mean performance and reduction percentage of the seven parental genotypes and their 21 F1 crosses under normal and stress conditions grain yield and its components are shown in Table 6. Means for no.

of kernel/ spike, 100-kernel weight (g) and grain yield/ plant (g) were 65.65 and 54.61 kernels, 44.56 and 39.80 g. and 68.32 and 62.16 g. under normal irrigation and drought stress, respectively. Drought stress caused reductions in these traits by 16.90, 10.67 and 8.98 % respectively.

Table 5. Means and reduction percentage of the studied traits for genotypes under normal and drought stress conditions.

Genotypes	Days to 50% heading (day)			Plant height (cm)			Spike length (cm)		
Parents:	Normal	Drought	Reduction	Normal	Drought	Redaction	Normal	Drought	Reduction
Sids 14	98.00	92.00	6.12	109.33	90.67	17.07	13.00	11.03	15.15
Sakha 95	93.33	89.33	4.29	115.67	95.33	17.58	12.33	10.10	18.09
Gemmiza 11	107.00	101.00	5.61	104.00	91.67	11.86	15.00	12.73	15.13
Misr 2	103.00	96.00	6.80	124.33	107.67	13.40	11.33	9.80	13.50
Line 115	94.00	90.00	4.26	118.33	107.67	9.01	15.00	12.13	19.13
Line 117	98.33	93.33	5.08	122.67	110.00	10.33	14.33	10.47	26.94
Line 136	94.00	88.00	6.38	115.67	102.00	11.82	12.67	9.47	25.26
Crosses									
Sids 14 x Sakha 95	97.33	93.00	4.45	117.00	102.00	12.82	12.93	10.67	17.48
Sids 14 x Gemmiza11	103.00	98.00	4.85	110.67	97.67	11.75	14.60	12.47	14.59
Sids 14 x Misr 2	100.33	97.00	3.32	119.67	105.33	11.98	12.73	10.40	18.30
Sids 14 x Line 115	94.33	90.33	4.24	118.33	103.67	12.39	14.63	12.57	14.08
Sids 14 x Line 117	97.67	93.33	4.44	119.67	106.00	11.42	14.10	11.93	15.39
Sids 14 x Line 136	94.67	89.00	5.99	114.00	102.67	9.94	13.90	11.67	16.04
Sakha5 x Gemmiza11	99.67	95.33	4.35	113.00	97.00	14.16	14.37	11.97	16.70
Sakha 95 xMisr 2	98.33	93.00	5.42	119.00	108.33	8.97	12.90	10.73	16.82
Sakha 95 xLine 115	94.33	89.00	5.65	117.00	103.67	11.39	14.07	11.63	17.34
Sakha 95 x Line 117	99.00	92.33	6.74	116.33	106.33	8.60	13.33	11.47	13.95
Sakha 95 x Line 136	94.33	88.33	6.36	113.67	102.67	9.68	13.33	11.13	16.50
Gemmiza 11 x Misr 2	104.00	99.00	4.81	116.00	105.00	9.48	13.10	11.50	12.21
Gemmiza 11 x Line 115	101.00	95.00	5.94	114.33	101.33	11.37	14.70	12.27	16.53
Gemmiza 11 x Line 117	98.33	95.00	3.39	113.00	101.33	10.33	13.23	11.80	10.81
Gemmiza 11 x Line 136	98.33	93.67	4.74	107.67	97.33	9.60	13.37	11.37	14.96
Misr 2 x Line 115	97.33	92.33	5.14	121.33	109.67	9.61	13.00	10.90	16.15
Misr 2 x Line 117	100.00	97.33	2.67	119.67	106.67	10.86	12.60	10.80	14.29
Misr 2 x Line 136	97.33	92.67	4.79	117.33	104.67	10.79	12.03	9.77	18.79
Line 115 x Line 117	95.33	89.33	6.29	119.67	109.33	8.64	14.27	12.10	15.21
Line 115 x Line 136	93.00	86.33	7.17	114.33	103.67	9.32	14.10	11.97	15.11
Line 117 x Line 136	93.67	88.00	6.05	116.33	107.00	8.02	13.40	11.47	14.40
Grand mean	97.82	92.75	5.19	116.00	103.08	11.15	13.51	11.30	16.39
L.S.D 0.05	2.329	2.844		3.745	4.787		1.115	1.074	
0.01	3.101	3.788		4.987	6.374		1.484	1.430	

Table 6. Means and reduction percentage of the studied traits for genotypes under normal and drought stress conditions.

