Penjelasan Terkait Pengembangan Penulisan

Judul : Screening of Capsicum Annuum L. Genotypes for Drought Tolerance Based on Drought Toleranc Indices
Penulis : Rosmaina, Sobir, Parjanto dan Ahmad Yunus
Jurnal : SABRAO Journal of Breeding and Genetics
Tahun Terbit : 2019
Tahun Disertasi : 2018

Pengembangan Dari Disertasi ± 71,25%

No	Uraian	Tulisan pada Disertasi	Pengembangan Pada jurnal	Persentase
1	Abstrak	Belum ada abstrak	Sudah ada Abstrak hasil kajian	100%
2	Pendahuluan	1. Pendahuluan masih sangat umum, menjelaskan latar belakang penelitian yang mencakup: a. Kehilangan Hasil akibat cekaman kering dan kaitannya dengan program pemuliaan tanaman b. Beberapa indek toleransi pada tanaman tercekam kering, Tetapi belum dijelaskan secara rinci dan detail.	1. Pendahuluan pada makalah ini, memiliki latar belakang yang kuat, lebih tajam dalam menyampaikan permasalahan dan solusi yang ditawarkan. Beberapa point yang disampaikan pada pendahuluan yaitu: a. Menjelaskan tentang dampak Global warming terhadap produksi, khususnya tanaman cabai b. Stategi dan efektivitas seleksi Pemuliaan konvensional pada tanaman tercekam kering **c.** Menjelaskan definisi dan fungsi beberapa indek seleksi dan serta aplikasinya pada beberapa tanaman	50%
3	Hasil dan Pembahasan	**HASIL** 1. Penyajian data pada Hasil langsung mengacu pada indek seleksi, 2. Korelasi antar indek toleransi dan 3. Analisis PCA untuk melihat hubungan antar Genotipe dan Indek Toleransi	**HASIL** 1. Penyajian data Hasil Menampilkan produktivitas pada dua kondisi yaitu kondisi lingkungan normal dan tercekam	75%

		kekeringan yang digunakan. 4. Tidak membandingkan produktivitas genotype pada kondisi Stress dan kondisi Normal. 5. Tidak melihat pengaruh Genotipe (G), Lingkungan (E) serta interaksi Genotipe dan Lingkungan (G*E) **PEMBAHASAN** 1. Pembahasan dilakukan pada 3 data yang disajikan: a. Indek Toleransi b. Korelasi antar Indek c. PCA antar Genotipe dan Indek (Analisi Bi Plot) 2. Pembahasan dan penyajian data lebih sederhana karena belom ada masukan dari Reviwer,	menggunakan anova, 2. Melihat dan melakukan analisis pengaruh genotype (G), Lingkungan (E) serta Interaksi antara Genetik dan Lingkungan (G*E) 3. Penyajian data Hasil mengacu pada indek seleksi, 4. Korelasi antar indek toleransi dan 5. Analisis PCA untuk melihat hubungan antar Genotipe dan Indek Toleransi kekeringan yang digunakan **PEMBAHASAN** 1. Pembahasan dilakukan pada 5 data yang disajikan: a. Hasil pada kondisi Normal dan tercekam b. Persen Penurunan Hasil c. Pengaruh Genotipe, Lingkungan dan Interaksi keduanya d. Indek Toleransi e. Korelasi antar Indek f. PCA antar Genotipe dan Indek (Analisi Bi Plot) 2. Pembahasan lebih komprehensif, lebih dalam dan tajam sesuai masukan dari Reviwer Jurnal.	
4	Daftar Pustaka		Improve daftar Pustaka, terutama referensi	60%

			bersumber dari Jurnal hasil riset terbaru 70% merupakan Referensi terbaru (10 tahun terakhir)	
Rata-rata Pengembangan				**71,25%**

RESEARCH ARTICLE

SABRAO Journal
of Breeding and Genetics
51 (3) 205-224, 2019

SCREENING OF *CAPSICUM ANNUUM* L. GENOTYPES FOR DROUGHT TOLERANCE BASED ON DROUGHT TOLERANC INDICES

ROSMAINA[1]*, PARJANTO[2], SOBIR[3] and A. YUNUS[2]

[1]Department of Agrotechnology, Faculty of Agriculture and Animal Sciences, Universitas Islam Negeri Sultan Syarif Kasim Riau, Panam Campus-Pekanbaru 28293, Riau, Indonesia.
[2]Department of Agrotechnology, Faculty of Agriculture, Sebelas Maret University, Surakarta, 57126, Indonesia.
[3]Departement of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agriculture University, Bogor, 16680, West Java, Indonesia
*Corresponding author's email: rosmaina@uin-suska.ac.id
Email addresses of coauthors: parjanto_uns@yahoo.co.id, rsobir@yahoo.com, yunus.uns7@yahoo.com

SUMMARY

The use of drought-tolerant cultivars is the most effective approach to cope with the drought stress in chili pepper production. The objectives of the present research were to assess the tolerance indices, and to identify the drought tolerance in 55 curly pepper genotypes. The performance of 55 chili pepper genotypes was screened and compared under drought stressed and non-stress environments using randomized complete blocks design (RCBD) with four replications during 2016 at Sultan Syarif Kasim State Islamic University, Riau, Indonesia. Based on the yield under stress (Y_S) and non-stress environment (Y_{NS}), fourteen indices of the drought tolerance were formulated. Correlation analysis revealed that yield under stress condition had no significant correlation with the yield under non-stress environment indicating high stress intensity. Therefore, the STI (Stress Tolerance Index), GMP (Geometric Mean Productivity), HM (Harmonic Mean), and MP (Mean productivity) indices could not be used as indicator to screen the drought tolerance in curly pepper genotypes. The principal component analysis showed that SSI and SDI indices were found more reliable as tolerance indicators for selection of drought-tolerant genotypes in chili pepper genotypes. Subsequently, bi-plot and cluster analyses separated the 55 chili pepper genotypes into three groups, the first cluster (tolerant group) consisted of the three genotypes i.e. UIN-RFC010, UIN-GM107, and UIN-RFC006, second cluster (semi-tolerant or semi-sensitive genotypes) comprising 11 genotypes i.e. UIN-RFC011, UIN-RFC015, UIN-GK065M, UIN-RFC002, UIN-GM102, UIN-GK073, UIN-GK071, UIN-RFC019, UIN-RFC014, UIN-GK072, and UIN-GK098, while the rest of the genotypes were classified into the third cluster (susceptible group). Results further revealed that SSI and SDI indices could be used as selection indicators in curly pepper if the stress conditions are severe. The drought tolerant genotypes identified in this research could be utilized in future breeding program for further improvement in curly pepper.

Key words: Drought tolerance indices, biplot analysis, cluster analysis, drought tolerant chili pepper, *Capsicum annuum* L.

Key findings: Drought tolerance indices are important for screening and identification of drought tolerant chili pepper genotypes. The two indices i.e. SSI and SDI were found as best tolerance indicators for selection of curly pepper genotypes when stress conditions are severe. Based on both indices, three chili peppers accessions (UIN-RFC010, UIN-GM107, and UIN-RFC006) were identified as drought tolerent genotypes.

Manuscript received: January 25, 2019; Decision on manuscript: July 30, 2019; Accepted: August 9, 2019.

Communicating Editor: Dr. Naqib Ullah Khan

INTRODUCTION

Global warming has become international issues in several last decades because it caused changes in climate factors such as temperature, precipitation, drought, floods, and wind storms and provided significant impact on many sectors, including agriculture. Nowadays, drought occurred in many parts of the world due to decline in rainfall which effect the plant growth and productivity. Drought caused disturbance in the normal process of metabolism of cells and tissues of the plant, restricted the plant growth, and finally reduced the crop production (Wadhwa *et al*., 2010; Chutia and Borah, 2012; Razak *et al*., 2013).

Chilli pepper (*Capsicum annuum* L.) is the most pivotal horticulture crop in the world, and it has been cultivated in many regions. Chilli pepper crop is one of the most sensitive crops to drought (Gonzalez-Dugo *et al*., 2007; Ahmed *et al*., 2014; Mardaninejad *et al*., 2017; Rosmaina *et al*., 2018). However, crop response to drought stress is influenced by stages of plant growth, stress intensity, duration of drought, the frequency of drought, and crop cultivar. Therefore, the development and tailoring of cultivars that resistant to drought stress will be the important steps to adapt the challenges we face nowadays and in future. The plant breeding program for drought tolerance is relatively difficult because drought tolerance is not a simple response but controlled by many genes and their simultaneous selection is also difficult (Richards, 1996). The traits that linked to yield usually are inherited quantitatively and influenced by environmental factors; therefore, the quantitative approaches are required as important tools for selection.

Effective breeding for development and identification of drought tolerant chilli pepper, good selection criteria are needed to distinguish the drought tolerant genotypes. Numerous selection indices based on mathematical relationship between stress and non-stress conditions has been established (Fischer and Maurer, 1978; Rosielle and Hamblin, 1981; Fisher and Wood, 1981; Bouslama and Schapaugh, 1984; Fernandez, 1992; Schneider *et al*., 1997; Gavuzzi *et al*., 1997; Lan, 1998; Farshadfar and Sutka, 2002; Moosavi *et al*., 2008; Farshadfar and Javadinia, 2011). These indices are based on vulnerability and tolerance of genotype to drought. Drought tolerance is defined as the ability of plants to grow and reproduce optimally and then provide satisfactory yields when water availability is limited (Fleury *et al*., 2010). Drought vulnerability genotype is often measured as a function of yield reduction under drought pressure (Blaum, 1988). Fischer and Maurer (1978) suggested the stress susceptibility index (SSI) for measurement of yield stability that understands the changes in both potential and actual yields in variable environments. Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between stress and normal conditions and mean productivity (MP) as the average yield of genotypes under stress and non-stress conditions.

