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Indices of tolerance and sensitivity to water deficit stress in different cucumber genotypes

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ABSTRACT

To identify genotypes tolerant to water stress and screen the tolerance and sensitivity indices to water stress, the present study was conducted in 2022 in the greenhouse of the Faculty of Agricultural Sciences, University of Guilan, Rasht, Iran. The study included 50 cucumber genotypes in split plots and a completely randomized basic design with two levels of irrigation: full irrigation and deficit irrigation (50% of the water provided in full irrigation), each with three replications and two plants per replication. Based on the yield observed under both full and deficit irrigation conditions, various indices were calculated to assess tolerance and sensitivity to water stress. These indices included SSI, SI, HM, TOL, MP, YSI, GMP, STI, MRP, YI, REI, and SRI. The results of the mean comparison indicated that genotype 42 achieved the highest yield under full irrigation, while genotype 45 produced the highest yield under deficit irrigation. The highest values for MP, MRP, REI, STI, GMP, and HM indices were recorded in genotypes 45, 42, 43, and 22. The correlation test results also indicated that these six indices had the highest correlation with yield under both full and deficit irrigation conditions, making them the most suitable indices for screening and identifying superior genotypes. Using various methods in the present study, such as three-dimensional diagrams, principal component analysis, and cluster analysis, genotypes 45, 43, and 42 were identified as superior for achieving high yield under water scarcity conditions. Given Iran's water crisis and its exacerbation by climate change, breeding cucumber cultivars resistant to deficit irrigation is crucial for developing new hybrids suitable for the Iranian environment.

Keywords: Breeding, Drip irrigation, Screening, Yield.
Article type: Research Article.

INTRODUCTION

Cucumber, *Cucumis sativus* L. is a popular member of the cucurbit family, enjoyed by many around the world. This creeping plant is scientifically recognized as a fruit vegetable and is known for its popularity as a vegetable. Greenhouse cultivation, a modern agricultural method, provides ideal conditions for cucumber growth, particularly for this plant, which is more adaptable to lower temperatures than other family members (Zarandi *et al.* 2024). According to statistics published by the FAO, China ranks first among global producers of cucumbers with an annual production of 61 million tons. Statistics from the Iranian Ministry of Agriculture indicate that about 75% of the country's greenhouse production is dedicated to cucumbers. These statistics underscore the economic and nutritional importance of cucumbers in the food basket of many countries, including Iran. Today, cucumbers are considered one of the main greenhouse products in Iran, playing a crucial role in supplying this product during the cold seasons. In 2022, according to the Center for Statistics, Information Technology, and Communications of the Ministry of Agriculture, cucumber production in Iran amounted to 577,418 tons, with a cultivated area of 22,686 hectares and a yield in the irrigated sector of 25,544 kg ha^{-1}. The South Kerman in Central Iran ranks first in production, with a yield of 95,437 tons (Agricultural Statistics 2022). Greenhouse cucumbers grow rapidly, benefiting from the ideal environmental conditions provided in this controlled environment. Typically, the plant begins to produce fruit just 60 to 70 days after seed planting. However, this high growth rate is accompanied by a high sensitivity to environmental conditions, including fertilizers, light, air temperature, soil moisture, carbon dioxide, and relative humidity (Moghadam 2018). Previous studies have shown that direct selection of varieties based on performance under both normal and stress conditions is an efficient method for improving yield in stressed environments. Genotypes are typically divided into four main groups: high-yielding under both normal and stress conditions (group A), high-yielding under normal conditions only (group B), high-yielding under stress conditions only (group C), and low-yielding under both conditions (group D; Fernandez 1992; Wang *et al.* 2018; Wang 2021). The relative yield of genotypes under stress and non-stress conditions is a key indicator for identifying drought-tolerant cultivars and exploiting them in breeding programs. An ideal indicator for selecting cultivars should accurately distinguish between cultivars with superior yield in both environments and those that perform well in only one environment. Despite the importance of this issue, comprehensive studies have not yet assessed the stability of cucumber lines and identified the most appropriate selection index for this trait under water stress conditions (Abbas *et al.* 2023; Das *et al.* 2024). Cluster analysis is a multivariate statistical method designed to determine the diversity between different plant and animal communities and classify them into groups based on genetic distance or similarity. This method is particularly beneficial to breeders in two key ways: first, it helps identify real groups of individuals based on genetic similarity; second, it aids in data reduction by selecting limited individuals from each group or category (Jobson 2012). In other words, cluster analysis highlights the nature of relationships between samples, expressed by descriptors. This analysis classifies genotypes into groups based on genetic distance and selects parents that can produce superior hybrids (Subramanian & Subbaraman 2010). For instance, Moradipour *et al.* (2018) evaluated the genetic diversity of 25 cucumber lines for 25 morphological traits using cluster analysis. The results grouped all lines into seven separate clusters, indicating high genetic diversity, which can be used for heterosis and selecting suitable parents in crossing programs to produce desirable traits. Similarly, a study on 9 cucumber inbred lines examined 33 quantitative and qualitative traits using cluster analysis, resulting in the lines being divided into three groups, reflecting significant genotypic differences (Zhang *et al.* 2012). To determine genetic diversity among 13 cucumber genotypes with different geographical origins, Parvathaneni *et al.* (2011) examined the genotypes for 19 morphological traits, such as yield, number of fruits, male flowers per node, first flower appearance, fruit diameter, fruit length, secondary branches, and plant length. The results showed significant differences in all traits, and the genotypes were grouped into six clusters based on cluster analysis. Generally, genotypes with higher mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HM), stress tolerance index (STI), yield index (YI), yield stability index (YSI), lower stress sensitivity index (SSI) and tolerance index (TOL) are more tolerant (Jafari-Rad *et al.* 2015). Although it is not possible to state with certainty which indices are fully correlated with drought stress tolerance, these indices show varying degrees of correlation with water stress tolerance, depending on the crop's genus and species (Rosielle & Hamblin 1981). While previous studies have examined drought tolerance in cucumber, further research is needed on genotype response to this stress. The main objective of this study was to identify and evaluate 50 different genotypes for breeding high drought tolerance. Using various methods to evaluate tolerance and sensitivity to drought stress, this study aimed to find genotypes with favorable yield under drought conditions for use in cucumber breeding programs.