Genotypes	No. of kernel/ spike			1000-kernel weight (g)			Grain yield/ plant (g)		
Parents:	Normal	Drought	Redaction	Normal	Drought	Redaction	Normal	Drought	Redaction
Sids 14	70.33	59.33	15.64	43.67	39.00	10.69	72.33	66.00	8.75
Sakha 95	74.00	62.00	16.22	48.67	43.00	11.65	74.00	68.33	7.66
Gemmiza 11	66.33	56.00	15.57	43.00	37.67	12.40	63.67	59.00	7.33
Misr 2	57.67	45.33	21.40	41.00	36.33	11.39	66.67	65.33	2.01
Line 115	62.33	52.00	16.57	43.00	38.00	11.63	68.00	60.33	11.28
Line 117	67.00	54.67	18.40	47.33	40.67	14.07	64.67	61.33	5.16
Line 136	56.00	45.00	19.64	44.33	40.00	9.77	66.33	62.00	6.53
Crosses									
Sids 14 x Sakha 95	72.33	61.67	14.74	46.00	41.67	9.41	68.33	67.67	0.97
Sids 14 x Gemmiza11	68.33	57.00	16.58	43.33	39.67	8.45	66.33	59.67	10.04
Sids 14 x Misr 2	66.00	53.33	19.20	42.67	38.00	10.94	65.00	60.67	6.66
Sids 14 x Line 115	67.33	55.67	17.32	43.67	39.00	10.69	70.00	62.67	10.47
Sids 14 x Line 117	69.33	59.67	13.93	46.67	42.00	10.01	66.00	62.00	6.06
Sids 14 x Line 136	65.33	52.33	19.90	44.33	39.00	12.02	67.00	62.33	6.97
Sakha 95 x Gemmiza11	71.67	60.00	16.28	43.33	38.33	11.54	70.00	62.67	10.47
Sakha 95 xMisr 2	68.00	56.00	17.65	43.67	38.67	11.45	72.00	64.67	10.18
Sakha 95 xLine 115	68.67	57.67	16.02	45.00	40.67	9.62	71.67	62.00	13.49
Sakha 95 x Line 117	71.00	61.00	14.08	47.00	42.33	9.94	68.00	61.33	9.81
Sakha 95 x Line 136	66.67	57.00	14.50	47.33	41.33	12.68	69.67	61.67	11.48
Gemmiza 11 x Misr 2	62.67	52.33	16.50	43.33	41.00	5.38	67.33	59.00	12.37
Gemmiza 11 x Line 115	63.67	53.00	16.76	42.67	38.00	10.94	69.67	59.00	15.32
Gemmiza 11 x Line 117	65.33	56.33	13.78	44.00	39.67	9.84	65.67	58.67	10.66
Gemmiza 11 x Line 136	62.33	51.33	17.65	45.00	40.00	11.11	67.00	57.67	13.93
Misr 2x Line 115	61.33	49.33	19.57	43.00	39.33	8.53	70.00	63.00	10.00
Misr 2 x Line 117	64.00	52.00	18.75	43.33	39.33	9.23	67.33	62.67	6.92
Misr 2 x Line 136	58.33	48.67	16.56	43.67	39.00	10.69	70.33	66.33	5.69
Line 115 x Line 117	66.00	55.33	16.17	44.67	40.00	10.45	70.67	60.67	14.15
Line 115 x Line 136	62.33	52.00	16.57	46.67	41.00	12.15	68.67	62.00	9.71
Line 117 x Line 136	64.00	53.00	17.19	47.33	41.67	11.96	66.67	61.67	7.50
G. Mean	65.65	54.61	16.90	44.56	39.80	10.67	68.32	62.16	8.98
L.S.D 0.05	2.503	3.389		2.503	2.285		4.646	4.272	
0.01	3.333	4.513		3.333	3.043		6.188	5.689	

For no. of kernel/spike the parental genotypes Sids 14 and Sakha 95 and the crosses Sids 14 x sakha95 , Sakha 95 x Gemmiza 11 and Sakha 95 x Line 117 had the highest mean values of no. of kernel/ spike under both conditions.

Regarding 1000 kernels weight, results showed that the parental Sakha 95 and Line117, also, the crosses Sids 14 x Sakha 95, Sids 14 x line 117, Sakha 95 x Line 117 and Line 117 x Line 136 gave the heaviest 1000 kernels weight among the crosses and were of common superiority in both conditions.