The geometric mean productivity (GMP) is often used by breeders interested in relative performance, since drought stress can vary in severity in field environments over years (Fernandez, 1992). Stress tolerance index (STI) is a useful tool for determining high yield and stress tolerance potential of the genotypes (Fernandez, 1992). The yield index (YI) suggested by Gavuzzi *et al*. (1997), yield stability index (YSI) suggested by Bouslama and Schapaugh (1984), and harmonic mean (HM) suggested by Schneider *et al*. (1997) in order to differentiate the stability of the genotypes in stress and non-stress conditions. Lan (1988) defined the new indices of drought resistance index (DI), which is commonly accepted to identify the genotypes producing high yield under both stress and non-stress conditions. Moosavi *et al*. (2008) proposed stress susceptibility percentage index (SSPI) for screening drought tolerant genotypes in stress and non-stress conditions. Farshadfar and Sutka (2002) introduced modified stress tolerance index (MSTI) in which STI is multiplied with a correction coefficient (Ki) specific for each stress and non-stress conditions. As a result, K1STI and K2STI were the selection criteria for stress and non-stress conditions, respectively.

Plant breeders have been utilized many biometrical procedures to evaluate the effectiveness of several drought tolerance indices for screening and identification of drought tolerant genotypes. Correlation analysis can be implemented to observe relationship between indices and to identify the level of stress severity. The best indices are those which have highest correlation with yield under both stress conditions and would be able to distinguish potential higher yielding and drought tolerant genotypes (Fernandez, 1992; Mitra, 2001). Some past researchers have also applied principal component analysis (PCA) to determine the combination of indices as selection criteria (Golabadi *et al*., 2006; Akura *et al*., 2011; Amiri *et al*., 2014). The PCA is one of the most successful techniques for reducing the multiple dimensions of the observed variables to a smaller intrinsic dimensionality of independent variables (Johnson and Wichern, 2007). Biplot analysis have been used for screening drought tolerant cultivars (Nazari and Pakniyat, 2010; Bonea and Urechean,

Table 1. Chili pepper genotypes tested under non-stressed and stressed conditions.

No.	Genotypes	No.	Genotypes	No	Genotypes
1	UIN-RFC008*	20	UIN-GR106M**	39	UIN-GM101**
2	UIN-RFC009*	21	UIN-RFC001*	40	UIN-GM102**
3	UIN-RFC010*	22	UIN-RFC002*	41	UIN-GM103**
4	UIN-RFC011*	23	UIN-RFC003*	42	UIN-KG041*
5	UIN-RFC015*	24	UIN-KG096*	43	UIN-KG048*
6	UIN-RFC016*	25	UIN-FRC005*	44	UIN-KG055*
7	UIN-RFC017*	26	UIN-RFC006*	45	UIN-K057*
8	UIN-RFC018*	27	UIN-GK097*	46	UIN-K058*
9	UIN-RFC019*	28	UIN-RFC012*	47	UIN-GK059*
10	UIN-RFC020*	29	UIN-RFC013*	48	UIN-K064*
11	UIN-GK059M**	30	UIN-RFC014*	49	UIN-GK065*
12	UIN-GK061*	31	UIN-KG035*	50	UIN-GK066*
13	UIN-GK065M**	32	UIN-KG036*	51	UIN-GK067*
14	UIN-GK071M**	33	UIN-KG037*	52	UIN-GK070*
15	UIN-GK072M**	34	UIN-GK38*	53	UIN-GK071*
16	UIN-GK073M**	35	UIN-GK39*	54	UIN-GK072*
17	UIN-GK074*	36	UIN-GK098*	55	UIN-GK073*
18	UIN-GM107**	37	UIN-GK099*		
19	UIN-GR105*	38	UIN-GM100**		

Notes: * landrace; and ** Mutations from landrace

2011; Aliakbari *et al*., 2014). The objective of this research was to assess tolerance indices in 55 chili pepper genotypes, and to identify the drought tolerant genotypes.

MATERIALS AND METHODS

Genetic material

Germplasm used in this study was a collection of curly pepper (*Capsicum annuum* L.) genotypes from the gene bank of Genetic and Breeding Laboratory, Faculty of Agricultural and Animal Science, Universitas Islam Negeri Sultan Syarif Kasim, Riau, Indonesia (Table 1).

Experimental design

The present research was conducted during 2016 in the greenhouse (which day temperature average was 32-33^{o}C, and average of relative humidity was 80-90%), Laboratory of Genetic and Breeding, Faculty of Agricultural and Animal Science, Sultan Syarif Kasim State Islamic University, Riau, Indonesia. The experiment was laid out following randomized complete block design (RCBD) with 55 genotypes as treatments with four replications. The seeds of each curly pepper genotype was sown in small polybags and then maintained at optimum conditions for germination. When the seedlings become four weeks old; then were transplanted into large polybags containing mixed media of soil and compost with ratio of 3:1, respectively. Field water capacity was determined by following the methods of Rosmaina *et al*. (2018). After one week of transplantion, non-stress plants were irrigated normally, while stressed plants growing up in 50% of the water field capacity. All the weeds were manually controlled.

Data recorded and statistical analyses

At harvest time, the number of fruit and yield were recorded for each genotype in both environments (non-stress and stressed) and subjected to calculate the drought tolerance indices. The criteria of harvesting of the fruit of curly pepper was fruit red colored.

Fourteen drought tolerance indices were calculated using the following formulas:

1. Stress susceptibility index (SSI) = $\frac{1-\left(Y_S/Y_{NS}\right)}{1-\left(\bar{Y}_S/\bar{Y}_{NS}\right)}$ (Fischer and Maurer, 1978).
2. Tolerance (TOL) = $Y_{NS} - Y_S$ (Rosielle and Hamblin, 1981).
3. Stress Tolerance Index (STI) = $\frac{Y_S \ x \ Y_{NS}}{\bar{Y}_{NS}^2}$ (Fernandez, 1992).
4. Drought Tolerance Efficiency (DTE) $=(Y_S/Y_{NS}) x \ 100$ (Fischer and Wood, 1981).
5. Mean productivity (MP) = $\frac{Y_S + Y_{NS}}{2}$ (Rosielle and Hamblin, 1981).
6. Geometric Mean Productivity (GMP) $= \sqrt{Y_S \ x \ Y_{NS}}$ (Fernandez, 1992).
7. Harmonic Mean (HM) = $\frac{2(Y_S \ x \ Y_{NS})}{Y_S + Y_{NS}}$ (Schneider *et al*., 1997).
8. Sensitivity Drought Index (SDI) $=(Y_{NS} - Y_S)/Y_{NS}$ (Farshadfar and Javadinia, 2011).
9. Drought Resistance Index (DI) = $Y_S \ x \left[\frac{Y_S/Y_{NS}}{\bar{Y}_S}\right]$ (Lan, 1998).
10. Relative drought index (RDI) = $[(Y_S/Y_{NS})/(\bar{Y}_S/\bar{Y}_{NS})]$ (Fisher and Maurer, 1978).
11. Stress Susceptibility percentage Index (SSPI) = $[(Y_{NS} - Y_S)/(2 \ x\bar{Y}_{NS})] \ x \ 100$ (Moosavi *et al*., 2008).
12. Yield Stability Index (YSI) = Y_S/Y_{NS} (Bouslama and Schapaugh, 1984).
13. Yield index (YI) = $Y_S/\bar{Y}_S$ (Gavuzzi *et al*., 1997).
14. Modified stress tolerance index = MSTI =KiSTI,

    $K_1 = Y_{NS}^2/\bar{Y}_{NS}^2$ and

    $K_2 = Y_S^2/\bar{Y}_S^2$,

    where ki is the correction coefficient (Farshadfar and Sutka, 2002).

Whereas, the Y_S, Y_{NS}, and $\bar{Y}_S$, $\bar{Y}_{NS}$, denoted the mean yield under stressed and non-stress conditions for each genotype, and yield mean in under stressed and non-stress condition for all genotypes, respectively. Analysis of variance was calculated according Steel *et al*. (1997) by using SAS Software version 9.1. Correlations analysis, principal component analysis (PCA), biplot and cluster analyses were carried out using MVSP software, version 3.22 (www.kovcomp.com)

RESULTS AND DISCUSSION

Assessment of drought tolerance genotypes

The variation among the genotypes for curly pepper yield under stressed and non-stress conditions are provided in Table 2. In non-stress condition, chili pepper genotypes i.e. UIN-GK066, UIN-KG059, UIN-RFC020, UIN-RFC011, and UIN-RFC017 had the highest yield and the genotype of UIN-GK055, UIN-GK058, UIN-GK048, UIN-GM101, and UIN-GM103 showed the lowest yield. In stressed condition, the chili pepper genotypes UIN-RFC010, UIN-GM107, UIN-GK072, UIN-RFC011, and UIN-RFC014 had the maximum yield while the genotypes i.e. UIN-RFC009, UIN-RFC018, UIN-GK059, UIN-GK073M, UIN-GK074, UIN-GR105, UIN-GR106M, UIN-RFC012, UIN-RFC013, UIN-K38, UIN-K39, UIN-GM100, UIN-GM101, UIN-GK055, and UIN-GK070 exhibited the lowest yield, and confirmed that these genotypes were highly vulnerable to drought stress. The genotypes having lowest yield under stressed/drought condition did not produce the fruit because all of their flowers suffered abortion (data not shown). Flowers abortion resulted in reduced pollen fertility which impact and disturbed the meiosis process during pollen development (Jager *et al*., 2008).