MATERIALS AND METHODS

This study was conducted in the vegetable greenhouse of the Department of Horticultural Science and Engineering, Faculty of Agricultural Sciences, University of Guilan, Rasht, Northwest Iran located at 49°36'E, 37°16'N, and 7 m above sea level in 2022. Fifty cucumber genotypes from the germplasm bank of the University of Guilan were examined. Cucumber genotypes were selected randomly. The experiment was conducted in split plots and a completely randomized design, including two levels: full- and deficit irrigation (50% of the amount of water given in full irrigation), with three replications (300 experimental units; Fig. 1). The water requirement of cucumbers was calculated based on the ETo calculated according to the meteorological data from the nearby Rasht Agricultural Meteorological Research station with CropWat software and the cucumber crop coefficients from FAO Publication No. 56 (Allen *et al.* 1998). The total cultivated area of the greenhouse was divided into two parts: full- and deficit irrigation. Greenhouse irrigation was carried out using a drip irrigation system with drip tape. Soil moisture sampling was used to control irrigation conditions. The amount of water required by greenhouse cucumbers was 223 mm. Based on this, two irrigation levels were applied: full irrigation (100% of water requirement) and deficit irrigation (50% of water requirement). After the seedlings were transplanted to the greenhouse and the plants were properly established, deficit irrigation was applied from the beginning of the mid-season stage until the end of the irrigation season. The amount of irrigation water in the deficit irrigation treatment was 135 mm. Before sowing, the seeds were germinated for 48 hours. After preparing the seedlings and a suitable growing medium, the seedlings were transplanted to the greenhouse. The fresh weight of the fruits per plant was determined as the plant yield (Balkaya *et al.* 2011). The present study aimed to investigate the response of 50 cucumber genotypes to water stress and determine their resistance and sensitivity indices based on yield. Various tolerance and sensitivity indices were used to evaluate the response of genotypes in terms of yield and to identify more stress-resistant cultivars (Table 1).

Table 1. Different tolerance and sensitivity indices.

