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Response of morpho-physiological traits to drought stress and screening of curly pepper (*Capsicum annuum*) genotypes for drought tolerance

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Abstract. *Rosmaina, Ridho A, Zulfahmi. 2022. Response of morpho-physiological traits to drought stress and screening of curly pepper (*Capsicum annuum*) genotypes for drought tolerance. Biodiversitas 23: 5469-5480.* Developing drought-tolerant genotypes are required to face drought condition that often occurs. The study aimed was to assess the growth, biomass, yield traits, and gas exchange of fifteen curly pepper (*Capsicum annuum* L.) genotypes under normal and drought-stress conditions and to determine the key traits as indicators for selecting and identifying the drought-tolerant curly pepper genotypes. Fifteen curly pepper genotypes were cultivated under normal and drought-stress conditions. Twenty-one morphological and physiological traits were recorded in the reproductive phase. The data obtained were subjected to analysis of variance, Principal Component Analysis (PCA), and UPGMA dendrogram cluster analysis. This study showed that drought stress conditions significantly reduced plant growth, biomass, yield characters, photosynthesis rate, stomatal conductance, transpiration rate, and mesophyll conductance compared to normal conditions. Based on PCA analysis, stomatal limitation, mesophyll and stomatal conductances, root length, photosynthesis rate, fruit weight per plant, chlorophyll b, number of fruit, and transpiration rate were established as indicators for screening drought tolerant genotypes. The UIN-70 and UIN-65 were highly drought-tolerant genotypes according to the MFVD index. UPGMA dendrogram displayed clustering of the curly pepper genotypes consistent with the genotype's cluster based on the MFVD index. This study's findings can be utilized to improve curly pepper's drought tolerance in the future.

Keywords: *Capsicum annuum*, drought tolerance, gas exchange, growth, memberships function value of drought tolerance

INTRODUCTION

Curly pepper (*Capsicum annuum* L.) is one of the horticultural crops economically important in the world after tomatoes. Curly pepper is often consumed as fresh, dried, or processed products, as vegetables, and as a condiment. Its fruits also contain several chemical compounds that are utilized as drugs, such as anti-inflammatory (Zimmer et al. 2012), antimicrobial (Omolo et al. 2014), antiviral (Marini et al. 2015), antioxidant, and anticancer (Batiha et al. 2020). The *C. annuum* has been cultured in sub-tropical and tropical areas and was frequently exposed to abiotic and biotic stresses as an impact of ongoing climate change.

Drought stress is one of the abiotic factors that influence crops' physiological metabolism, growth, and yield. Some researchers reported that drought stress-induced stomatal closure, reduced transpiration, increased oxidative stress, interfered with photosynthesis, and changed chlorophyll contents (Ying et al. 2015; Liu et al. 2017; Li et al. 2017; Nemeskéri and Helyes 2019; Almuwayhi 2021). The morphology changes of curly pepper also occurred during drought stress, such as reduced plant growth, flower abortion, declined biomass, and yield (Mardani et al. 2017; Rosmaina et al. 2018; Widuri et al. 2020). The magnitude of drought stress impact on the crops' morpho-physiological depends on genotypes species, crop development stages, stress intensity, and stress duration (Saeidi and Abdoli 2015; Rosmaina et al. 2018). Meanwhile, the plant adaptation strategies to drought stress conditions included drought tolerance, drought avoidance, and drought escape (Farooq et al. 2012).

Local genotypes of curly pepper are a potential genetic resource that can be utilized to develop the drought-tolerant curly pepper in the future. Therefore, a reliable and extensive assessment of the morpho-physiological of the curly pepper genetic resource under drought stress conditions is needed to know the response of each genotype, establish indicators for the selection of drought tolerance, and identify drought-tolerant genotypes. In addition, plant morpho-physiological properties are pivotal for selection in breeding programs to increase drought tolerance because many morpho-physiological traits are interrelated with drought resistance.