Results further revealed that drought stress declined yield in all the genotypes, except three chili pepper genotypes viz., UIN-RFC010, UIN-GM107, and UIN-RFC006 (Table 2). These genotypes showed increased yield even under stressed conditions with values of 92.44%, 36.92% and 40.34%, respectively, however, the yield reduction was ranged between 30-100%. Genotypes revealed significant variation for reduction in yield under stressed condition, and it may be linked to stress intensity. Stress intensity (SI) during experiment was 0.8. The standard of stress intensity value ranged between 0 and 1. Dejen *et al*. (2008) explained that the larger values of stress intensity indicating more severe stress conditions.

Analysis of variance displayed highly significant differences for all the tolerance indices used in the genotypes (Table 3). The average value of tolerance indices for each genotypes was exhibited in Table 4. Stress susceptibility index (SSI) was used to assess the reduction in yield by comparing the non-stress to stressed conditions. The lower SSI values indicated the lower differences in yield between non-stress and stressed conditions, however, in other words, the lower SSI is categorized as more tolerance to drought (Prakash, 2007; Raman *et al*., 2012). The chili pepper genotype UIN-RFC010 was recorded with lowest SSI value of -1.20, followed by two other genotypes i.e. UIN-RFC006 (-0.50) and UIN-GM107(-0.46). Whereas the genotypes i.e. UIN-RFC018, UIN-GK059, UIN-GK073M, UIN-GK074, UIN-GR105, UIN-GR106, UIN-RFC012, UIN-RFC013, UIN-K38, UIN-K39, UIN-GM100, UIN-GM101, UIN-GK055, and UIN-GK070 showed higher SSI value (1.25). According to Kumar *et al*. (2014), the SSI value can be categorized as highly drought tolerant (SSI < 0.50), drought tolerant (SSI = 0.51-0.75), moderately drought tolerant (SSI = 0.76-1.00) and drought susceptible (SSI > 1.00). Based on the SSI index, the chili pepper genotypes viz., UIN-RFC010, UIN-GM107, UIN-RFC006, UIN-GK098, and UIN-RFC019 were categorized as

Table 2. Average yield per curly pepper genotype (g) tested under non-stressed (Y_{NS}) and stressed (Y_S) conditions and yield reductions (YR).

No.	Genotypes	Y_{NS}	Y_S	YR (%)
1	UIN-RFC008	232.79	26.52	-88.60bcde
2	UIN-RFC009	236.48	0.00	-100.00a
3	UIN-RFC010	123.96	238.55	92.44n
4	UIN-RFC011	267.90	107.68	-59.81hij
5	UIN-RFC015	87.65	37.00	-57.79ij
6	UIN-RFC016	229.35	8.69	-96.21ab
7	UIN-RFC017	238.44	1.36	-99.43a
8	UIN-RFC018	41.83	0.00	-100.00a
9	UIN-RFC019	73.09	46.26	-36.70lk
10	UIN-RFC020	279.01	56.89	-79.61fe
11	UIN-GK059	182.56	0.00	-100.00a
12	UIN-GK061	211.64	52.49	-75.20fg
13	UIN-GK065M	169.75	76.57	-54.89j
14	UIN-GK071M	197.48	29.98	-84.82cde
15	UIN-GK072M	131.86	13.48	-89.78abcd
16	UIN-GK073M	107.20	0.00	-100.00a
17	UIN-GK074	189.54	0.00	-100.00a
18	UIN-GM107	123.98	169.75	36.92m
19	UIN-GR105	113.32	0.00	-100.00a
20	UIN-GR106	73.40	0.00	-100.00a
21	UIN-RFC001	146.15	2.59	-98.2ab
22	UIN-RFC002	57.11	18.33	-67.90hg
23	UIN-RFC003	86.35	7.29	-91.56abc
24	UIN-GK096	85.67	7.29	-91.49abc
25	UIN-FRC005	159.83	4.85	-96.97ab
26	UIN-RFC006	56.57	79.39	40.34m
27	UIN-GK097	96.19	9.70	-89.92abcd
28	UIN-RFC012	106.09	0.00	-100.00a
29	UIN-RFC013	164.53	0.00	-100.00a
30	UIN-RFC014	165.69	95.65	-42.27k
31	UIN-GK035	65.35	1.40	-97.86ab
32	UIN-GK036	71.51	4.37	-93.89abc
33	UIN-GK37	116.76	21.01	-82.01def
34	UIN-GK38	95.93	0.00	-100.00a
35	UIN-GK39	49.24	0.00	-100.00a
36	UIN-GK098	39.27	27.43	-30.15l
37	UIN-GK099	132.78	8.15	-93.86abc
38	UIN-GM100	145.06	0.00	-100.00a
39	UIN-GM101	37.73	0.00	-100.00a
40	UIN-GM102	108.72	37.65	-65.37hi
41	UIN-GM103	38.58	1.63	-95.78ab
42	UIN-GK041	101.80	5.41	-94.69ab
43	UIN-GK048	36.18	3.15	-91.29abc
44	UIN-GK055	8.70	0.00	-100.00a
45	UIN-GK057	204.38	7.38	-96.39ab
46	UIN-GK058	20.00	0.95	-95.25ab
47	UIN-GK059	296.95	16.62	-94.40abc
48	UIN-GK064	72.45	3.00	-95.86ab
49	UIN-GK065	181.29	27.34	-84.92cde
50	UIN-GK066	352.76	24.10	-93.17abc
51	UIN-GK067	106.78	2.37	-97.78ab
52	UIN-GK070	74.58	0.00	-100.00a
53	UIN-GK071	71.80	26.93	-62.49hij
54	UIN-GK072	189.37	108.83	-42.53k
55	UIN-GK073	47.12	16.89	-64.16hi

Means followed by same letter(s) in each column are not significantly different ($P < 0.05$)

Table 3. Analysis of variance for yield under non-stressed (Y_{NS}), stressed (Y_S) environments and other tolerance indices in chilli pepper genotypes.

SOV	d.f.	Mean Square																
		Y_{NS}	Y_S	TOL	SSI	STI	DTE	GMP	HM	SDI	DI	MP	SSPI	RDI	YSI	YI	K1STI	K2STI
Genotype	54	23905.84**	8164.32**	26912.28**	0.91**	0.74**	5792.55**	8949.97**	7683.30**	0.58**	29.54**	9307.01**	4014.39**	14.13**	0.58**	11.88**	8.50**	2078.66**
Error	164	241.50	66.12	227.17	0.01	0.02	32.76	62.01	57.96	0.00	0.59	97.01	33.89	0.08	0.00	0.10	1.03	145.20
CV (%)		12.00	31.03	14.60	9.85	55.98	26.13	18.53	23.31	7.33	94.89	12.66	14.60	26.13	26.13	31.03	166.60	216.87

SOV: Source of variation; CV: Coefficient of variation; d.f. : degree of freedom; Y_{NS}: Yield under non-stressed; Y_S: Yield under stressed; TOL: Tolerance; SSI: Stress susceptibility index; STI: Stress tolerance index; DTE: Drought tolerance efficiency; GMP: Geometric mean productivity; HM: Harmonic mean; SDI: Sensitivity drought index; DI: Drought resistance index; MP: Mean productivity; SSPI: Stress susceptibility percentage index; RDI: Relative drought index; YSI: Yield stability index; YI: Yield index; K1STI: Modified stress tolerance index for favorable condition; K2STI: Modified stress tolerance index for stress condition. *, **: significant difference at the 5% and 1% levels of probability, respectively.

Table 4. Mean values of drought indices in chilli pepper genotypes.

