International Journal of Agricultural Technology 2022Vol. 18(3):1233-1246
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Drought tolerance indices for yield improvement in local varieties of chili pepper

Saendamuen, M. [1], Chutteang, C.[2], Chanprame, S.[2] and Kongsamai, B.[2*]

[1]Program in Agricultural Research and Development, Faculty of Agriculture at Kamphaeng Saen, Kasetsart University, Kamphaeng Saen Campus, Kamphaeng Saen, Nakhon Pathom 73140 Thailand; [2]Department of Agronomy , Faculty of Agriculture at Kamphaeng Saen, Kasetsart University, Kamphaeng Saen Campus, Kamphaeng Saen, N akhon Pathom 73140 Thailand.

Saendamuen, M., Chutteang, C., Chanprame, S. and Kongsamai, B. (2022). Drought tolerance indices for yield improvement in local varieties of chili pepper. International Journal of Agricultural Technology 18(3):1233-1246.

Abstract Drought is one of the major limiting factors that affects the productivity of chili pepper grown in rainfed areas of Thailand. Therefore, chili varieties with high adaptability in the drought environment are of interest. To identify the drought tolerance of chili pepper, six drought tolerance indices, including mean productivity (MP), stress susceptibility index (SSI), geometric mean productivity (GMP), stress tolerance index (STI), yield index (YI), and stress non-stress production index (SNPI) calculated based on yield under stressed (YS) and irrigated (YP) conditions, were assessed among 43 accessions of chili pepper. Significant differences among genotypes were observed for YP, YS, and all drought tolerance indices. Correlation analysis revealed that yields under irrigated and stressed environments were positively and highly correlated with GMP, MP, and SNPI. The principal component analysis also indicated that GMP, MP, and SNPI were more reliable as tolerance indices for screening genotypes for drought tolerance. Hence, the improvement for yield increased under drought could be achieved through direct selection or screening through GMP, MP and SNPI indices. Subsequently, cluster analysis separated the 43 chili pepper genotypes into three groups according to potential yield and yield stability under both stress and non-stress conditions. Through the results, genotypes C17, C18, C19, C24, C25, MHS44, MHS44, TRF18, TRF19, TRF207, TRF6, TRF192, and MHS59 were identified as tolerant.

Keywords: Fruit yield, Stress tolerance indices, Biplot analysis, Cluster analysis

Introduction

Chili pepper is a commercial vegetable that has been cultivated in the subtropical and tropical regions (FAOSTAT, 2020). In Thailand, the main cultivated varieties are the improved and local varieties that possess a medium fruit type of chili pepper. These peppers are grown under rainfed conditions in the northern, central, and northeastern parts of the country. The fruits are often consumed as fresh, dry, or processed products. Nowadays, declining

* **Corresponding Author:** Kongsamai, B.; **Email:** agrbuk@ku.ac.th

precipitation in several regions of the world significantly affects crop growth and productivity (Rosmaina *et al*., 2019). Chili pepper is extremely sensitive to water stress, especially during the blossoming stage or the fruit development stage. Therefore, chili varieties that are able to adapt to the drought environment are of interest. Effective selection of plants tolerant to abiotic stresses depends upon the plant breeder's ability to find a reasonable compromise among grain yield under stress conditions, yield losses due to stress and yield stability (Bahrami *et al*., 2014; Bahrami *et al*., 2021). Identification of drought tolerance, based on yield, is necessary for the screening of tolerant genotypes. Effective breeding of chili peppers with this target trait is equally necessary. Sofi *et al*. (2018) reviewed several selection indices based on tolerance and vulnerability to drought. Drought tolerance is the ability of plants to grow and provide desirable yield under limited water availability (Rosmaina *et al*., 2019). Various biometrical approaches have been proposed to evaluate the effectiveness of drought tolerance indices aimed at screening and identification of tolerant genotypes (Rosielle and Hamblin, 1981). The highest values in the correlation between selection index and yield, heritability, genetic advance and coefficients of variation under normal and stress conditions are able to identify potential high yielding and drought tolerant genotypes (Fernandez, 1992). Moreover, principal component analysis (PCA) and biplot analysis have also been used for screening drought tolerant genotypes in several crops, such as triticale (Lonbani and Arzani, 2011), bread wheat (Farshadfar *et al*., 2012), maize (Moradi *et al*., 2012), safflower (Bahrami *et al*., 2014), sorghum (Abebe *et al*., 2020), and onion (Gedam *et al*., 2021). In view of these, the objectives were to assess drought tolerance based on tolerance indices of 43 accessions of chili pepper and to use the potential selection indices to screen the germplasm for their drought tolerance.

Materials and methods

Experimental materials and sites

Forty-one genotypes of chili pepper and two check drought tolerant varieties, C2 and C8, were used in this experiment (Table 1). These served as the chili pepper germplasm for the study. The peppers were cultivated at the Mae Hong Son Agriculture Research and Development Center, Mae Hong Son province, Thailand, situated at 19° 16’18.9”N latitude and 97° 56’59.1“E longitude at an elevation of 147 m above sea level.