Many researchers determined the drought tolerance of the crops only based on yield character. Then it was analyzed with several tolerance indices, such as stress susceptibility index (SSI), stress tolerance (TOL), geometric mean productivity (GMP), stress tolerance index (STI), yield index (YI), yield stability index (YSI), harmonic mean (HM), relative drought index (RDI), stress susceptibility percentage index (SSPI), and another index (Rosmaina et al. 2019a; Mau et al. 2019; Shahrokhi et al. 2020; Sánchez-Reinoso et al. 2020). However, the mechanism of drought tolerance in the crops is complicated and polygenic traits; thus, utilization of a single character cannot perfectly and accurately assess the plant drought tolerance because a single character only reflects the sensitivity of the particular character to drought stress and undescribed the overall performance of the crops under drought stress conditions. To overcome this weakness, a comprehensive index is required to incorporate multiple characters together for drought tolerance assessment. The memberships function value of drought tolerance (MFVD) is a multivariate index that is often used to comprehensively evaluate drought tolerance of crops such as wheat (Chen et al. 2012), soybean (Yan et al. 2020), cotton (Sun et al. 2021), and canola (Wang et al. 2021). This index effectively separated the genotypes into the degree of drought tolerance. This study aimed to assess the growth, biomass, yield, and gas exchange parameters of the fifteen curly pepper genotypes under drought stress and normal conditions, to identify the main character as an indicator for selecting curly pepper drought tolerance, and to determine the drought-tolerant genotypes of curly pepper for the future breeding program.

MATERIALS AND METHODS

Plants material and experimental design

A total of 15 curly pepper genotypes were used in this study. All genotypes originated from the landraces in Riau Province, Indonesia. The experiments were conducted in the greenhouse at the Faculty of Agriculture and Animal Sciences, Universitas Islam Negeri Sultan Syarif Kasim Riau, Indonesia (latitude 0º28’6” N, longitude 101º21’4” E, and altitude 15 m.asl) in which an average of relative humidity and day temperature was 80-90% and 32-33ºC, respectively. Seeds of each genotype were sown on the tissue paper, and after two weeks, germinated seeds were transferred into small polybags and maintained in the greenhouse. After one month, the seedlings were transferred into a big polybag (height and diameter sizes were 35 cm and 30 cm, respectively) containing sand and compost mix with a ratio of 1: 3 (v/v). The soil moisture for all polybags was kept at 100% of field capacity (FC) until four weeks after transplanting. Each polybag was supplied with NPK compound fertilizer containing N (16%), P_2O_5 (16%), and K_2O (16%) with doses of 0.50 g/polybag/week for eight weeks.

This experiment was assigned a two factors treatment design laid out in a completely randomized design with four replicates for each treatment unit. Two treatments of water regimes were applied, namely, normal conditions (NC) and drought stress conditions (DS). The soil water content of normal conditions was kept at 100% field capacity, while drought stress conditions were maintained at 43% field capacity. The selection of 43% field capacity in this study was based on a previous study by Rosmaina et al. (2018) that found a critical threshold of 50% reduction in the yield of curly pepper when drought stress was applied at the flowering stage. Fifteen genotypes of curly pepper were used in this experiment. Each treatment consisted of four polybags, and each polybag contained one plant as a replication and was placed randomly. The soil field capacity was determined before the experiment, and then the weight of the polybag and water for each treatment (the weight of the plant is ignored) was calculated. The polybags were weighed daily to maintain the soil moisture at the target weight by re-watering them. Drought stress was conducted at the beginning of the flowering stage for two months.

Observation of growth, biomass, and yield variables

Observed variables included plant height, stem diameter, root length, root width, shoot fresh weight, shoot dry weight, fresh root weight, root dry weight, number of fruits, and fruit weight per plant. Each genotype from well-watered and water deficit treatments was uprooted carefully. The roots were cleared of adhered soil particles. The roots and shoots were detached for fresh weight (RFW and SFW, respectively) determination and then entered in the oven at 85ºC for 48 hours till constant weights and noted the root dry weight (RDW) and the shoot dry weight (SDW).