No.	Genotypes	TOL	SSI	STI	DTE	GMP	HM	SDI	DI	MP	SSPI	RDI	YSI	YI	K1STI	K2STI
1	UIN-RFC008	206.27	1.11	0.37	11.39	78.57	47.62	0.89	0.11	129.66	80.31	0.56	0.11	1.01	1.20	0.38
2	UIN-RFC009	236.48	1.25	0.00	0.00	0.00	0.00	1.00	0.00	118.24	92.07	0.00	0.00	0.00	0.00	0.00
3	UIN-RFC010	-114.59	-1.16	1.79	192.45	171.96	163.14	-0.92	17.46	181.25	-44.62	9.40	1.92	9.07	1.65	149.65
4	UIN-RFC011	160.23	0.75	1.75	40.19	169.84	153.61	0.60	1.65	187.79	62.38	1.96	0.40	4.10	7.54	29.81
5	UIN-RFC015	50.65	0.72	0.20	42.21	56.95	52.03	0.58	0.59	62.32	19.72	2.06	0.42	1.41	0.09	0.40
6	UIN-RFC016	220.65	1.20	0.12	3.79	44.65	16.75	0.96	0.01	119.02	85.91	0.19	0.04	0.33	0.38	0.01
7	UIN-RFC017	237.08	1.24	0.02	0.57	18.01	2.70	0.99	0.00	119.90	92.31	0.03	0.01	0.05	0.07	0.00
8	UIN-RFC018	41.83	1.25	0.00	0.00	0.00	0.00	1.00	0.00	20.91	16.28	0.00	0.00	0.00	0.00	0.00
9	UIN-RFC019	26.83	0.46	0.21	63.30	58.15	56.66	0.37	1.11	59.67	10.44	3.09	0.63	1.76	0.07	0.66
10	UIN-RFC020	222.12	1.00	0.96	20.39	125.98	94.51	0.80	0.44	167.95	86.48	1.00	0.20	2.16	4.48	4.56
11	UIN-GK059	182.56	1.25	0.00	0.00	0.00	0.00	1.00	0.00	91.28	71.08	0.00	0.00	0.00	0.00	0.00
12	UIN-GK061	159.15	0.94	0.67	24.80	105.40	84.12	0.75	0.50	132.07	61.96	1.21	0.25	2.00	1.80	2.71
13	UIN-GK065M	93.19	0.69	0.79	45.11	114.01	105.53	0.55	1.31	123.16	36.28	2.20	0.45	2.91	1.37	6.80
14	UIN-GK071M	167.50	1.06	0.36	15.18	76.94	52.05	0.85	0.17	113.73	65.22	0.74	0.15	1.14	0.84	0.48
15	UIN-GK072M	118.38	1.12	0.11	10.22	42.16	24.46	0.90	0.05	72.67	46.09	0.50	0.10	0.51	0.11	0.03
16	UIN-GK073M	107.20	1.25	0.00	0.00	0.00	0.00	1.00	0.00	53.60	41.74	0.00	0.00	0.00	0.00	0.00
17	UIN-GK074	189.54	1.25	0.00	0.00	0.00	0.00	1.00	0.00	94.77	73.80	0.00	0.00	0.00	0.00	0.00
18	UIN-GM107	-45.77	-0.46	1.28	136.92	145.07	143.30	-0.37	8.84	146.86	-17.82	6.69	1.37	6.46	1.18	54.19
19	UIN-GR105	113.32	1.25	0.00	0.00	0.00	0.00	1.00	0.00	56.66	44.12	0.00	0.00	0.00	0.00	0.00
20	UIN-GR106	73.40	1.25	0.00	0.00	0.00	0.00	1.00	0.00	36.70	28.58	0.00	0.00	0.00	0.00	0.00
21	UIN-RFC001	143.56	1.23	0.02	1.77	19.46	5.09	0.98	0.00	74.37	55.89	0.09	0.02	0.10	0.03	0.00
22	UIN-RFC002	38.78	0.85	0.06	32.10	32.35	27.75	0.68	0.22	37.72	15.10	1.57	0.32	0.70	0.01	0.03
23	UIN-RFC003	79.06	1.14	0.04	8.44	25.09	13.44	0.92	0.02	46.82	30.78	0.41	0.08	0.28	0.02	0.00
24	UIN-GK096	78.38	1.14	0.04	8.51	24.99	13.44	0.91	0.02	46.48	30.52	0.42	0.09	0.28	0.02	0.00
25	UIN-FRC005	154.98	1.21	0.05	3.03	27.84	9.41	0.97	0.01	82.34	60.34	0.15	0.03	0.18	0.08	0.00
26	UIN-RFC006	-22.82	-0.50	0.27	140.34	67.02	66.07	-0.40	4.24	67.98	-8.89	6.86	1.40	3.02	0.05	2.50
27	UIN-GK097	86.50	1.12	0.06	10.08	30.54	17.61	0.90	0.04	52.94	33.68	0.49	0.10	0.37	0.03	0.01
28	UIN-RFC012	106.09	1.25	0.00	0.00	0.00	0.00	1.00	0.00	53.05	41.31	0.00	0.00	0.00	0.00	0.00
29	UIN-RFC013	164.53	1.25	0.00	0.00	0.00	0.00	1.00	0.00	82.27	64.06	0.00	0.00	0.00	0.00	0.00
30	UIN-RFC014	70.04	0.53	0.96	57.73	125.89	121.28	0.42	2.10	130.67	27.27	2.82	0.58	3.64	1.58	12.90
31	UIN-GK035	63.95	1.22	0.01	2.14	9.56	2.74	0.98	0.00	33.37	24.90	0.10	0.02	0.05	0.00	0.00
32	UIN-GK036	67.14	1.17	0.02	6.11	17.67	8.23	0.94	0.01	37.94	26.14	0.30	0.06	0.17	0.01	0.00
33	UIN-GK37	95.75	1.03	0.15	17.99	49.53	35.61	0.82	0.14	68.88	37.28	0.88	0.18	0.80	0.12	0.10
34	UIN-GK38	95.93	1.25	0.00	0.00	0.00	0.00	1.00	0.00	47.97	37.35	0.00	0.00	0.00	0.00	0.00
35	UIN-GK39	49.24	1.25	0.00	0.00	0.00	0.00	1.00	0.00	24.62	19.17	0.00	0.00	0.00	0.00	0.00
36	UIN-GK098	11.84	0.38	0.07	69.85	32.82	32.30	0.30	0.73	33.35	4.61	3.41	0.70	1.04	0.01	0.08
37	UIN-GK099	124.63	1.17	0.07	6.14	32.90	15.36	0.94	0.02	70.47	48.52	0.30	0.06	0.31	0.07	0.01
38	UIN-GM100	145.06	1.25	0.00	0.00	0.00	0.00	1.00	0.00	72.53	56.48	0.00	0.00	0.00	0.00	0.00
39	UIN-GM101	37.73	1.25	0.00	0.00	0.00	0.00	1.00	0.00	18.86	14.69	0.00	0.00	0.00	0.00	0.00
40	UIN-GM102	71.07	0.82	0.25	34.63	63.98	55.93	0.65	0.50	73.18	27.67	1.69	0.35	1.43	0.18	0.52
41	UIN-GM103	36.95	1.20	0.00	4.23	7.93	3.13	0.96	0.00	20.10	14.38	0.21	0.04	0.06	0.00	0.00
42	UIN-GK041	96.39	1.18	0.03	5.31	23.47	10.27	0.95	0.01	53.61	37.53	0.26	0.05	0.21	0.02	0.00
43	UIN-GK048	33.03	1.14	0.01	8.71	10.68	5.80	0.91	0.01	19.67	12.86	0.43	0.09	0.12	0.00	0.00
44	UIN-GK055	8.70	1.25	0.00	0.00	0.00	0.00	1.00	0.00	4.35	3.39	0.00	0.00	0.00	0.00	0.00
45	UIN-GK057	197.00	1.20	0.09	3.61	38.84	14.25	0.96	0.01	105.88	76.70	0.18	0.04	0.28	0.23	0.01
46	UIN-GK058	19.05	1.19	0.00	4.75	4.36	1.81	0.95	0.00	10.48	7.42	0.23	0.05	0.04	0.00	0.00
47	UIN-GK059	280.33	1.18	0.30	5.60	70.25	31.48	0.94	0.04	156.79	109.15	0.27	0.06	0.63	1.59	0.12
48	UIN-GK064	69.45	1.20	0.01	4.14	14.74	5.76	0.96	0.00	37.73	27.04	0.20	0.04	0.11	0.00	0.00
49	UIN-GK065	153.95	1.06	0.30	15.08	70.40	47.51	0.85	0.16	104.32	59.94	0.74	0.15	1.04	0.59	0.33
50	UIN-GK066	328.66	1.16	0.52	6.83	92.20	45.12	0.93	0.06	188.43	127.96	0.33	0.07	0.92	3.88	0.44
51	UIN-GK067	104.41	1.22	0.02	2.22	15.91	4.64	0.98	0.00	54.58	40.65	0.11	0.02	0.09	0.01	0.00
52	UIN-GK070	74.58	1.25	0.00	0.00	0.00	0.00	1.00	0.00	37.29	29.04	0.00	0.00	0.00	0.00	0.00
53	UIN-GK071	44.87	0.78	0.12	37.51	43.97	39.17	0.62	0.38	49.37	17.47	1.83	0.38	1.02	0.04	0.13
54	UIN-GK072	80.54	0.53	1.25	57.47	143.56	138.22	0.43	2.38	149.10	31.36	2.81	0.57	4.14	2.69	21.75
55	UIN-GK073	30.23	0.80	0.05	35.84	28.21	24.87	0.64	0.23	32.01	11.77	1.75	0.36	0.64	0.01	0.02

TOL: Tolerance; SSI: Stress susceptibility index; STI: Stress tolerance index; DTE: Drought tolerance efficiency; GMP: Geometric mean productivity; HM: Harmonic mean; SDI: Sensitivity drought index; DI: Drought resistance index; MP: Mean productivity; SSPI: Stress susceptibility percentage index; RDI: Relative drought index; YSI: Yield stability index; YI: Yield index; K1STI: Modified stress tolerance index for favorable condition; and K2STI: Modified stress tolerance index for stress condition.

highly drought tolerant (SSI < 0.50), genotypes UIN-GK072, UIN-RFC014, UIN-GK065M, UIN-RFC015, and UIN-RFC011 were classified as drought tolerant (SSI = 0.51-0.75), and genotypes UIN-GK061, UIN-RFC002, UIN-GM102, UIN-071, UIN-GK073, and UIN-RFC020 were considered as moderately drought tolerant (SSI = 0.76-1.00). Earlier researchers have commonly used SSI as tolerance indice (Akcura *et al*., 2011; Fischer and Maurer, 1978).