Table 1. Chili pepper genotypes collected from different sources of Thailand and tested under non-stressed and stressed conditions

Genotypes	Species[1/]	Sources	Genotypes	Species	Sources
1) C2 (check1)	*F*	Sisaket	23) TRF257	*A*	Nakhon Pathom
2) C8 (check2)	*F*	Khon Kaen	24) MHS15	*F*	Mae Hong Son
3) C9	*A*	Chiang Mai	25) MHS16	*F*	Mae Hong Son
4) C17	*F*	Loei	26) MHS17	*F*	Mae Hong Son
5) C18	*F*	Loei	27) MHS18	*F*	Mae Hong Son
6) C19	*F*	Loei	28) MHS21	*F*	Mae Hong Son
7) C20	*F*	Loei	29) MHS33	*F*	Mae Hong Son
8) C24	*F*	Kanchanaburi	30) MHS36	*F*	Mae Hong Son
9) C25	*F*	Kanchanaburi	31) MHS38	*F*	Mae Hong Son
10) C27	*F*	Sisaket	32) MHS39	*F*	Mae Hong Son
11) C29	*F*	Suphan Buri	33) MHS40	*F*	Mae Hong Son
12) C30	*F*	Kanchanaburi	34) MHS43	*F*	Mae Hong Son
13) TRF6	*F*	Nakhon Pathom	35) MHS44	*F*	Mae Hong Son
14) TRF18	*F*	Prachuap Khiri Khan	36) MHS45	*F*	Mae Hong Son
15) TRF19	*F*	Phetchaburi	37) MHS59	*F*	Mae Hong Son
16) TRF27	*F*	Tak	38) MHS73	*F*	Mae Hong Son
17) TRF33	*F*	Kanchanaburi	39) MHS77	*F*	Mae Hong Son
18) TRF37	*A*	Kalasin	40) MHS79	*F*	Mae Hong Son
19) TRF100	*F*	Uttaradit	41) MHS80	*F*	Mae Hong Son
20) TRF155	*F*	Loei	42) MHS91	*F*	Mae Hong Son
21) TRF192	*F*	Suphan Buri	43) MHS92	*F*	Mae Hong Son
22) TRF207	*A*	Nakhon Pathom			

[1/] F = *C. frutescence* and A = *C. annuum*

Experimental design

The experiment was carried out during 2017–2018 growing season in a randomized complete block design (RCBD) with three replications under sparsely and fully irrigated conditions. Sparsely irrigated plots were not irrigated after flowering stage. A two-row plot with a spacing of 0.75 m between rows and plants was maintained to accommodate four plants per row and eight plants per plot. All recommended agricultural practices concerning chili pepper productions were followed the Good Agricultural Practices (GAP) for peppers (2005), Department of Agriculture and Extension of Thailand to achieve normal plant growth.

Data collection and data analysis

Four plants were randomly selected from each plot and harvested at the red-fruit stage. Fruit yield per plant was recorded. Six drought tolerance indices shown in Table 2 were calculated. Genotypic correlation was also calculated for fruit yield and for all indices. Analysis of variance was performed to calculate for fruit yield and the tolerance indices using STAR software (STAR version 2.0.1, 2014). To classify the indices as well as the tolerant and susceptible genotypes, a biplot diagram, principal component analysis (PCA) and cluster analysis were performed. Genotypes were grouped using Ward's method based on Euclidean distance. PCA and Cluster analysis were analysed using Past 4.04 (Hammer *et al*., 2001).

Table 2. Drought tolerance indices used for the evaluation of chili pepper genotypes to drought conditions

Drought tolerance indices	Equation[1/]	Reference
Mean productivity (MP)	$\frac{Y_P + Y_S}{2}$	Rosielle and Hamblin,1981
Geometric mean productivity(GMP)	$\sqrt{Y_P.Y_S}$	Fernandez, 1992
Stress tolerance index (STI)	$(Y_S.Y_P)/\bar{Y}_P^2$	Fernandez, 1992
Yield index (YI)	$Y_S/\bar{Y}_S$	Gavuzzi *et al*.,1997
Stress susceptibility index (SSI)	$\frac{[1-(Y_S/Y_P)]}{[1-(\bar{Y}_S/\bar{Y}_P)]}$	Fischer and Maurer,1978
Stress non-stress production index (SNPI)	$\sqrt[3]{\frac{(Y_P+Y_S)}{(Y_P-Y_S)}}.\sqrt[3]{Y_P+Y_S+Y_S}$	Moosavi *et al*., 2008

[1/]: Y_P and Y_S are the yield of each genotype under non-stress and stress condition, respectively. $\bar{Y}_P$ and $\bar{Y}_S$ are the mean fruit yield of all genotypes in non-stress and stress condition, respectively.