Indices	Relations	References	Indices	Relations	References
Stress Sensitivity Index	$SSI = \frac{(1 - \frac{Y_S}{Y_p})}{SI}$	Fischer & Maurer, 1978	Yield Stability Index	$YSI = \frac{Y_S}{Y_P}$	Bouslama & Schaugh, 1984
Stress Index	$SI = 1 - \frac{\bar{Y}_S}{\bar{Y}_p}$	Fischer & Maurer, 1978	Geometric Mean Productivity	$\mathrm{GMP} = \sqrt{\mathrm{Y_p \times Y_s}}$	Fernandez, 1992
Harmonic Mean	$HM = \frac{2Y_pY_s}{(Y_p + Y_s)}$	Rosielle & Hamblin, 1981	Stress Tolerance Index	$\mathrm{STI} = \frac{\mathrm{Y_p - Y_s}}{(\bar{\mathrm{Y}}_\mathrm{p})}$	Fernandez, 1992
Stress Tolerance	$TOL = Y_{P\_}Y_S$	Rosielle & Hamblin, 1981	Mean relative performance	$MRP = \frac{Y_S}{\overline{Ys}} + \frac{Y_p}{\overline{Y_P}}$	Hossain *et al.* 1999
Mean Productivity	$MP = \left(\frac{Y_p + Y_s}{2}\right)$	Rosielle & Hamblin, 1981	Yield Index	$YI = \frac{Y_s}{\bar{Y}_S}$	Gavuzzi *et al.* 1997
Relative Efficiency Index	$REI = \frac{Y_S}{\overline{Ys}} \times \frac{Y_p}{\overline{Y_P}}$	Hossain *et al.* 1999	Stress Tolerance Index	$\mathrm{SRI} = \frac{\mathrm{Ys} \times \left(\frac{\mathrm{Ys}}{\mathrm{Yp}}\right)}{\overline{\mathrm{Ys}}}$	Lan, 1998

Note: Yp = the yield of the desired genotype in the full irrigation treatment; Ys = the yield of the desired genotype in the deficit irrigation condition; $\overline{Y_P}$ = the average yield of all genotypes in the full irrigation treatment; $\overline{Ys}$ = the average yield of all genotypes in the deficit irrigation condition.

The normality of the data was checked using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Analysis of variance and comparison of means were performed using Tukey's method with SPSS software. To determine the most appropriate index for detecting stress-tolerant genotypes, the correlation between yield (under stress and non-stress conditions) and various indices was calculated. Indices that showed a relatively high correlation with yield in both environments were identified as the best indices. For a more precise separation of genotypes, a three-dimensional X, Y, and Z diagram was used, created by SPSS statistical software. To evaluate genetic diversity and select desirable genotypes for hybridization, principal component analysis and cluster analysis using Ward's minimum variance method were conducted. The results were presented in the form of a biplot and a dendrogram, respectively.

Fig. 1. Different cucumber genotypes evaluation under two irrigation regimes in greenhouse.

RESULTS AND DISCUSSION

The analysis of variance for the studied traits under two irrigation treatments (full and deficit) across 50 different cucumber genotypes is presented in Table 2. The significant differences observed among the genotypes indicate the presence of inherent genetic diversity ($p < 0.05$). Understanding these differences is crucial as it provides a foundation for selecting superior genotypes based on the researchers' criteria (Ndukaula *et al.* 2015). Studies by Raghunendra *et al.* (2011) and Mirhosseini *et al.* (2024) also report the diversity and significant differences in yield as well as its components among different cucumber genotypes.

Table 2. Analysis of Variance on the Effect of Full and Deficit Irrigations on the Yield of 50 Cucumber Genotypes.

		Mean square
SOV	**df**	**Yield per plant**
Irrigation (I)	1	4.1×10^{-7} ns
Replication (I)	4	0.003
Genotype (G)	49	0.108**
I×G	49	0.07**
Error	196	0.025
CV (%)		20

Note: ns: non-significant, **: significant at 1% levels of probability, respectively.