Based on the TOL, the genotypes UIN-RFC010, UIN-GM107, and UIN-RFC006 were identified as drought tolerant genotypes under stressed condition, while the genotypes UIN-GK066 UIN-GK059, UIN-RFC017, UIN-RFC009 and UIN-RFC020 were noted with highest value of TOL and these genotypes were categorized as drought susceptible under stressed condition. Raman *et al*. (2012) also reported the similar findings that genotype with low value of TOL was classified as drought tolerant under stressed condition.

The TOL and SSI indices favor genotypes with good yield under drought stressed condition; therefore, both indices can be utilized for identifying the genotypes which performance is well under drought condition. A high value of TOL and SSI indicated its more sensitivity to stress as reported by Bruckner and Frohberg (1987). Based on these two indices, the three genotypes i.e. UIN-RFC010, UIN-GM107, and UIN-RFC006 had the lowest TOL and SSI values which authenticated that these genotypes were more tolerant to stressed conditions.

Stress tolerance index (STI) was used to identify the curly pepper genotypes that produce high yield under drought stressed and non-stress conditions (Table 4). In present study for selection efficiency, the value of STI was classified into two groups i.e. STI > 1 for tolerant genotypes and STI < 1 value for sensitive genotypes. The genotype UIN-RFC010 showed the highest value of STI (1.79), followed by three other genotypes viz., UIN-RFC011, UIN-GM107, and UIN-GK072. These four curly pepper genotypes were the top performer under stressed conditions. Thirty-four others curly pepper genotypes showed lowest STI values (< 0.10) which imply that these genotypes were highly susceptible to drought stressed conditions. Genotypes with high STI values usually have high differences for yield under stressed and non-stress conditions (Kumar *et al*., 2014; Moosavi *et al*., 2008; Fernandez, 1992; Farshadfar *et al*., 2012).

Drought tolerance efficiency (DTE) is a measure of drought resistance mechanisms, determines the consistency of selected genotypes in response to drought stress having different severity, timing, and duration, and thus may be helpful in identifying genotypes that possess drought resistance capability in chili pepper. The values of this variable were ranged from 0.00 to 192.45%. The highest DTE value was recorded in chili pepper genotype UIN-RFC010 (192.45%), followed by UIN-RFC006 (140.34%), and UIN-GM107 (136.92%). However, the lowest and same DTE value (0.00) was observed in the chili pepper genotypes i.e. UIN-RFC009, UIN-RFC018, UIN-GK059, UIN-GK073M, UIN-GK074, UIN-GR105, UIN-GR106, UIN-RFC012, UIN-RFC013, UIN-K38, UIN-K39, UIN-GM100, UIN-GM101, UIN-GK055, and UIN-GK070 (Table 4). The zero value of the DTE means that these genotypes were not able to form the fruits under stressed conditions which confirmed that 50% field capacity of water is highest stress for chili peppers in this study.

Based on the GMP value, the chili pepper genotypes i.e. UIN-RFC010, UIN-RFC011, UIN-GM107, and UIN-K072 were identified as drought tolerant genotypes under the stressed condition, while the remaining genotypes displayed the lowest value of GMP (Table 4). According to the harmonic mean (HM), the genotypes UIN-RFC010, UIN-RFC011, UIN-GM107, and UIN-GK072 were identified as drought tolerant genotypes, while all other genotypes showed the lowest value of HM (Table 4). Results about both GMP and HM indices were completely similar due to the nature of their calculating formulas, and in future one of them can be used. Based on the MP, the highest value was observed in chili pepper genotype UIN-GK066, followed by UIN-RFC011, UIN-RFC010, and UIN-RFC020 and were classfied as drought tolerant genotypes. The higher MP value is an indicator of the genotype with higher yield potential. If the difference between non-stress and stress condition is too high, estimation of MP value can bias because MP value is calculated based on arithmetic mean. The use of mean productivity index with biased results is also reported by Moosavi *et al*. (2008) and Zangi (2005) in wheat and cotton crops, respectively.

The YSI index was more useful in discriminating drought tolerant from susceptible genotypes. The greater values of YSI index were observed in chili pepper genotypes UIN-RFC010, UIN-GM107, and UIN-RFC006. Genotypes with high YSI values were high yielding under stressed and yielding low under non-stress conditions. Therefore, breeders should select this index for selection of stress-tolerant genotypes. The YSI value can be categorized as highly stability in drought tolerant (YSI > 0.60), stable in drought tolerant (YSI = 0.41-0.60), moderately stability in drought tolerant (YSI = 0.20-0.40) and drought susceptible (YSI < 0.20). Based on categories, genotypes viz., UIN-RFC010, UIN-GM107, UIN-RFC006, UIN-GK098 and UIN-RFC019 were found highly stable and drought tolerant (YSI > 0.60). Genotypes UIN-GK072, UIN-RFC014, UIN-GK065M, UIN-RFC015, and, UIN-RFC011 were observed as stable and drought tolerant (YSI = 0.41-0.60), while genotypes i.e. UIN-GK061, UIN-RFC002, UIN-GM102, UIN-GK071, UIN-GK073, and UIN-RFC020 were considered as moderately stability and drought tolerant (YSI = 0.2-0.40). However, all others genotypes (YSI < 0.20) were confirmed as unstable. Present results were consistent with findings of Naghavi *et al*. (2013) who reported that corn genotypes were found unstable under drought condition with YSI value of less than 0.20, and present investigations also got support from earlier observations in wheat genotypes (Mohammadi *et al*., 2010).

The YI index is suitable for distinguishing of the high yielding genotypes under drought stressed condition. According to Khan and Dhurpe (2016), the genotypes with YI > 1 value were considered as tolerant, while the genotypes having value of YI < 1 were denoted as susceptible one. According to YI value, seventeen genotypes were considered as tolerant genotypes, while 39 others were found susceptible (Table 4). Based on the SDI and SSPI, the three chili pepper genotypes UIN-RFC010, UIN-RFC006, and UIN-GM107 revealed the lowest values and were identified as tolerant under stress conditions. The genotypes with a low value of SDI will be more desirable. According to DI index, four genotypes UIN-RFC010, UIN-RFC006, UIN-GM107, and UIN-GK072 displayed higher DI values as compared to other genotypes and were categorized as drought tolerant genotypes.

Based on RDI index, the higher value is obtained for genotype UIN-RFC010 (9.4), followed by chili pepper genotypes i.e. UIN-RFC006 (6.86), UIN-GM107 (6.69), UIN-GK098 (3.42), UIN-RFC019 (3.09), UIN-RFC014 (2.82), UIN-GK072 (2.81), UIN-GK065M (2.20), UIN-RFC015 (2.06), UIN-GK071 (1.83), UIN-GK073 (1.75), UIN-GM102 (1.69), UIN-RFC002 (1.57), and UIN-GK061 (1.21) (Table 4). Fisher and Maurer (1978) classfied RDI value into two groups i.e. the genotypes with RDI value > 1 were relatively drought tolerant, while the genotypes with RDI value < 1 were considered drought susceptible. According to above categories, these genotypes were categorized as tolerant to stress environment while rest of the genotypes were drought susceptible. However, Bidinger *et al*. (1978) stated that genotypes with positive values of RDI indicating stress tolerance. Moosavi *et al*. (2008) also reported that RDI is not effectively used as an indicator for selection of tolerant genotypes under stress conditions in wheat. According to the modified stress tolerance index (K1STI and K2STI), chili pepper genotypes UIN-RFC011, UIN-RFC020, UIN-RFC011, UIN-GK061, UIN-GK065M, UIN-GM107, UIN-RFC014, and UIN-GK072 were identified as drought tolerant genotypes while rest of the genotypes were sensitive to drought. The K1STI and K2STI indices related to STI were found as convenient variables to differentiate high-yielding wheat genotypes under stressed and non-stress conditions (Ilker *et al*., 2011).

Correlation analysis

The estimation of drought tolerance and identification of drought tolerant genotypes based on single index is contradictory (Farshadfar *et al*., 2012), however, selection based on combination of indices may provide a useful criterion for improving drought resistance in chili pepper. To determine the most desirable drought tolerance criteria, the correlation analysis between Y_S, Y_{NS} and other drought tolerance indices were calculated (Table 5). In other words, that correlation analysis between Y_S, Y_{NS} and tolerance indices will provide a good criterion for screening the best genotypes and indices used. A suitable index must have a significant correlation with grain yield under stressed and non-stress conditions (Mitra, 2001). Yield under stressed condition (Y_S) had no significant correlation with yield under non-stressed condition (Y_{NS}) (r = 0.19), and showed the high stress intensity. Similar results were also reported in wheat by Talebi *et al*. (2009) and Yasir *et al*. (2013), in maize by Bonea and Urechean (2011), in sweet potato by Agili *et al*. (2012), in barley by Subhani *et al*. (2015). Zare (2012) reported that barley genotypes yield under drought stressed condition was not significantly correlated with grain yield under non-stress condition (r = 0.39), indicating that high yield under normal condition does not correlate to yield under stressed condition. Therefore, indirect selection for a

Table 5. Correlation coefficient among yield under non-stressed (Y_{NS}), stressed (Y_S) environments and other tolerance indices in chili pepper genotypes.