Results

Analysis of variance and mean for yield performance

The result of analysis of variance showed a highly significant influence of water stress on fruit yield and a significant variation ($P > 0.01$) among the genotypes for fruit yield under both stress conditions, and the various stress indices were observed (Table 3). The average fruit yield under the non-stress condition was 760.5 g/plant, while it was 114.0 g/plant in the stress condition, with a decrease of 82.8%. In the non-stress condition, the following genotypes had fruit yields higher than 1,000 g/plant: C24, C18, C19, TRF6, TRF18, TRF19, TRF192, TRF207, MHS40, MHS44, and MHS59. The genotypes of C20, MHS21, MHS36, MHS39, and MHS45 showed the lowest fruit yields (less than 150 g/plant) (Table 4). In the stress conditions, genotypes C9, C18, TRF6, TRF33, TRF192, and TRF207 had the highest fruit yield, while genotypes MHS40, MHS91, MHS73, MHS79, and MHS36 exhibited the lowest fruit yield. Overall, the decrease in fruit yield of chili pepper affected by drought ranged from 45.46% to 98.28% relative to the non-stress condition.

Table 3. Analysis of variance for fruit yield under non-stressed (Y_P), stressed (Y_S) environments and various tolerance indices in chilli genotypes

Drought to tolerance indices	**Means square**			**CV%**
	Replications (df=2)	**Genotypes (df =42)**	**Error (df=86)**	
Yield in non-stressed; Y_P	100,002.34	576,903.99**	34,897.65	25.28
Yield in stressed; Y_S	4,549.35	36,362.76**	2,497.11	42.72
Mean productivity; MP	29,202.20	196,376.90**	9,822.30	23.15
Geometric mean productivity; GMP	33.10	304.75**	8.28	10.05
Stress tolerance index; STI	0.02	0.05**	0.01	46.21
Yield index; YI	0.32	2.52**	0.17	42.24
Stress susceptibility index ;SSI	0.86	0.86^{ns}	0.48	105.1
Stress non-stress production index; SNPI	17,247.75	108999.44**	8135.75	38.45

^{ns} ,** means non-significant difference and significant difference at 1% levels of probability,respectively.

Comparison of genotypes based on drought tolerance indices

According to the analysis of variance and mean performance of tested genotypes under stress conditions in Table 3 and 5, drought stress caused a reduction in the yield of chili pepper. Thus, drought tolerance of tested genotypes can be evaluated (Blum, 1988). Drought tolerance indices were calculated based on fruit yield of genotypes under stress and non-stress conditions (Table 4). The maximum yield in stress conditions, compared to check varieties, was observed for genotypes TRF192, TRF6, TRF207, TRF33, C18, MHS44, and MHS59. According to MP, GMP, STI, and YI, the genotypes with high values of these indices will be more desirable. The selected genotypes will be high in their tolerance and yield potential under both stress and non-stress conditions. These index values showed that C9, C17, C18, TRF6, TRF33, TRF192, and TRF207 had the highest tolerance and exhibited high yield stability in both stress and non-stress conditions, whereas C20, C30, C19, C37, MHS21, MHS36, MHS39, MHS45, MHS80, MHS91, and MHS92 had the lowest tolerance. A larger SSI value represents more sensitivity to stress. Guttieri *et al*. (2001) verified that the genotypes with SSI < 1 were more tolerant to moisture stress condition and were the least susceptible. Therefore, genotypes with smaller SSI values (C9-TRF207) were selected for high yield under stress conditions, but they may have low yield under non-stress conditions such as C2 and MHS45. In contrast, genotypes TRF19, TRF37, TRF100, MHS73, MHS80, and MHS91 showed high sensitivity to stress. According to Khan and Dhurve (2016), genotypes with YI > 1 were considered tolerant, while genotypes with a value of YI < 1 were denoted as susceptible varieties. The YI index is suitable for distinguishing high yielding genotypes under drought stress conditions. According to the YI value, 14 genotypes were considered tolerant genotypes.

Based on the SNPI index, it can be deduced that the C9, C17, C18, C19, C24, C27, TRF6, TRF33, TRF192, TRF207 and TRF257, MHS44 and MHS59 genotypes showed high stability and high yield in both conditions simultaneously. Moosavi *et al*. (2008) suggested using this index to select genotypes with high and stable yields in both stress and non-stress conditions for commercial aims.

Correlation analysis for stress tolerance indices and yields

In order to determine the most appropriate drought tolerance criterion for screening the best genotypes and indices used, the relationship between Yp, Ys, and other drought tolerance indices was calculated (Table 5). The yield (Y_P) under non-stress conditions had a weak association ($r = 0.58$, $P < 0.01$) with the yield under stress conditions (Y_S), indicating that high yield potential under irrigated conditions did not necessarily correspond to superior yield under stress conditions. Therefore, indirect selection for drought environments based on the crop yield under irrigated conditions would not be effecient.

The Y_P and Y_S had significant and positive correlation with MP, GMP, STI, YI, and SNPI, while SSI and YR were non-significant correlation with Y_P. A negative correlation was observed between SSI and YR with Y_S (Table 5). A strong correlation was also found between drought tolerance indices MP, GMP, STI, YI and SNPI.