The interaction effect of irrigation and genotype on fruit yield per plant was significant at the 1% probability level (Table 2), indicating the different responses of genotypes to deficit irrigation regarding this trait. The average fruit yield per plant of the 50 cucumber genotypes under full and deficit irrigation conditions are presented in Table 3. Under full irrigation, genotype 45 had the highest yield, while under deficit irrigation, genotype 42 had the highest yield. The change rate of this trait in different genotypes ranged from 0% (genotype 16) to 188% (genotype 41). A small reduction in the yield of a genotype indicates its tolerance to the applied environmental conditions (e.g., a decline in fruit yield under deficit irrigation versus full irrigation). However, if a genotype has low inherent production capacity, tolerance to stress conditions alone will not be effective in a breeding project. Breeders seek genotypes that, in addition to tolerating stress conditions, yield well in both stressed and non-stressed (normal) conditions. It should be noted that there was a statistically significant difference between the yield of each genotype under the two environmental conditions. In any case, the difference in plant yield depends on irrigation management in addition to the inherent differences between genotypes (Panghal *et al.* 2016; Arab-Salmani *et al.* 2023). The results of the present study are consistent with those of Cakir *et al.* (2017), Liu *et al.* (2021), and Parkash *et al.* (2021), reporting that deficit irrigation causes yield reduction. While for some genotypes (12, 14, 17, 18, 33, 37, 45, and 50), which were androcious and pickling genotypes in this study, deficit irrigation treatment increased yield by elevating the number of female flowers and the number of fruits. Conversely, in other genotypes of the fresh-eating type, deficit irrigation treatment reduced yield by decreasing fruit size but not the number of fruits (data not shown).

Table 3. Interaction effect of irrigation and genotype on cucumber yield (gr/plant).

Genotypes	**Full irrigation**	**Deficit irrigation**	**Comparison between Irrigations**	**Genotypes**	**Full irrigation**	**Deficit irrigation**	**Comparison between Irrigation**
1	194	155	**	26	235	122	**
2	116	71	**	27	318	170	**
3	185	127	**	28	188	133	**
4	131	91	**	29	222	83	**
5	242	126	**	30	140	92	**
6	175	74	**	31	119	57	**
7	241	122	**	32	184	149	**
8	118	104	**	33	150	181	**
9	123	67	**	34	106	75	**
10	130	46	**	35	244	147	**
11	76	63	**	36	140	127	**
12	84	97	**	37	100	131	**
13	74	44	**	38	199	160	**
14	65	81	**	39	176	93	**
15	75	62	**	40	256	80	**
16	49	49	ns	41	297	54	**
17	60	88	**	42	355	201	**

18	77	85	**	43	245	243	**
19	207	97	**	44	119	100	**
20	152	73	**	45	300	311	**
21	307	178	**	46	137	100	**
22	289	198	**	47	175	119	**
23	224	169	**	48	78	60	**
24	235	122	**	49	95	75	**
25	318	170	**	50	170	186	**
Critical standard range		0.51					

Note: ns: non-significant, **: significant at 1% levels of probability, respectively.