Traits	Y_{NS}	Y_S	TOL	SSI	STI	DTE	GMP	HM	SDI	DI	MP	SSPI	RDI	YSI	YI	K1STI	K2STI
Y_{NS}	1.00																
Y_S	0.19	1.00															
TOL	1.84**	-0.37**	1.00														
SSI	0.07	-0.97	0.56**	1.00													
STI	0.42**	0.92**	-0.11	-0.68**	1.00												
DTE	-0.07	0.90**	-0.56**	-0.99**	0.68**	1.00											
GMP	0.49**	0.87**	-0.02	-0.68**	0.95**	0.68**	1.00										
HM	0.34*	0.93**	-0.19	-0.76**	0.96**	0.78**	0.97**	1.00									
SDI	0.07	-0.90**	0.56**	0.99**	-0.68**	-1.00**	-0.68**	-0.76**	1.00								
DI	0.00	0.89**	-0.49**	-0.88	0.70**	0.88**	0.60**	0.67**	-0.88**	1.00							
MP	0.89**	0.62**	0.50**	-0.36**	0.76**	0.36**	0.80**	0.71**	-0.36**	0.42**	1.00						
SSPI	0.84	-0.37**	1.00**	0.56**	-0.11	-0.56**	-0.02	-0.19	0.56**	-0,49**	0.50**	1.00					
RDI	-0.07	0.90**	-0.56**	-1.00**	0.68**	1.00**	0.68**	0.76**	-1.00**	0.88**	0.36**	-0.56**	1.00				
YSI	-0.07	0.90**	-0.56**	-1.00**	0.68**	1.00**	0.68**	0.76**	-1.00**	0.88**	0.36**	-0.56**	1.00**	1.00			
YI	0.19	1.00**	-0.37**	-0.90**	0.92**	0.90**	0.87**	0.93**	-0.90**	0.89**	0.62**	-0.37**	0.90**	0.90**	1.00		
K1STI	0.96**	0.14	0.83**	0.10	0.39**	-0.10	0.45**	0.30	0.90**	-0.04	0.83**	0.83**	-0.09	-0.09	0.14	1.00	
K2STI	0.07	0.92**	-0.44**	-0.84**	0.78**	0.84**	0.67**	0.73**	-0.84**	0.98**	0.49**	-0.44**	0.85	0.84**	0.92**	0.03	1.00

Y_{NS}: Yield under non-stressed; Y_S: Yield under stressed; TOL: Tolerance; SSI: Stress susceptibility index; STI: Stress tolerance index; DTE: Drought tolerance efficiency; GMP: Geometric mean productivity; HM: Harmonic mean; SDI: Sensitivity drought index; DI: Drought resistance index; MP: Mean productivity; SSPI: Stress susceptibility percentage index; RDI: Relative drought index; YSI: Yield stability index; YI: Yield index; K1STI: Modified stress tolerance index for favorable condition; K2STI: Modified stress tolerance index for stress condition. *,**: significant difference at the 5% and 1% levels of probability, respectively.

drought condition based on the results of non-stress condition was unreliable and inefficient. However, Farshadfar *et al*. (2012) and Ali and El-Sadek (2016) findings revealed that Y_S value was positively correlated with Y_{NS} which means that high-yielding genotypes under normal conditions will also have high production under stress condition.

The Y_{NS} had significant correlation with TOL, STI, GMP, HAM, MP, and K_1STI while SSI, DTE, SDI, DI, RDI, YSI and YI were non-significantly correlated with Y_{NS}. Present results observed no correlation between SSI and yield under non-stressed condition which also in analogy with observations of Ehdaie and Shakiba (1996). However, positive correlation between SSI and Y_{NS} were observed in wheat (Amiri *et al*., 2014), while negative correlation between SSI and Y_{NS} was noted in wheat (Moosovi *et al*., 2008). The negative and non-significant correlation was observed between yield Y_{NS} and YSI, RDI and DTE, whereas a positive and non-significant correlation was observed between Y_{NS} and SSI, SDI, DI, YI and K_2STI. However, Y_S had significant positive correlation with all tolerance indices, except SSI and K_1STI index.

For selection of drought tolerant genotypes, the most suitable indices are those which relatively have significant and positive correlation with yield in stressed and non-stress conditions (Mitra, 2001). Results revealed that yield was significantly and positively correlated with STI, GMP, HM and MP indices under stressed and non-stress conditions. Therefore, these indices could be used as the selection criterion for selecting high yielding genotypes under stressed and normal conditions. In earlier studies, these indices were mostly recommended for screening drought tolerant genotypes with high yield under stressed and non-stress conditions (Jafari *et al*., 2009; Mohammadi *et al*., 2010; Nazari and Pakniat, 2010; Ilker *et al*., 2011). There was positive correlation between Y_{NS} and Y_S, however, in present results the association between these two components was non-significant (Table 5), which revealed that these indices could not be used for drought tolerance study in chilli pepper genotypes (Akcura *et al*., 2011).

Futhermore, results also suggested that with high stress intensity, SSI variable was more suitable to be used as selection criteria whereas STI, GMP, HM, and MP indices are used if the stress conditions are not more severe. Akcura and Ceti (2011) suggested that yield stability index (YSI) can also be used as indicator to differentiate between sensitive and resistant genotypes when the stress conditions are severe. The YSI had a negative correlation with mean yield under non-stress condition referred to drought resistant genotypes (UIN-RFC010, UIN-RFC006, and UIN-GM107). Khayatnezhad *et al*. (2010) explained that none of the tolerance indices could perfectly identify the high yielding genotypes under stressed and non-stress conditions. However, Thiry *et al*. (2016) stated that tolerance indices are not ideal to determine genotypes with best yield and high stress tolerant both environments.

Principal component analysis (PCA) and cluster analysis

To assess the relationship between chili pepper genotypes and drought

Table 6. Principal component analysis for yield under non-stressed (Y_{NS}), stressed (Y_S) environments and other tolerance indices in 55 chili pepper genotypes.

Indices	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Y_{NS}	0.39	-0.03	-0.24	0.15	-0.01	-0.26
Y_S	0.13	0.28	0.06	-0.10	0.10	-0.10
TOL	0.29	-0.18	-0.26	0.20	-0.06	-0.19
SSI	0.39	-0.33	0.45	-0.11	0.08	0.12
STI	0.15	0.24	-0.12	-0.42	0.23	0.17
DTE	0.11	0.28	0.21	0.24	-0.33	0.10
GMP	0.22	0.22	-0.09	-0.4	-0.17	0.04
HM	0.18	0.25	-0.03	-0.43	-0.16	-0.14
SDI	0.39	-0.33	0.45	-0.11	0.08	0.12
DI	0.06	0.27	0.13	0.34	0.44	0.04
MP	0.37	0.11	-0.17	0.07	0.04	-0.25
SSPI	0.29	-0.18	-0.26	0.20	-0.06	-0.19
RDI	0.11	0.28	0.21	0.24	-0.33	0.10
YSI	0.11	0.28	0.21	0.24	-0.33	0.10
YI	0.13	0.28	0.06	-0.10	0.10	-0.10
K1STI	0.24	-0.02	-0.43	0.11	0.02	0.82
K2STI	0.07	0.27	0.09	0.17	0.58	-0.01
Eigen values	24.57	11.04	1.97	0.57	0.4	0.06
Variation (%)	63.58	28.57	5.09	1.49	1.03	0.15
Cumulative Percentage (%)	63.58	92.15	97.24	98.72	99.76	99.91

tolerance indices, the principal component analysis was utilized. The total variation expressed between the two components was 92.15% (Table 6). The first PC explained 63.58% of the total variation and the second PC explained 28.57% of the total variability. The variable that has the highest PCA1 value and the lowest PC2 were found excellent in screening genotype under stress and non-stress conditions. Based on the results of the principal component analysis, the SSI and SDI index have the highest values in PC1 and the lowest values in PC2, so that both indices can be used to screen the drought-tolerant genotypes in present study. The selection of SSI and SDI as criteria for screening the drought resistant genotypes is linked to severe stress intensity. Akcura *et al*. (2011) suggested that only SSI variable can be used as selection criteria when the stress intensity is strong, however, in present study, the two indices (SSI and SDI) could be utilized for screening drought-tolerant genotypes.

The PCA analysis using SSI and SDI indices, explained 97.558% of the total variation, that first PC and the second PC explained 84.71% and 12.85%, respectively (Table 7). Biplot analysis was carried out and utilized to identify the superior chili pepper genotypes in different environments (Figure 1). Fernandez (1992) proposed that chili pepper genotypes can be categorized into four groups based on their performance under stress and non-stress conditions. Genotypes express uniform superiority

Table 7. Principal component analysis for yield under non-stressed (Y_{NS}), stressed (Y_S) environments, SSI and SDI indices in 55 chili pepper genotypes.