Table 4. Values of tolerance indices from the potential yield and the stress yield data for 43 chilli pepper genotypes

No	Genotypes	Yp[1/]	Ys	%YR[2/]	MP	GMP	STI	YI	SSI	SNPI
1	C2	767.5	175.4	77.1	471.4	366.9	0.24	1.47	0.92	335.02
2	C8	574.3	114.6	80.0	344.5	256.6	0.12	0.96	0.95	224.49
3	C9	752.2	298.1	60.4	525.1	473.5	0.39	2.49	0.72	536.66
4	C17	1055.9	208.8	80.2	632.4	469.6	0.39	1.74	0.95	409.68
5	C18	1177.3	302.0	74.4	739.7	596.3	0.62	2.52	0.88	566.11
6	C19	1266.6	203.1	84.0	734.9	507.2	0.45	1.70	1.00	416.42
7	C20	110.0	26.3	76.1	68.2	53.7	0.01	0.22	0.90	49.78
8	C24	1709.7	145.5	91.5	927.6	498.7	0.44	1.22	1.09	350.11
9	C25	1103.3	130.8	88.1	617.0	379.8	0.25	1.09	1.05	288.21
10	C27	845.2	151.9	82.0	498.6	358.3	0.22	1.27	0.97	303.88
11	C29	195.5	105.8	45.9	150.7	143.8	0.04	0.88	0.54	194.52
12	C30	865.4	66.0	92.4	465.7	239.0	0.10	0.55	1.10	163.82
13	TRF6	1257.4	427.0	66.0	842.2	732.8	0.94	3.57	0.78	774.80
14	TRF18	1196.2	97.8	91.8	647.0	341.9	0.20	0.82	1.09	237.90
15	TRF19	1280.1	46.3	96.4	663.2	243.4	0.10	0.39	1.15	143.36
16	TRF27	416.7	103.4	75.2	260.0	207.6	0.08	0.86	0.89	194.82
17	TRF33	927.0	293.7	68.3	610.4	521.8	0.48	2.45	0.81	536.20
18	TRF37	700.4	41.0	94.1	370.7	169.4	0.05	0.34	1.12	109.78
19	TRF100	369.7	29.9	91.9	199.8	105.1	0.02	0.25	1.09	72.98
20	TRF155	260.4	49.0	81.2	154.7	112.9	0.02	0.41	0.96	97.01
21	TRF192	1530.2	459.7	70.0	994.9	838.7	1.23	3.84	0.83	843.91
22	TRF207	1164.7	298.8	74.3	731.8	589.9	0.61	2.50	0.88	560.13
23	TRF257	868.1	178.7	79.4	523.4	393.9	0.27	1.49	0.94	347.90
24	MHS15	791.7	97.0	87.7	444.4	277.2	0.13	0.81	1.04	212.06
25	MHS16	521.6	88.2	83.1	304.9	214.5	0.08	0.74	0.99	178.79
26	MHS17	536.5	78.9	85.3	307.7	205.7	0.07	0.66	1.01	164.94
27	MHS18	782.7	113.5	85.5	448.1	298.0	0.16	0.95	1.02	238.13
28	MHS21	83.2	21.3	74.4	52.2	42.1	0.00	0.18	0.88	39.94
29	MHS33	314.3	79.1	74.8	196.7	157.6	0.04	0.66	0.89	148.67
30	MHS36	75.3	20.9	72.2	48.1	39.7	0.00	0.17	0.86	38.73
31	MHS38	658.2	66.7	89.9	362.4	209.5	0.08	0.56	1.07	153.02
32	MHS39	78.4	21.6	72.5	50.0	41.1	0.00	0.18	0.86	40.00
33	MHS40	1075.9	13.3	98.8	544.6	119.7	0.03	0.11	1.17	58.05
34	MHS43	921.4	59.1	93.6	490.3	233.3	0.10	0.49	1.11	154.06
35	MHS44	1023.9	156.7	84.7	590.3	400.5	0.28	1.31	1.01	324.67
36	MHS45	120.1	61.1	49.1	90.6	85.7	0.01	0.51	0.58	111.25
37	MHS59	1537.3	150.5	90.2	843.9	480.9	0.40	1.26	1.07	348.58
38	MHS73	729.7	16.5	97.7	373.1	109.9	0.02	0.14	1.16	59.33
39	MHS77	399.9	46.9	88.3	223.4	136.9	0.03	0.39	1.05	103.64
40	MHS79	380.3	20.2	94.7	200.2	87.5	0.01	0.17	1.13	55.58
41	MHS80	899.0	36.0	96.0	467.5	179.9	0.06	0.30	1.14	108.05
42	MHS91	800.3	13.8	98.3	407.0	105.1	0.02	0.12	1.17	54.01
43	MHS92	390.2	32.2	91.7	211.2	112.1	0.02	0.27	1.09	78.21
	Mean	760.5	114.0	82.8	437.2	276.0	0.2	1.0	1.0	233.28

[1/]: Y_P: Yield in non-stressed, Y_S: Yield in stressed, MP: Mean productivity, GMP: Geometric mean productivity, STI: Stress tolerance index, YI: Yield index, SSI: Stress susceptibility index, and SNPI: Stress non-stress production index.

[2/]: %YR = percentage of yield reduction, calculated as $(Y_P - Y_S)/ Y_P \times 100$.