Table 4 shows the average yield tolerance and sensitivity indices of 50 cucumber genotypes under full and deficit irrigation conditions. There was a significant difference among genotypes in terms of tolerance and sensitivity indices to water stress and yield under both full and deficit irrigation conditions. This indicates genetic diversity and the potential for selecting superior genotypes that can tolerate water shortage while producing an appropriate yield. In terms of water stress resistance indices, the highest values were recorded for MP, MRP, REI, STI, GMP, and HM indices in genotypes 45, 42, 43, and 22. The relationship between yield and tolerance indices in the present study is consistent with the findings of Fernandez (1992) and Mahdavi *et al.* (2012). The lowest value of the stress sensitivity index was observed for SSI in genotypes 17, 14, 16, 12, and 18, with the TOL index in genotypes 21, 23, 7, 5, and 19, and with the YSI index in genotypes 17, 37, and 50. Overall, the sensitivity indices SSI, TOL, and YSI introduced genotypes 17, 37, and 50 as water stress-sensitive genotypes. Selection based on the TOL index (genotypes 21, 23, 7, 5 and 19) favors low-yielding genotypes in non-stress conditions, making it less effective in distinguishing high-yielding genotypes (Fernandez 1992). Selection based on the SSI index (genotypes 17, 14, 16, 12 and 18) is effective in environments with water stress conditions, as was the case in this experiment. A lower SSI value indicates less variation in the yield of a genotype under stress conditions and greater stability (Acosta-Gollegos & Adams 1991). One disadvantage of the SSI index is that it calculates the ratio of yield under stress and non-stress conditions for each genotype compared to the same ratio for all genotypes in the study. Thus, two genotypes with high and low yields can have the same SSI value (Dargahi *et al.* 2011). Additionally, selection based on the SSI index will select genotypes tolerant to water stress but reduce yield potential under non-stress conditions (Clark *et al.* 1992). The STI index can identify genotypes with high yield potential under both stress and non-stress conditions. High STI values (genotypes 22, 21, 25, 24, 1 and 5) indicate greater stability of the genotype's yield under water deficit conditions (Dargahi *et al.* 2011). Table 5 shows the genotypes that obtained ranks one to five in various indices of tolerance and sensitivity to water stress in the two treatments of full and deficit irrigation. Genotypes 45, 42, 43, and 22 obtained the highest ranks one to five in terms of various indices of tolerance and sensitivity to stress, respectively. Identifying water stress-resistant genotypes by separately considering different indices of tolerance and sensitivity to water stress or yield in stress and non-stress conditions is challenging and often yields contradictory findings. Therefore, by using the correlation coefficient between the indices of tolerance and sensitivity to water stress and the yield of different genotypes in both full and deficit irrigation conditions, the most appropriate indices were determined, and based on these indices, the best water stress-resistant genotypes were introduced. Table 6 shows the average indices of tolerance and sensitivity of yield of 50 cucumber genotypes under full and deficit irrigation conditions. The MRP index had the highest positive and significant correlation coefficient with the yield in both full and deficit irrigation conditions. Zahravi *et al.* (2009) and Mahdavi *et al.* (2012) used a similar strategy to identify water stress-resistant genotypes in their studies. The MRP index had a positive and significant correlation with the MP, GMP, STI, HM, YI, and REI indices. Given that the MRP index had the highest correlation with yield in both full and deficit irrigation conditions, it can be considered the most appropriate index for water deficit stress tolerance. Genotypes with the highest values for this index can be introduced as water stress-resistant genotypes. To determine the genotypes resistant to water stress, a three-dimensional diagram was used with three factors: yield under full irrigation, yield under deficit irrigation, and the value of the MRP index, which had the highest correlation with yield under both full and deficit irrigation conditions. Fig. 2 shows the relationship between the MRP index and the yield of different cucumber genotypes under both full and deficit irrigation conditions. According to the graph in Fig. 2, genotypes 45, 43, and 42 have the highest values of the MRP index and yield under both full and deficit irrigation conditions, placing them in region A. Genotypes are typically divided into four main groups: genotypes with high yield under both full and deficit irrigation conditions (Group A), genotypes with high yield only under full irrigation conditions (Group B), genotypes with high yield only under deficit irrigation conditions (Group C), and genotypes with low yield under both full and deficit irrigation conditions (Group D; Fernandez, 1992; Wang *et al.* 2018; Wang, 2021). Genotypes 45, 42, and 43 are located in region A and are introduced as water stress-resistant genotypes.

Table 4. Potential yield (Yp), stressed yield (Ys), and average yield tolerance and sensitivity indices of cucumber genotypes in two treatments: full irrigation and deficit irrigation.