Indices	PC 1	PC 2	PC 3	PC 4
Y_{NS}	0.47	0.57	-0.67	0.00
Y_S	0.08	0.73	0.68	0.00
SSI	0.62	-0.26	0.21	-0.71
SDI	0.62	-0.26	0.21	0.71
Eigenvalues	13.38	2.03	0.39	0.00
Variance (%)	84.71	12.85	2.44	0.00
Cumulative Variance (%)	84.71	97.56	100.00	100.00

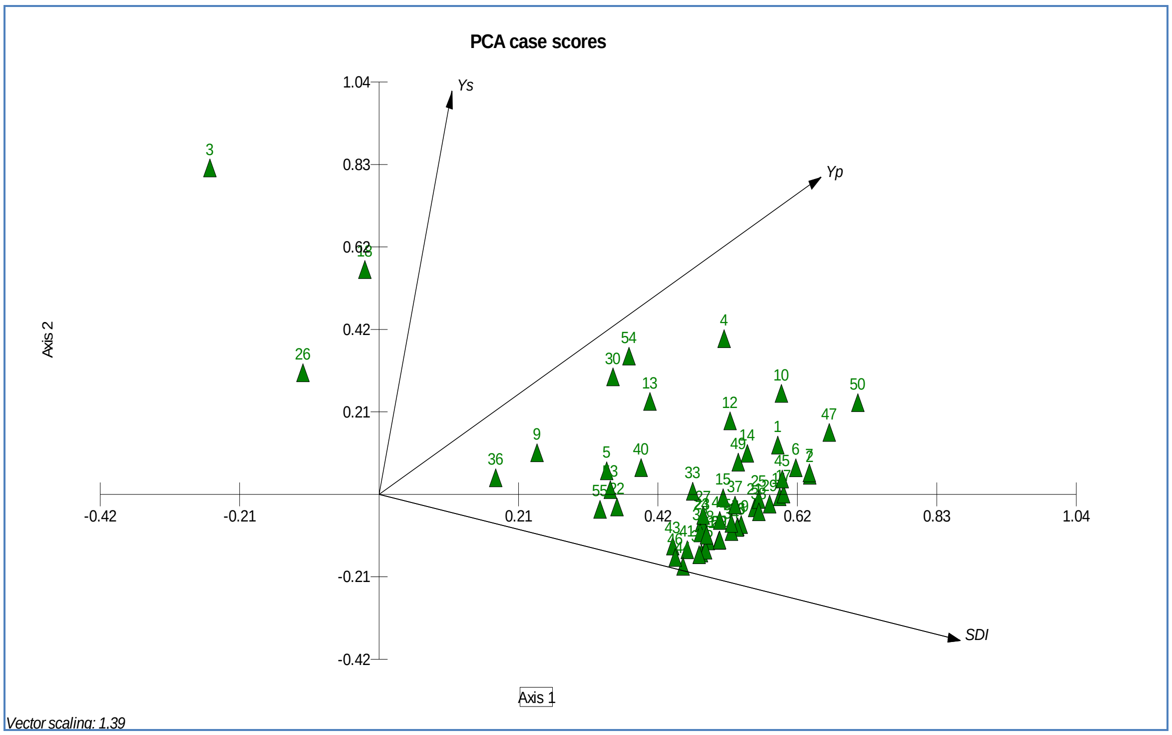

Figure 1. Biplot for quantitative indices of chili pepper genotypes, SSI = Stress Susceptibility index, SDI = Sensitivity Drought Index, Δ: the number of genotypes followed the list in Table 1.

under both stress and non-stress conditions (Group A), genotypes perform favorably only in non-stress conditions (Group B), genotypes gives relatively higher yield only in stress conditions (Group C), and cultivars perform poorly under stress and non-stress conditions (Group D). Based on biplot analysis, the chili pepper genotypes UIN-RFC010, UIN-GM107, and UIN-RFC006 were classified into group C (drought tolerant genotype) with high yield under stress condition, while other genotypes were placed in groups A and B.

Dendrogram analysis divided all the genotypes into three groups (Figure 2). The first cluster (drought tolerant group) comprising three chili pepper genotypes i.e. UIN-RFC010, UIN-GM107, and UIN-RFC006, second cluster (semi-tolerant or semi-sensitive genotypes) consisted of 11 other genotypes viz., UIN-RFC011, UIN-RFC015, UIN-GK065M, UIN-RFC002, UIN-GM102, UIN-GK073, UIN-GK071, UIN-RFC019, UIN-RFC014, UIN-GK072, and UIN-GK098, while rest of the genotypes classified into third cluster (susceptible to drought). Based on findings of El-Mohsen *et al*. (2015) regarding cluster analysis, genotypes were divided into three groups i.e. tolerant, semi-tolerant and susceptible. Cluster analysis has been generally used for grouping genotypes based on tolerance indices.

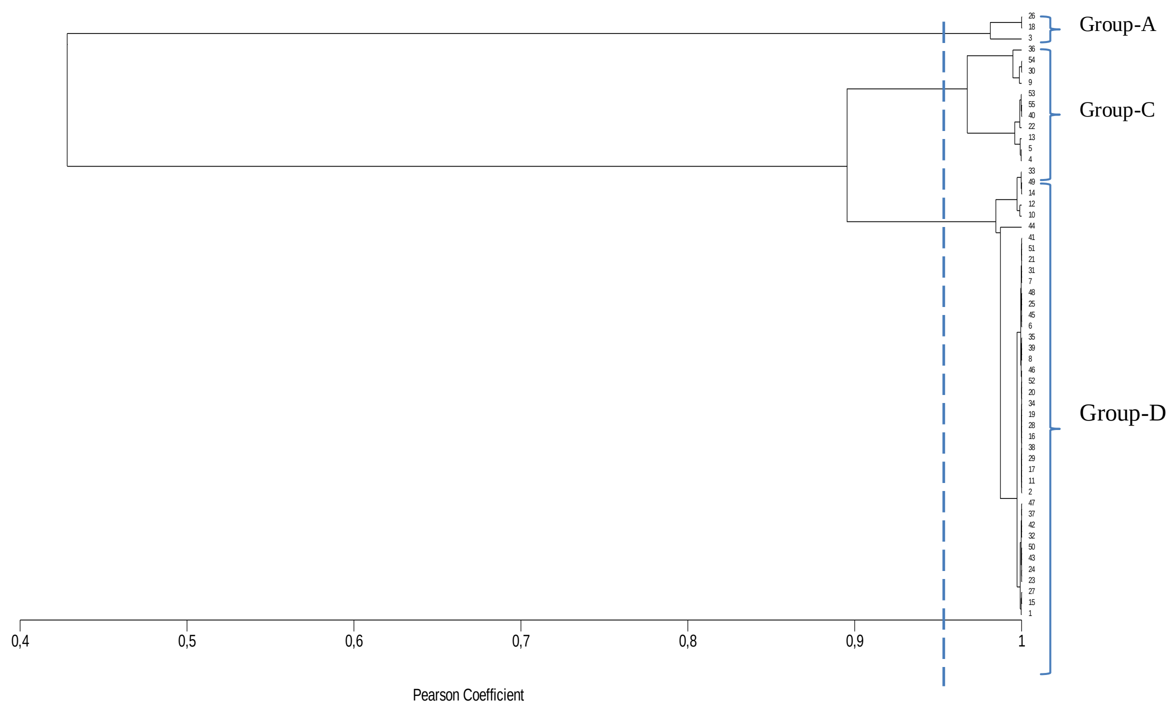

Figure 2. Dendogram UPGMA method to classification of chili pepper genotypes based on tolerance indices. The number of genotypes followed the list in Table 1.

CONCLUSION

Present findings revealed that SSI and SDI indices could be used as a potential indicators for selection in chili pepper with severe stress conditions. Biplot and clustering analyses can divide genotypes into tolerant, semi-tolerant and sensitive to drought. Based on biplot and cluster analyses, the three chili pepper accessions viz., UIN-RFC010, UIN-GM107 and UIN-RFC006 were identified as drought tolerent genotypes.

ACKNOWLEDGEMENT

The authors would like to thank to Educational Fund Management Board (LPDP), Ministry of Finance, Republic of Indonesia, for funding this research project with contract number of PRJ-4576/LPDP.3/2016.

REFERENCES

Ahmed AF, Yu H, Yang X, Jiang W (2014). Deficit irrigation affects growth, yield, vitamin C content, and irrigation water use efficiency of hot pepper grown in soilless culture. *Hort. Sci*. 49(6):722–728.

Agili S, Nyenda B, Ngamau K, Masinde P (2012). Selection, yield evaluation, drought tolerance indices of orange-flesh sweet potato (*Ipomoea batatas* Lam) hybrid clone. *J. Nutr. Food Sci*. 2:1-8

Ali MB, El-Sadek AN (2016). Evaluation of drought tolerance indices for wheat (*Triticum aestivum* L.) under irrigated and rainfed conditions. *Commun. in Biomet*. *Crop Sci*. 11:77–89.

Aliakbari M, Razi H, Kazemeini SH (2014). Evaluation of drought tolerance in rapeseed (*Brassica napus* L.) cultivars using drought tolerance indices. *Int. J. Adv. Biol. Biomet. Res*. 2:696-705

Ahmadizadeh M, Valizadeh M, Shahbazi H, Nori A (2012). Behavior of durum wheat genotypes under normal irrigation and drought stress conditions in the greenhouse. *Afr. J. Biotechnol*. 11:1912-1923.

Akcura M, Partigoc F, Kaya Y (2011). Evaluating of drought stress tolerance based on selection indices in Turkish bread wheat landraces. *J. Anim. Plant Sci*. 21:700-709.

Amiri R, Bahraminejad S, Sasani SH, Ghobadi (2014). Genetic evaluation of 80 irrigated Bread Wheat genotypes for drought tolerance indices. *Bulg. J. Agric. Sci*. 20: 101-111.

Bidinger FR, Mahalakshmi V, Rao GDP (1978). Assessment of drought resistance in millet factors effecting yields under stress. *Aust. J. Agric. Res*. 38:37-78.