Table 5. The correlation between yield under non-stress conditions (Y_P), yield under stress conditions (Y_S) and drought tolerance indices

Parameters	Yp	Ys	YR[1/]	MP	SSI	GMP	STI	YI
Ys	0.58**	1.00						
YR	0.31	-0.45**	1.00					
MP	0.98**	0.72**	0.16	1.00				
SSI	0.31	-0.45**	0.99**	0.17	1.00			
GMP	0.79**	0.95**	-0.21	0.89**	-0.21	1.00		
STI	0.69**	0.95**	-0.29	0.81**	-0.29	0.95**	1.00	
YI	0.58**	1.00**	-0.45**	0.72**	-0.45**	0.95**	0.95**	1.00
SNPI	0.66**	0.99**	-0.38*	0.78**	-0.38*	0.98**	0.97**	0.99**

*and **: significant at 5% and 1% levels of probability, respectively.
[1/]: YR: percentage of yield reduction, MP: Mean productivity, GMP: Geometric mean productivity, STI: Stress tolerance index, YI: Yield index, SSI: Stress susceptibility index, and SNPI: Stress non-stress production index.

Principal component analysis

To assess the relationship between chili pepper genotypes and five drought tolerance indices simultaneously, principal component analysis was applied. The greatest variation among the data was due to the two first components: PC1 (89.68%) and PC2 (10.23%) (Table 6). Biplot analysis was carried out to identify the superior chili pepper genotypes in different environments. The first PCA had a high and positive correlation with fruit yield under non-stress conditions, MP, and GMP. Thus, the first dimension could be named yield potential and drought tolerance. The second PCA showed a positive correlation with fruit yield under stress conditions, GMP and SNPI, while showing a negative correlation with yield under normal conditions. This component can be called the stress-resistant dimension. Stress-tolerant genotypes can be separated from non-stress genotypes (Fernandez, 1992). Then genotypes with high PCA values and high relative stress tolerance are favored for both stress and non-stress environments (Figure 1). The genotypes with high PCA1 and low PCA2 are classified as the relative stress tolerant genotypes (Moosavi *et al*., 2008). In contrast, most genotypes having low PCA1 and high PCA2 values were classified as susceptible genotypes.

Regarding the biplot display based on the first two components, TRF192, TRF6, TRF33, C18, and TRF207, in the vicinity of GMP and SNPI indices, were identified as stable high yielding genotypes and were found to possess relative stress tolerance in stress conditions. This was mainly due to yield potential and drought tolerance region (Figure 1: upper right). Genotypes C19, C25, TRF18, and MHS44 were identified as relative stress tolerant. They showed high yield and stability (Figure 1: lower right). Finally, genotypes MHS36, MHS21, MHS39, MHS45, C29, TRF155, TRF100, MHS33, MHS77, MHS97, and MHS79 were grouped as drought sensitive, as they were located in regions sensitive to drought stress and produced a low yield (Figure 1: left side).

Table 6. Principal component analysis for yield under non-stressed (Y_P), stressed (Y_S) environments, MP, GMP, STI, YI and SNPI indices in 43 chilli pepper genotypes

Indices	PC1	PC2
Y_P	0.764	-0.482
Y_S	0.147	0.400
MP	0.456	-0.041
GMP	0.323	0.445
STI	0.000	0.001
YI	0.001	0.003
SNPI	0.288	0.639
Eigenvalue	301,049	34,319
Variance (%)	89.68	10.23
Cumulative Percentage	89.68	99.92

[1/] MP: Mean productivity, GMP: Geometric mean productivity, STI: Stress tolerance index, YI: Yield index, SSI: Stress susceptibility index, and SNPI: Stress non-stress production index.

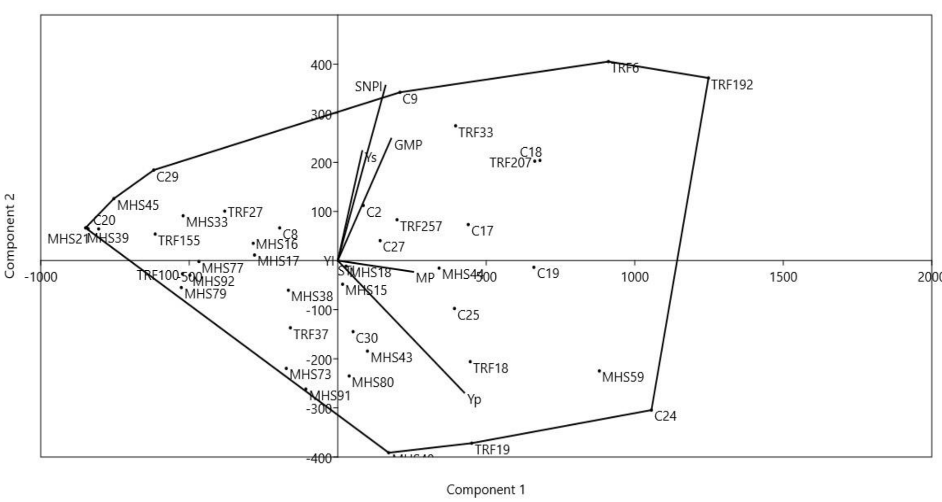

Figure 1. Biplot diagram of principal components analysis of forty- three genotypes according to mean measured of drought tolerance indices under optimal and stress conditions