Genotyp	**Yp**	**Ys**	**SSI**	**HM**	**TOL**	**MP**	**YSI**	**GMP**	**STI**	**MRP**	**YI**	**REI**	**SRI**	**SI**
-	**g/plant**	**g/plant**	**-**	**g/plant**	**g/plant**	**g/plant**	**-**	**g/plant**	**-**	**-**	**-**	**-**	**-**	**-**
1	194	155	0.54	172	39	175	0.82	173	1.10	2.48	1.35	1.63	1.08	0.33
2	116	71	1.16	87	45	93	0.62	90	0.28	1.29	0.61	0.41	0.39	0.33
3	185	127	0.55	148	58	156	0.82	152	0.90	2.18	1.10	1.33	0.83	0.33
4	131	91	0.77	107	40	111	0.75	109	0.45	1.56	0.79	0.67	0.57	0.33
5	242	126	1.43	165	116	184	0.53	174	1.04	2.50	1.09	1.54	0.58	0.33
6	175	74	0.89	90	101	125	0.71	104	0.40	1.66	0.64	0.60	0.48	0.33
7	241	122	1.45	138	119	181	0.52	156	0.97	2.46	1.06	1.44	0.94	0.33
8	118	104	0.36	111	14	111	0.88	111	0.42	1.59	0.90	0.62	0.80	0.33
9	123	67	1.18	82	56	95	0.61	88	0.26	1.29	0.58	0.39	0.38	0.33
10	130	46	1.88	66	84	88	0.38	76	0.20	1.15	0.40	0.30	0.15	0.33
11	76	63	0.52	69	13	70	0.83	69	0.16	0.99	0.55	0.24	0.45	0.33
12	84	97	-0.47	90	-13	91	1.15	90	0.28	1.33	0.84	0.41	0.97	0.33
13	74	44	1.28	54	30	59	0.58	56	0.12	0.81	0.38	0.17	0.24	0.33
14	65	81	-0.75	72	-16	73	1.25	73	0.18	1.08	0.70	0.27	0.88	0.33
15	75	62	0.48	68	13	69	0.84	68	0.16	0.98	0.54	0.24	0.46	0.33
16	49	49	-0.54	47	0	49	1.18	48	0.08	0.71	0.43	0.12	0.50	0.33
17	60	88	-1.44	71	-28	74	1.47	73	0.18	1.12	0.76	0.27	1.13	0.33
18	77	85	-0.32	81	-8	81	1.10	81	0.22	1.19	0.74	0.33	0.81	0.33
19	207	97	1.62	132	110	152	0.47	142	0.68	2.05	0.84	1.02	0.39	0.33
20	152	73	1.53	98	79	113	0.50	105	0.38	1.52	0.63	0.56	0.32	0.33
21	307	178	1.25	218	130	243	0.59	230	1.83	3.33	1.54	2.72	1.01	0.33
22	289	198	0.91	234	91	243	0.70	239	1.95	3.40	1.72	2.91	1.20	0.33
23	224	102	1.64	140	122	163	0.46	151	0.78	2.19	0.89	1.16	0.41	0.33
24	211	142	0.80	168	69	176	0.74	172	1.21	2.46	1.23	1.80	0.86	0.33
25	224	169	0.63	193	55	197	0.79	195	1.59	2.78	1.47	2.37	1.12	0.33
26	235	122	1.18	158	113	179	0.61	168	1.07	2.43	1.06	1.60	0.61	0.33
27	318	170	1.47	217	148	244	0.52	230	1.94	3.33	1.48	2.88	0.86	0.33
28	188	133	0.98	153	55	161	0.68	157	0.91	2.25	1.16	1.36	0.88	0.33
29	222	83	1.87	120	138	153	0.39	135	0.62	2.02	0.72	0.93	0.28	0.33
30	140	92	1.04	109	48	116	0.66	112	0.44	1.62	0.80	0.65	0.57	0.33
31	119	57	1.40	76	62	88	0.54	81	0.25	1.18	0.49	0.37	0.25	0.33
32	184	149	0.45	163	35	167	0.85	165	0.95	2.37	1.30	1.41	1.09	0.33
33	150	181	-0.63	164	-31	166	1.21	165	0.92	2.45	1.57	1.37	1.90	0.33
34	106	75	0.86	87	31	90	0.72	89	0.27	1.27	0.65	0.40	0.47	0.33
35	244	147	1.09	177	97	196	0.64	186	1.30	2.70	1.28	1.94	0.89	0.33
36	140	127	0.09	131	13	134	0.97	132	0.60	1.92	1.10	0.90	1.07	0.33
37	100	131	-0.94	114	-31	116	1.31	115	0.45	1.72	1.14	0.66	1.49	0.33
38	199	160	0.59	177	39	179	0.81	178	1.08	2.55	1.39	1.61	1.12	0.33
39	176	93	1.32	120	83	135	0.57	127	0.56	1.84	0.81	0.83	0.46	0.33
40	256	80	1.80	116	176	168	0.41	139	0.70	2.18	0.69	1.04	0.28	0.33
41	297	54	2.50	91	243	175	0.18	126	0.55	2.20	0.47	0.82	0.09	0.33
42	355	201	1.28	250	155	278	0.58	263	2.41	3.81	1.74	3.60	1.11	0.33
43	245	243	-0.04	243	1	244	1.01	244	2.06	3.54	2.11	3.07	2.12	0.33
44	119	100	0.47	109	19	110	0.84	109	0.40	1.56	0.87	0.60	0.73	0.33
45	300	311	-0.11	305	-11	306	1.04	305	3.17	4.45	2.70	4.72	2.80	0.33
46	137	100	0.73	114	37	118	0.76	116	0.46	1.66	0.87	0.69	0.66	0.33
47	175	119	0.80	138	56	147	0.74	142	0.70	2.05	1.03	1.04	0.78	0.33
48	78	60	0.62	67	18	69	0.80	68	0.16	0.97	0.52	0.24	0.42	0.33
49	95	75	0.43	80	20	85	0.86	82	0.23	1.20	0.65	0.35	0.58	0.33
50	170	186	-0.84	164	-16	178	1.28	171	1.01	2.60	1.61	1.50	2.29	0.33