For grain yield / plant the parental genotypes Sids 14 and Sakha 95, also the two crosses Sakha 95 x

Misr 3 and Sakha 95 x Line 115had the highest grain yield / plant under both conditions. The decrease in grain weight due to drought conditions could be attributed to reduced grain filling period and / or reduction in photosynthesis and translocation of reserves to grains.

3.3. ***Mean grain yield / plant under normal (Yp) and drought stress (Ys) and different drought tolerance indices for 28 bread wheat genotypes***

The drought tolerance indices were calculated based on grain yield under normal (Yp) and stress (Ys) conditions, as shown in Table 7. Genotypes with high values of mean productivity (MD), geometric mean productivity (GMP), harmonic mean productivity (HM) and stress tolerance index (STI) could be selected as drought-tolerant genotypes.

Table 7. Estimation of sensitivity rate of 28 wheat genotypes by different drought tolerance indices under normal and stressed conditions.

Genotype Code	**Yp**	**Ys**	**TOL**	**MP**	**GMP**	**HM**	**SSI**	**STI**	**YI**	**YSI**	**RSI**
Sids 14	72.3	66.0	6.3	69.2	69.1	69.0	1.0	1.0	1.1	0.9	1.0
Sakha 95	74.0	68.3	5.7	71.2	71.1	71.1	0.8	1.1	1.1	0.9	1.0
Gemmiza 11	63.7	59.0	4.7	61.3	61.3	61.2	0.8	0.8	0.9	0.9	1.0
Misr 2	66.7	65.3	1.3	66.0	66.0	66.0	0.2	0.9	1.1	1.0	1.1
Line 115	68.0	60.3	7.7	64.2	64.1	63.9	1.2	0.9	1.0	0.9	1.0
Line 117	64.7	61.3	3.3	63.0	63.0	63.0	0.6	0.8	1.0	0.9	1.0
Line 136	66.3	62.0	4.3	64.2	64.1	64.1	0.7	0.9	1.0	0.9	1.0
Sids 14 x Sakha 95	68.3	67.7	0.7	68.0	68.0	68.0	0.1	1.0	1.1	1.0	1.1
Sids 14 x Gemmiza11	66.3	59.7	6.7	63.0	62.9	62.8	1.1	0.8	1.0	0.9	1.0
Sids 14 x Misr 2	65.0	60.7	4.3	62.8	62.8	62.8	0.7	0.8	1.0	0.9	1.0
Sids 14 x Line 115	70.0	62.7	7.3	66.3	66.2	66.1	1.2	0.9	1.0	0.9	1.0
Sids 14 x Line 117	66.0	62.0	4.0	64.0	64.0	63.9	0.7	0.9	1.0	0.9	1.0
Sids 14 x Line 136	67.0	62.3	4.7	64.7	64.6	64.6	0.8	0.9	1.0	0.9	1.0
Sakha 95 x Gemmiza11	70.0	62.7	7.3	66.3	66.2	66.1	1.2	0.9	1.0	0.9	1.0
Sakha 95 x Misr 2	72.0	64.7	7.3	68.3	68.2	68.1	1.1	1.0	1.0	0.9	1.0
Sakha 95 x Line 115	71.7	62.0	9.7	66.8	66.7	66.5	1.5	1.0	1.0	0.9	1.0
Sakha 95 x Line 117	68.0	61.3	6.7	64.7	64.6	64.5	1.1	0.9	1.0	0.9	1.0
Sakha 95 x Line 136	69.7	61.7	8.0	65.7	65.5	65.4	1.3	0.9	1.0	0.9	1.0
Gemmiza 11 x Misr 2	67.3	59.0	8.3	63.2	63.0	62.9	1.4	0.9	0.9	0.9	1.0
Gemmiza 11 x Line115	69.7	59.0	10.7	64.3	64.1	63.9	1.7	0.9	0.9	0.8	0.9
Gemmiza 11 x Line117	65.7	58.7	7.0	62.2	62.1	62.0	1.2	0.8	0.9	0.9	1.0
Gemmiza 11 x Line136	67.0	57.7	9.3	62.3	62.2	62.0	1.5	0.8	0.9	0.9	0.9
Misr 2 x Line 115	70.0	63.0	7.0	66.5	66.4	66.3	1.1	0.9	1.0	0.9	1.0
Misr 2 x Line 117	67.3	62.7	4.7	65.0	65.0	64.9	0.8	0.9	1.0	0.9	1.0
Misr 2 x Line 136	70.3	66.3	4.0	68.3	68.3	68.3	0.6	1.0	1.1	0.9	1.0
Line 115 x Line 117	70.7	60.7	10.0	65.7	65.5	65.3	1.6	0.9	1.0	0.9	0.9
Line 115 x Line 136	68.7	62.0	6.7	65.3	65.2	65.2	1.1	0.9	1.0	0.9	1.0
Line 117 x Line 136	66.7	61.7	5.0	64.2	64.1	64.1	0.8	0.9	1.0	0.9	1.0
Grand mean	65.65	54.61	16.90	44.56	39.80	10.67	68.32	62.16	8.98	65.65	54.61