Blum A (1996). Crop responses to drought and the interpretation of adaptation. *Plant Growth Regul*. 20:135-148

Bonea D, Urechean V (2011). The evaluation of water stress in maize (*Zea mays* L.) using selection indices. *Rom. Agric. Res*. 28:79-86.

Bouslama M, Schapaugh WT (1984). Stress tolerance in soybeans. I. Evaluation of three screening techniques for heat and drought tolerance. *Crop Sci*. 24:933–937.

Bruckner PL, Frohberg RC (1987). Stress tolerance adaptation in spring wheat. *Crop Sci*. 27:31-36.

Chutia J, Borah SP (2012). Water stress effects on leaf growth and chlorophyll content but not the grain yield in traditional rice (*Oryza sativa* Linn.) genotypes of Assam, India II. Protein and proline status in seedlings under PEG induced water stress. *Am. J. Plant Sci*. 3:971–980

Dehbalaei S, Farshadfar E, Farshadfar M (2013). Assessment of drought tolerance in bread wheat genotypes based on resistance/tolerance indices. *Int. J. Agri. Crop Sci*. 5: 2352-2358.

Dejan D, Miroslav Z, Desimier K, Stephen RK, Gordana SM (2008). Genotype x environment interaction for wheat yield in different drought stress conditions and agronomic traits suitable for selection. *Aust. J. Agric. Res*. 59:536-545.

Ehdaie B, Shakiba MR (1996). Relationship of internode-specific weight and water soluble carbohydrates in wheat. *Cereal. Res. Commun*. 24: 61-67.

El-Mohsen AAA, El-Shafi MAA, Gheith EMS, Suleiman HS (2015). Using different statistical procedures for evaluating drought tolerant indices of bread wheat genotypes. *Adv. Agric. Biol*. 4:19-30

Farshadfar E, Elyasi P, Jamshidi B, Chaghakabodi R (2012). Effective selection criteria for screening drought tolerant landraces of bread wheat (*Triticum aestivum* L.). *Ann. Biol. Res*. 3: 2507-2516.

Farshadfar E, Sutka J (2002). Screening drought tolerance criteria in maize. *Acta Agron. Hung*. 50:411–416.

Farshadfar E, Javadinia J (2011). Evaluation of chickpea (*Cicer arietinum* L.) genotypes for drought tolerance. *Seed Plant Improv. J*. 27:517–537.

Fernandez GCJ (1992). Effective selection criteria for assessing stress tolerance. In: Kuo CG (Ed) Proceedings of the International Symposium on Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress. Tainan, Taiwan.

Fischer RA, Maurer R (1978). Drought resistance in spring wheat cultivars. I. Grain yield responses. *Crop Pasture Sci*. 29:897–912.

Fishers RA, Wood T (1981). Drought resistance in spring wheat cultivar III. Yield association with morphological traits. *Aust. J. Agric. Res*. 30:1001-1020.

Fleury D, Fefferies S, Kuchel H, Langridge P (2010). Genetic and genomic tools to improve drought tolerance in wheat. *J. Exp. Bot*. 61:3211-3222.

Gavuzzi P, Rizza F, Palumbo M, Campanile RG, Ricciardi GL, Borghi B (1997). Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. *Can. J. Plant Sci*. 77:523–531.

Golabadi M, Arzani ASAM, Maibody M (2006). Assessment of drought tolerance in segregating populations in durum wheat. *Afr. J. Agric. Res*. 1:162-171

Gonzalez-Dugo V, Orgaz F, Fereres E (2007). Responses of pepper to deficit irrigation for paprika production. *Sci. Hortic.* 114:77-82.

Ilker E, Tatar O, Aykut TF, Tosun M and Turk J (2011). Determination of tolerance level of some wheat genotypes to post-anthesis drought. *Turk. J. Field Crops* 16:59-63.

Jafari A, Paknejad F, Al-Ahmadi MJ (2009). Evaluation of selection indices for drought tolerance of corn (*Zea mays* L.) hybrids. *Int. J. Plant Prod*. 3:33-38.

Jager K, Fabian A, Barnabas B (2008). Effect of water deficit and elevated on pollen development of drought sensitive and tolerant winter wheat (*Triticum aestivum* L.) genotypes. *Acta. Biol. Szeged*. 52:67-71.

Johnson RA, Winchern DW (2007). Applied Multivariate Statistical Analysis. New Jersey: Prentice Hall.

Khan IM, Dhurve OP (2016). Drought response indices for identification of drought tolerant genotypes in rainfed upland rice (*Oryza sativa* L.). *Int. J. Sci. Environ. Technol*. 5:73–83

Khayatnezhad M, Zaeifizadeh M, Gholamin R (2010). Investigation and selection index for drought stress. *Aust. J. Basic. Appl. Sci*. 4:4815-4822

Kumar S, Dwivedi SK, Singh SS, Jha K, Lekshmy S, Elanchezhian R, Singh ON, Bhatt BP (2014). Identification of drought tolerant rice genotypes by analysing drought tolerance indices and morpho-physiological traits. *SABRAO J. Breed. Genet*. 46:217-230.

Lan J (1998). Comparison of evaluating methods for agronomic drought resistance in crops. *Acta. Agricult. Bor. Occid. Sinic*. 7:85–87.

Mardaninejad S, Tabatabaei SH, Pessarakli M, Zareabyaneh H (2017). Physiological responses of pepper plant (*Capsicum annuum* L.) to drought stress. *J. Plant Nutr*. 40:1453-1464.

Mardeh ASS, Ahmadi A, Poustini K, Mohammadi N (2006). Evaluation of drought resistance indeces various environmental conditions. *Field Crop. Res*. 98:222-229

Mitra J (2001). Genetic and genetic improvement of drought resistance in crop plants. *Curr. Sci*. 80:758-762

Mohammadi R, Armion M, Kahrizi D, Amri A (2010). Efficiency of screening techniques for evaluating durum wheat genotypes under mild drought conditions. *Int. J. Plant Prod*. 4:11-24.

Moosavi SS, Samadi BY, Naghavi MR, Zali AA, Dashti H, Pourshahbazi A (2008). Introduction of new indices to identify relative drought tolerance and resitance in wheat genotypes. *Desert* 12:165-178

Naghavi MR, Pour-Aboughadareh AR, Khalili M (2013). Evaluation of drought tolerance indices for screening some of corn (*Zea mays* L) cultivars under environmental conditions. *Not. Sci. Biol*. 5:388-393.

Nazari L, Pakniyat H (2010). Assessment of drought tolerance in barley genotypes. *J. Appl. Sci*. 10:151-156.

Prakash V (2007). Screening of wheat (*Triticum aesticum* L.) genotypes under limited moisture and heat stress environments. *Indian J. Genet*. 67:31-33.

Raman A, Verulkar S, Mandal NP, Varrier M, Shukla VD, Dwivedi JL, Singh BN, Singh ON, Swain P, Mall AK, Robin S, Chandrababu R, Jain A, Ram TR, Hittalmani S, Haefele S, Piepho HS, Kumar A (2012). Drought yield index to select high yielding rice lines under different drought stress severities. *Rice* 5:1-12.

Razak AA, Ismail MR, Karim MF, Wahab FEM, Abdullah SN, Kausar H (2013). Changes in leaf gas exchange, biochemical properties, growth and yield of chilli grown under soilless culture subjected to deficit fertigation. *Aust. J. Crop Sci*. 7:1582–1589

Richards RA (1996). Defining selection criteria to improve yield under drought. *Plant Growth Regul*. 20:157-166.

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

Rosmaina, Sobir, Parjanto, Yunus A (2018). Selection criterias development for chili pepper under different field water capacity at vegetative stage. *Bulg. J. Agric. Sci*. 24: 80–90.

Schneider KA, Rosales-Serna R, Ibarra-Perez F, Cazares-Enriquez B, Acosta-Gallegos JA, Ramirez-Vallejo P, Wassimi N, Kelly JD (1997). Improving common bean performance under drought stress. *Crop Sci*. 37:43–50.

Subhani GM, Abdullah, Ahmad J, Anwar J, Hussain M, Mahmood A (2015). Identification of drought tolerant genotypes of barley (*Hordeum vulgare* L.) through stress tolerance indices. *J. Anim. Plant Sci*. 25:686-692.

Talebi R, Fayaz F, Naji AM (2009). Effective selection criteria for assessing drought stress tolerance in durum wheat (*Triticum durum* desf.). *Gen. Appl. Plant Physiol*. 35:64-74.

Thiry AA, Bulanto PNC, Reynolds MP, Davies WJ (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. *J. Exp. Bot*. 67:5593-5603.

Wadhwa R, Kumari N, Sharma V (2010). Varying light regimes in naturally growing *Jatropha curcus*: pigment, proline and photosynthetic performance. *J. Stress Physiol. Biochem*. 6:67–80

Yasir TA, Chen X, Tian L, Condon AG, Yin GH (2013). Screening of Chinese bread wheat genotypes under two water regimes by various drought tolerance indices. *Aust. J. Crop Sci*. 7:2005-2013

Zangi MR (2005). Correlation between drought resistance indices and cotton yield in stress and non-stress conditions. *Asian J. Plant Sci*. 4:106-108.

Zare M (2012). Evaluation of drought tolerance indices for the selection of Iranian barley (*Hordeum vulgare*) cultivars. *Afr. J. Biotechnol*. 11:15975-15981.