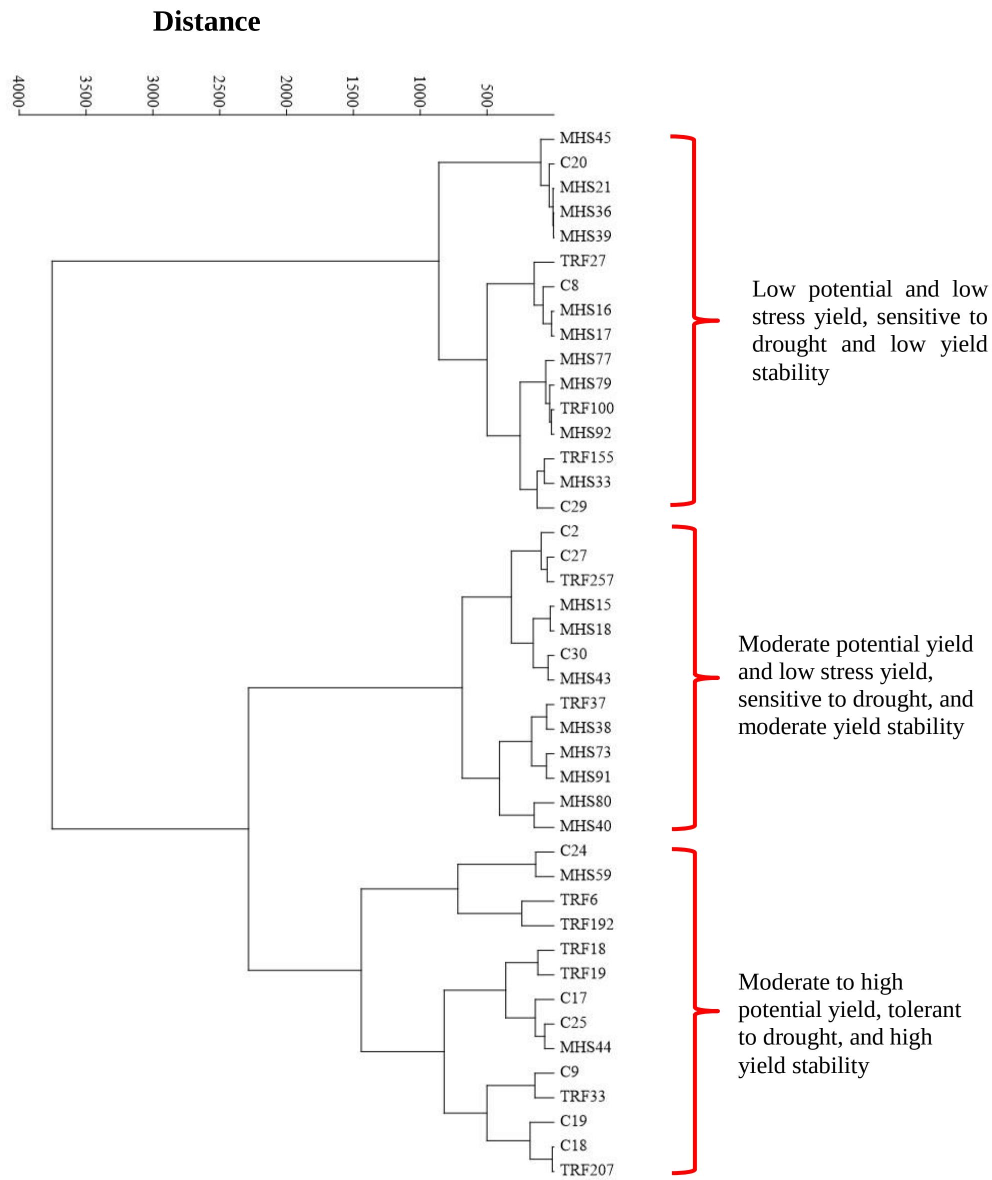

Figure 2. Dendogram Ward's method to classification of chili pepper genotypes based on tolerance indices

Cluster analysis

Cluster analysis based on fruit yield under stress and non-stress conditions and drought tolerance indices were divided all the genotypes into three groups (Figure 2). The first cluster (drought sensitive and yield stability) comprised 16 chili pepper genotypes: C29, MHS33, TRF155, TRF27, TRF100, MHS79, MHS92, MHS77, MHS21, MHS36, MHS39, C20, and MHS45. The second cluster (drought sensitive and low stability to drought) consisted of 13 other genotypes: C2, C27, TRF257, TRF37, MHS15, MHS18, and MHS40. The third cluster (drought tolerant with high yield and stability under both non-stress and stress conditions) included 14 genotypes, including genotype C9, C18, C19, C24, MHS44, MHS59, TRF6, and TRF192.