Where: TOL, Tolerance index; MP, mean productivity; GMP, geometric mean productivity; HM, harmonic mean; SSI, stress susceptibility index STI, stress tolerance index; YI, yield index; YSI, yield stability index; RSI, Relative Stress Index.

Data showed that STI index ranged from 0.8 to 1.10. The higher values indicate high-stress tolerance. The highest indices were detected by the genotypes Sids 14, Sakha 95 and the crosses Sids 14 x Sakha 95, Sakha 95 x Misr2 , Sakha 95 x Line 115 and Misr2 x Line 136 . Therefore, it is considered the highly drought tolerant

genotypes, While, Gemmiza 11, Line 117 and the crosses Sids 14 x Gemmiza 11, Sids 14 X Misr 2, Gemmiza 11 x Line 117 and Gemmiza 11 x Line136 had the lowest value of M p, G M P , H M and STI indices, subsequently; it is considered drought-sensitive genotypes.

Genotypes with low tolerance index (TOL) would be more tolerant to drought stress, also stress susceptibility index (SSI) estimates the rate of change for each genotype in yield between the normal and drought conditions relative to the mean change for all genotypes. Values of (SSI) lower than 1 denotes low drought susceptibility (high yield stability), while values higher than 1 indicate high drought susceptibility (poor yield stability). Data in Table 6 showed that the lowest values of these indices (TOL and SSI) were the parent Misr 2 and the cross Sids14 X Sakha 95 (1.3 and 0.7) and (0.2 and 0.1) for TOL and SSI, respectively) and could identify as the Yield index (YI), the genotypes with high values of (YI) will be suitable for drought stress condition (tolerant genotypes). Therefore, the parental genotypes Sids 14, Sakha 93 and Misr 2 and the crosses Sids 14 x Sakha 95 and Misr2 x Line136 were identified as drought tolerant genotypes, and can be selected as tolerant to water stress. Concerning yield stability index (YSI), the genotypes with high (YSI) values can be selected and regarded as stable genotypes under normal and drought conditions. Data in Table 6 revealed that the parental genotype Mise2 and the cross Sids 14 x Sakha 95 with high values of this index (YSI) can be selected as tolerant genotypes to water stress. Regarding relative stress index (RSI), the genotypes Misr2 and the cross Sids 14 x Sakha 95 were the most tolerant genotypes based on (RSI) index. The genotypes Sids14 and Sakha 95, also the crosses Sakha95 x Misr 2 and Sakha 95 x Line 115 had greater values for M P, G M P, H M, STI and Yi indices.

3.4. Cluster analysis

All genotypes were grouped into two major clusters in the dendrogram based on yield reduction under two conditions (Figure 1). The first cluster included Line 117 and Line 136 represents the drought tolerant wheat genotypes, while the second cluster including the remain genotypes which divided into two sub-cluster one of them including two genotypes represents low yield reduction Misr 2 and cross Sids14 x Sakha 95.

The moderately-tolerant and susceptible wheat genotypes were located into other sub and sub-sub clusters. Hence, yield reduction may be an efficient tool for varietal identification and assessing genetic diversity in wheat.

4. Discussion

Highly significant variations were observed among the tested genotypes for all studied under normal and water deficit conditions. under water deficit conditions. These findings revealed the existence of wide genetic variability in the assessed materials, which could be exploited for developing drought-tolerant wheat genotypes. These findings coincide with those of Badu-Apraku *et al.* (2017) and Mafouasson *et al*. (2018).