Table 5. Genotypes ranked one to five in terms of tolerance and sensitivity indices to water stress in two treatments of full irrigation and deficit irrigation.

Genotype	Yp	Ys	SSI	HM	TOL	MP	YSI	GMP	STI	MRP	YI	REI	SRI
42	1	3		2		2		2	2	2	3	2	
27	2					3		5	5			5	
21	3			5						5			
45	4	1		1		1		1	1	1	1	1	1
41	5												
50		5	3		5		3				5		2
43		2		3		4		3	3	3	2	3	3
22		4		4		5		4	4	4	4	4	
33			5		1		5						4
37			2		2		2						5
17			1		3		1						
14			4		4		4						

Table 6. Correlation coefficients between yield tolerance and sensitivity indices of different cucumber genotypes in two treatments of full irrigation and deficit irrigation.

	Yp	Ys	SSI	HM	TOL	MP	YSI	GMP	STI	MRP	YI	REI
Ys	0.65**											
SSI	0.49**	-0.24^{ns}										
HM	0.83**	0.95**	0.03^{ns}									
TOL	0.71**	-0.06^{ns}	0.87**	0.20^{ns}								
MP	0.94**	0.87**	0.21^{ns}	0.97**	0.43**							
YSI	0.49**	0.24^{ns}	-1. 0**	-0.03^{ns}	-0.87**	-0.21^{ns}						
GMP	0.88**	0.92**	0.11^{ns}	0.99**	0.31*	0.99**	-0.11^{ns}					
STI	0.84**	0.92**	0.07^{ns}	0.98**	0.25^{ns}	0.96**	-0.07^{ns}	0.98**				
MRP	0.90**	0.91**	0.13^{ns}	0.98**	0.34*	1.00**	-0.13^{ns}	1.0**	0.97**			
YI	0.65**	1.00**	-0.24^{ns}	0.95**	-0.08^{ns}	0.87**	0.24^{ns}	0.92**	0.92**	0.91**		
REI	0.84**	0.92**	0.07^{ns}	0.98**	0.25^{ns}	0.96**	-0.07^{ns}	0.98**	1.00**	0.97**	0.92**	
SRI	0.26ns	0.87**	-0.62**	0.69**	-0.46**	0.57**	0.62**	0.64**	0.66**	0.64**	0.87**	0.66**

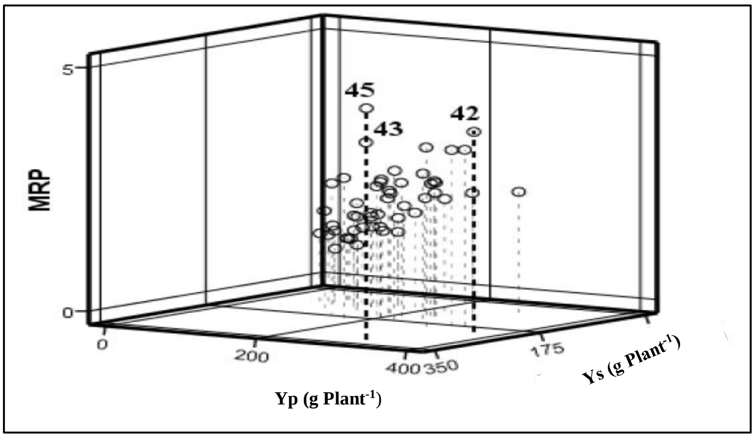

Fig. 2. Relationship between MRP index of different cucumber genotypes to water stress under two conditions of full irrigation and deficit irrigation.