Discussion

The existence of variation among the chili pepper genotypes for fruit yield under both stress conditions was observed in our experiment. It is indicated that if genetic variation is exist for gene controlling yield potential, and drought tolerance, then selection of tolerant genotypes is possible. (Saba *et al*., 2001; Golabadi *et al*., 2006; Gholipouri *et al*., 2009, Amini *et al*., 2013; Gedam *et al*., 2021). The means values of all studied traits reduced under stress conditions for all genotypes. However, the average yield loss was more obvious in the high yielding genotypes under normal conditions than in the low yielding genotypes such as MHS39 and MHS45.

Identification of drought tolerant genotypes based on appropriate drought tolerance indices has been used in several studies (Rosmaina *et al*., 2019). Mitra (2001) suggested that a significant relationship of suitable indicators with yield under both stress and non-stress conditions must be observed. However, this study revealed a weak association of fruit yield under stress and non-stress conditions. Similar results were also reported in wheat (Talebi *et al*., 2009), corn (Jafari *et al*., 2009) and chili pepper (Rosmaina *et al*., 2019). A strong positive correlation among yield under both stress and non-stress conditions was observed for MP, GMP, STI, YI, and SNPI, while a moderate negative correlation was recorded between SSI, YR, and yield in the stress condition. The negative association of these indices indicated that genotypes with low SSI and YR values had lower yield reduction under stress environments (Ceccarelli *et al*., 1998). Moreover, the positive and negative correlations showed that some of the indices are similar or dissimilar in genotyping ranking, respectively (Abebe *et al*., 2020; Farshadfar *et al*. (2012). Ilker E *et al*. (2011) reported that MP, GMP, and STI are suitable indices for selecting high-yielding wheat genotypes in both optimal and non-stress conditions. However, the occurrence of biased results obtained from the mean productivity index has also been reported by Moosavi *et al.* (2008) Jafari *et al*. (2009) found that STI and GMP indices can be used as the best indices for maize breeding programs with the aim of producing drought-tolerant hybrids. Khayatnezhad *et al*. (2010) also explained that none of the tolerance indices could perfectly identify the high yielding genotypes under stress and non-stress conditions. However, Thiry *et al.* (2016) stated that tolerance indices are not ideal for determining genotypes with the best yield and high stress tolerance in both environments.

Our results also showed a significant and positive correlation between SNPI and both YP and YS. Thus, this index may be suitable for screening tolerant cultivars. Moosavi *et al*. (2008) stated that SNPI is the ideal index for identifying genotypes with stable and high yields in both stress and non-stress conditions but is especially applicable in stress conditions. SNPI usually has a strong correlation with YS.

However, Talebi *et al*. (2009) stated that PCA and cluster analysis were a better method than a linear correlation for identification of genotype resistant and susceptive to both stress conditions. It showed that the GMP and SNPI had the highest values in PC1 and PC2, therefore, both indices can be used to screen the drought tolerant genotypes in this study.

According to the correlation and principal component analysis, drought tolerance indices, MP, GMP, and SNPI are the most suitable indicators for screening genotypes that yield well under stress and non-stress conditions because they had the highest positive correlation with YP and YS. Under high stress intensity, GMP and SNPI were more suitable to be used as selection criteria, whereas MP should be used if the stress conditions are not too severe. It was also found that 14 genotypes could be classified as the superior genotypes under both conditions: C17, C18, C19, C24, TRF6, TRF18, TRF19, TRF192, TRF207, MHS40, MHS44 and MHS59. From these genotypes, C17, C18, TRF6, TRF192 and TRF207 were drought tolerant and specifically adapted to water deficit conditions.

Acknowledgements

The author would like to offer particular thanks to Agricultural Research Development Agency (Public Organization) for financial support to this research.

References

Abebe, T., Belay, G., Tadesse1, T. and Keneni, G. (2020). Selection efficiency of yield based drought tolerance indices to identify superior sorghum [*Sorghum bicolor* (L.) Moench] genotypes under two-contrasting environments. African Journal of Agricultural Research, 5:379-392.

Amini, H., Arzani, A. and Bahrami, F. (2013). Seed yield and some physiological traits of safflower as affected by water deficit stress. International Journal of Plant Production, 7:597-614.

Bahrami, F., Arzani, A. and Karimi, V. (2014). Evaluation of yield-based drought tolerance indices for screening safflower (*Carthamus tinctorius* L.) genotypes. Agronomy Journal, 106:1219-1224.

Bahrami, F., Arzani, A. and Rahimmalek, M. (2021). Tolerance to high temperature at reproductive stage: Trade-offs between phenology, grain yield and yield-related traits in wild and cultivated barleys. Plant Breeding, 140:812-826.

Blum, A. (1988). Plant breeding for stress environments. CRC Press, Boca Raton, Florida, USA, 231 p.

Ceccarelli, S., Grando, S. and Impiglia, A. (1998). Choice of selection strategy in breeding barley for stress environments. Euphytica, 103:297-318.

FAOSTAT (2020). Food and agriculture data: crop production. Retrieved from http://www.faostat.fao.org.