The presence of genetic variability among the test genotypes for traits related to stress tolerance is paramount for successful breeding, which aimed to develop cultivars adapted to a range of stress environments. Also, the differences between the genotypes were significant. (Asfaw and Blair 2014; Noreldin and Mahmoud (2017) and Shalaby *et al* (2020). The crosses Sids 14 x Line 115 and Gemmiza11 X Line 115 had the highest mean values of spike length. So, drought stress caused reductions in the days to 50 % heading, plant height and spike length traits by 5.19, 11.15 and 16.39 % respectively. These results are in agreement with those obtained by Abd El- Aty *et al* (2016); Mwadzingeni *et al.* 2017; Fouad (2018); Mathew *et al.* (2018); Abd El Kreem *et al* (2019); and Mohamed *et al* (2022).They found that spike length was significantly affected by water stress treatments and wheat genotypes.

Drought stress caused reductions in No. of kernel/ spike, 100-kernel weight (g) and grain yield/ plant (g) by 16.90, 10.67 and 8.98 % respectively. This reduction might b due to effect of water deficiency on pollination and fertilization processes. This is consistent with previous studies where drought was shown to have a greater influence on grain number, largely accounting for the decline in wheat yield (Dolferus *et al* 2011). Drought has a highly adverse effect on meiosis and anthesis, directly affecting grain number. This causes a substantial reduction in grain yield (Cattivelli *et al* 2008). Moreover, pollen becomes sterile during drought during the early microspore stage of pollen development, reducing the grain number Shiran *et al* (2010). These results are in agreement with those obtained by. Abd El-Aty *et al* (2016) Fouad (2018), Abd El Kreem *et al* (2019), Shalaby *et al (*2020) and Mohamed *et al* (2022).