Fig. 3 shows the dendrogram obtained from cluster analysis using the WARD method based on data related to six water stress tolerance indices including MP, GMP, STI, MRP, YI and REI indices and the yield of genotypes under two conditions of full and deficit irrigation. The aim of cluster analysis was to identify genotypes with the highest genetic distance from each other in terms of Yp, Ys, MP, GMP, STI, MRP, YI, and REI. Based on these indicators, the studied genotypes were divided into three separate groups: resistant, relatively resistant, and sensitive to water stress. Genotypes 45, 42, 43, 22, 27, and 21 were placed in one group which was the water stress-tolerant group. The results of cluster analysis were consistent with other methods used in the present study. Given the maximum genetic distance between the studied genotypes in terms of yield and water deficit stress tolerance, crossing between the studied genotypes can be used to genetically analyze quantitative indices of water stress tolerance and yield under full and deficit irrigation conditions (Mahdavi *et al.* 2012).

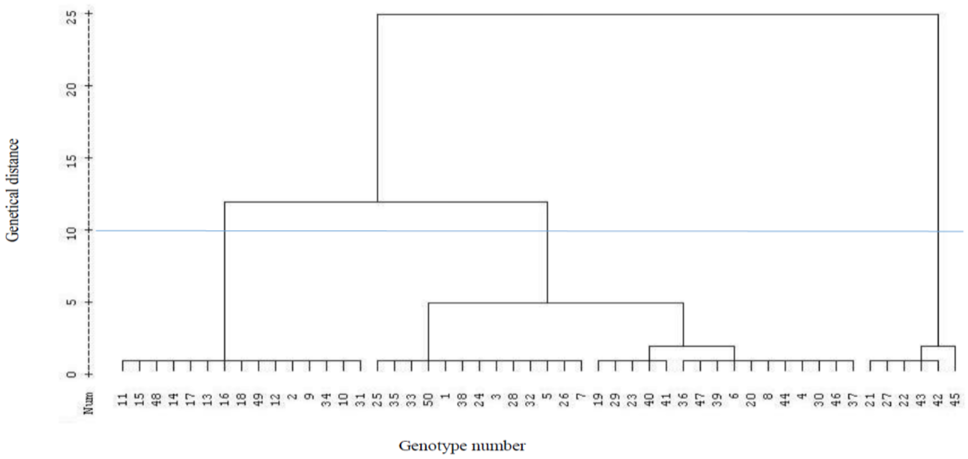

Fig. 3. Dendrogram resulting from cluster analysis using the WARD method based on data related to water stress tolerance and sensitivity indices and genotype yield under two conditions of full irrigation and deficit irrigation.

CONCLUSION

The overall conclusion from the evaluation of the indices used in the present study showed that six water stress tolerance indices including MP, GMP, STI, MRP, YI, and REI were superior compared to other water stress tolerance and sensitivity indices, since the mentioned indices had a high correlation with the performance of the studied genotypes under both full and low irrigation conditions and were able to select water stress resistant genotypes. In general, genotypes 45, 43 and 42 were identified. Three-dimensional plot based on the selected water stress tolerance index, i.e. MRP index, identified genotypes 45, 42, and 43 as superior genotypes in terms of water stress resistance. Cluster analysis by WARD method placed genotypes 45, 42, 43, 22, 27, and 21 that exhibited high tolerance to water stress in one group. According to these results, the mentioned genotypes can be considered as valuable genetic materials in cucumber breeding programs for water stress tolerance. Also, the results of correlation evaluation of different indices of tolerance and sensitivity to water stress showed that MP, GMP, STI, MRP, YI and REI are the most suitable indices for identifying genotypes resistant to water stress. The use of simple and reliable methods for identifying superior genotypes under water stress conditions has always been a concern for breeders. Although these methods may have some weaknesses, they are effective in breeding programs to adapt to water scarcity conditions due to their intensification, results from global warming, and they provide the appropriate volume of materials needed by the breeds in a short period of time.

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