Farshadfar, E., Moradi, Z., Elyasi, P., Jamshidi, B.and Chaghakabodi, R. (2012). Effective selection criteria for screening drought tolerant landraces of bread wheat (*Triticum aestivum* L.). Annals of Biological Research, 3:2507-2516.

Fernandez, G. C. J. (1992). Effective selection criteria for assessing stress tolerance. In: Kuo, C. G. (Ed). Proceedings of the International Symposium on Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress. 13-16 August 1992, Tainan, Taiwan, pp. 257-270.

Fischer, R. A. and Maurer, R. (1978). Drought resistance in spring wheat cultivars. I. Fruit yield responses. Crop Pasture Sciece, 29:897-912.

Gavuzzi, P., Rizza, F., Palumbo, M., Campaline, R. G., Ricciardi, G. L. and Borghi, B. (1997). Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. Canadian Journal of Plant Science, 77:523-531.

Gedam, P. A., Thangasamy, A., Shirsat, D. V., Ghosh, S., Bhagat, K. P., Sogam, O. A., Gupta, A. J., Mahajan, V., Soumia, P. S., Salunkhe, V. N. and Khade, Y. P. (2021). Screening of onion (*Allium cepa* L.) genotypes for drought tolerance using physiological and yield based ındices through multivariate analysis. Front Plant Science, 12:122.

Gholipouri, A., Sedghi, M., Sharifi, R. S. and Nazari, N. M. (2009). Evaluation of drought tolerance indices and their relationship with grain yield in wheat cultivars. Recent Research Science Technology, 1:195-198.

Golabadi, M., Arzani, A. and Maibody, S. A. M. M. (2006). Assessment of drought tolerance in segregating populations in durum wheat. African Journal of Agricultural Research, 1:162-171.

Guttieri, M. J., Stark, J. C., Brien, K. and Souza, E. (2001). Relative sensitivity of spring wheat grain yield and quality parameters to moisture deficit. Crop Science, 41:327-335.

Hammer, D. A., Harper, T. and Ryan, P.D. (2001). PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica, 4:1-9.

Ilker E, Ö., Tatar, F., Aykut Tonk. and Tosun, M. (2011). Determination of tolerance level of some wheat genotypes to post-anthesis drought. Turkish Journal of Field Crops, 16:59-63.

Jafari, A., Paknejad, F. and Al-Ahmadi, J. M. (2009). Evaluation of selection indices for drought tolerance of corn (*Zea mays* L.) hybrids. International Journal of Plant Production, 3:33-38.

Khan, I. M. and Dhurve, O. P. (2016). Drought response indices for identification of drought tolerant genotypes in rainfed upland rice (*Oryza sativa* L.). International Journal of Science, Environment and Technology, 5:73-83.

Khayatnezhad, M., Zaeifizadeh, M. and Gholamin, R. (2010). Investigation and selection index for drought stress. Australian Journal of Basic and Applied Sciences, 4:4815-4822.

Lonbani, M. and Arzani, A. (2011). Morpho-physiological traits associated with terminal drought stress tolerance in triticale and wheat. Agronomy Research, 9:315-329.

Mitra, J. (2001). Genetics and genetic improvement of drought resistance in crop plants. Current Science, 80:758-762.

Moosavi, S. S., Samadi, B. Y., Naghavi, M. R., Zali, A. A., Dashti, H. and Pourshahbazi, A. (2008). Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes. Desert, 12:165-178.

Moradi, H., Akbari, G. A., Khorasani, S. K. and Ramshini, H. (2012). Evaluation of drought tolerance in corn (*Zea mays* L.) new hybrids with using stress tolerance indices. Sustainable Development, 1:543-560.

Rosielle, A. A. and Hamblin, J. (1981). Theoretical aspects of selection for yield in stress and non-stress environment. Crop Science, 21:943-946.

Rosmaina, Parjanto, Sobir and Yunus, A. (2019). Screening of *Capsicum annuum* L. genotypes for drought tolerance based on drought tolerance indices. SABRAO Journal of Breeding and Genetics, 51:205-224.

Saba, J., Moghaddam, M., Ghassemi, K. and Nishabouri, M. R. (2001). Genetic properties of resistance indices. Journal of Agricultural Science and Technology, 3:43-49.

Sofi, P. A., Rehman, K., Ara, A. and Gull, M. (2018). Stress tolerance indices based on yield, phonology, and biomass partitioning: A review. Agricultural Reviews, 39:292-299.

STAR, version 2.0.1. (2014). Biometrics and Breeding Informatics, PBGB Division, International Rice Research Institute, Los Baños, Laguna.

Talebi, R., Fayaz, F. and Naji, A. M. (2009). Effective selection criteria for assessing drought stress tolerance in durum wheat (*Triticum durum* Desf.) General and Applied Plant Physiology, 35:64-74.

Thiry, A. A., Bulanto, P. N. C., Reynolds, M. P. and Davies, W. J. (2016). How can we improve crop genotypes to increase stress resilience and productivity in a future climate? A new crop screening method based on productivity and resistance to abiotic stress. Journal of Experimental Botany, 67:5593-5603.

(Received: 18 October 2021, accepted: 10 April 2022)