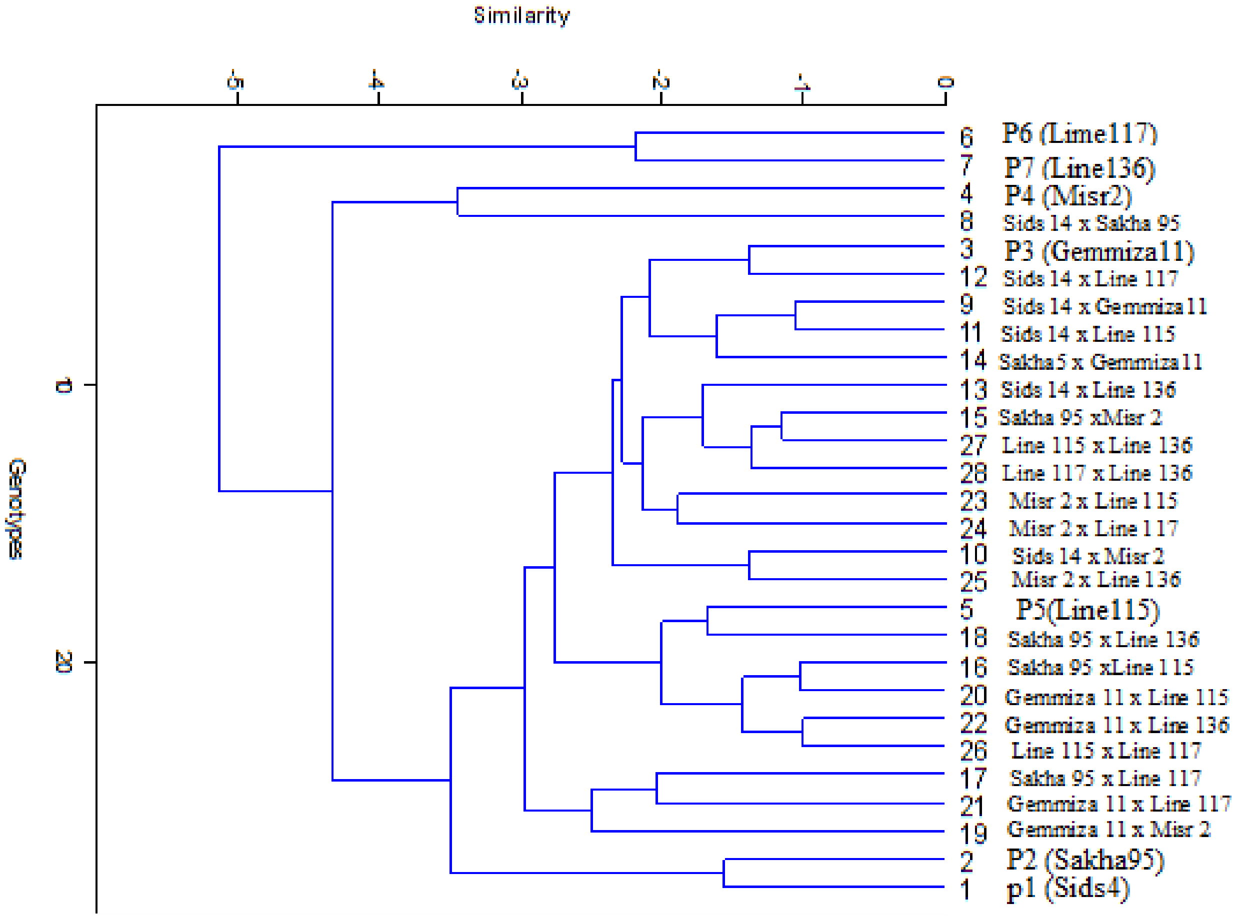

Fig. 1. Dendrogram derived from cluster analysis of 28 wheat genotypes based on yield reduction under water stress.

Kobata *et al* (1992) showed that, the grain yield was reduced under water stress by 33%. Also, Dencic *et al.* (2000) found that decreasing soil moisture caused significant reduction in grain yield. While, Salem (2005) reported that normal irrigation treatment significantly maximized grain yield. Therefore, selection based on STI might lead to high-yielding tolerant genotypes Menezes *et al.* (2014), (Abdelghany *et. al* (2016), Abd El-Kreem *et al* (2019)., Manal and Samah (2019) and Arab *et al* (2021) reported a high STI rate for the genotype presents its high drought tolerance and its high yield. Mevlut and Sait (2011) considered that, the genotypes with high STI have difference in yield under stress and non-stress environment that may be revealed small or minor yield reductions under drought condition. These findings are coincident with those reported by Farshadfar *et al.* (2013) Kumar *et al. (*2014); Manal and Samah (2019) and Mohamed *et al* (2022). So, these genotypes might be used as parents in breeding programs to produce new genotypes with desirable characters related to drought to tolerance.

Drought tolerance indices play a crucial role in assessing and understanding the ability of plants to withstand and recover from drought stress. These indices provide valuable information for plant breeders, agronomists, and policymakers in developing strategies to mitigate the impacts of drought on agriculture and the environment. Here are some key reasons why drought tolerance indices are important:

Plant breeding and selection: Drought tolerance indices help plant breeders identify and select plants with enhanced drought tolerance. By evaluating and comparing different varieties or genotypes based on their performance under drought conditions, breeders can identify the most drought-tolerant plants for further breeding programs. This facilitates the development of drought-tolerant cultivars that can withstand water scarcity and maintain productivity even in challenging environments. Crop management and resource allocation: Drought tolerance indices provide guidance for optimizing crop management practices and resource allocation in water-limited conditions. By understanding the drought tolerance levels of different crops or varieties, farmers can make informed decisions regarding irrigation scheduling, fertilizer application, and other management practices. This improves water use efficiency, reduces input costs, and ensures sustainable agricultural production in drought-prone regions. Risk assessment and mitigation: Drought tolerance indices help in assessing the risk of drought and predicting crop performance under varying water availability scenarios. By considering the drought tolerance of crops or varieties, policymakers and farmers can make informed decisions regarding land-use planning, crop selection, and risk management strategies. This can help reduce the vulnerability of agricultural systems to drought and minimize potential economic losses. Climate change adaptation: With the increasing frequency and intensity of drought events due to climate change, understanding and enhancing drought tolerance in crops is crucial for adaptation. Drought tolerance indices provide a framework for evaluating the performance of different crops or varieties under changing climatic conditions. This knowledge can guide the development of climate-resilient agricultural systems and help farmers adapt to the challenges posed by water scarcity. Conservation and environmental sustainability: Drought tolerance indices also have implications for sustainable water management and environmental conservation. By identifying and promoting drought-tolerant crops or varieties, farmers can reduce their reliance on irrigation and minimize water consumption. This contributes to water conservation efforts, mitigates the depletion of water resources, and promotes environmental sustainability. In conclusion, drought tolerance indices are essential tools for assessing, selecting, and managing drought-tolerant crops. They enable breeders and farmers to make informed decisions, reduce risks, adapt to changing climatic conditions, and promote sustainable agriculture in water-limited environments.

Conclusions

Assessment of drought tolerance indices indicated that, the two parents Sids 14 and Sakha 95 and the two crosses Sakha 95 x Misr 2 and Sakha 95 x line 115 could be used in breeding programs for breading wheat under water stress to produce new genotypes with high yielding ability.

Conflicts of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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