Measurement of chlorophyll content

Determining chlorophyll a and b contents followed Arnon's (1949) methods. The chlorophyll contents were calculated using formula as follows: chlorophyll a (mg/g) = [12.7 × (OD663) - 2.67 × (OD645)] x VE/1000 x WFL, and chlorophyll b (mg/g) = [22.9 × (OD645) - 4.68 × (OD663)] x VE/1000 x WFL, where OD = optical density, VE = volume of extract, and WFL = weight of fresh leaves

Gas exchange parameters measurement

Photosynthesis rates (Pr), stomatal conductance (gs), transpiration rate (Tr), intercellular CO_2 concentration (Ci), and the ratio of intercellular CO_2 concentration and intracellular CO2 concentration (Ci/Ca) were measured using a LICOR Infra-Red Gas Analyser IRGA, LI-6400 XT (LI-COR Inc., Lincoln, NE, USA). Gas exchange was measured at the end of the generative phase. The fourth youngest fully expanded leaves from the apex of each plant were used for gas exchange parameter measurements. Gas exchange parameters were measured on a clear sunny between 10:00 a.m-1:00 p.m., and environmental parameters under natural conditions (natural light source; uncontrolled CO_2 concentration and humidity). In addition, the intrinsic water use efficiency (iWUE) was calculated according to the ratio between photosynthesis rates and stomatal conductance (iWUE = Pr/gs) following Medrano et al. (2015), and mesophyll conductance (gm) was determined based on the ratio between the rates of photosynthesis and intercellular CO_2 concentration (gm = Pr/Ci) following Brito et al. (2014), as well as the stomatal limitation (Ls) was calculated using the following formula: 1-(Ca/Ci) (HaiJun and KunMing 2012).

Data analysis

The data obtained were subjected to analysis of variance and Duncan's multiple range post hoc test performed using SAS statistical software version 9.1. The drought tolerance of each genotype was evaluated by the drought tolerance coefficient (DC) and membership function values of drought tolerance (MFVD). Each genotype's morphological and physiological traits data were converted into drought tolerance coefficient. The drought tolerance coefficient was the ratio between the average value of a single character under drought treatment and the mean of a single character under the control treatment in the same genotype (Wang et al. 2021). The DC data were analyzed using principal component analysis (PCA), which employed SAS statistical software version 9.1. UPGMA dendrogram was constructed based on the drought tolerance coefficient using NTSYS software version.2.01.

The membership function values of drought tolerance (MFVD) (Chen et al. 2012) were calculated as follows :

$$G_{ij} = \frac{DC_{ij} - DC_{jmin}}{DC_{jmax} - DC_{jmin}}$$

$$Gi = \frac{1}{n}\sum_{i=1}^{n} G_{ij}$$

Where G_{ij} is the membership function value of the j-th character for i-th genotype for drought tolerance, DC_{ij} is the drought tolerance coefficient of the j-th character for i-th genotype, DC_{jmin} is the minimum value of the drought tolerance coefficient of the j-th character, and DC_{jmax} is the maximum value of drought tolerance coefficient of the j-th character, G_i is the average membership function values of drought tolerance of all the target traits for the genotype. Drought tolerance of chili pepper genotypes was classified into five categories based on the average value ($\bar{G}$) and standard deviation (SD) of MFVD. The level and category of drought tolerance are exhibited in Table 1.

RESULTS AND DISCUSSION

Response of plant growth, biomass and yield

The results of variance analysis showed that the genotypes and stress conditions highly significantly affected all morphological traits (Table 2). Furthermore, the interaction effect between genotypes and stress conditions was highly significant on all morphological traits except for root length and width. Similar results were reported by Rosmaina et al. (2018) that genotype factor and water stress factor had a significant effect on all morphological traits of the chili pepper tested, whereas Budiyati et al. (2017) found that the interaction of genotypes factor and water-stressed factor significantly affected the shoot dry weight, fruit number, and fruit weight.

The reduction of morphology traits of each genotype is displayed in Table S1. The reduction in plant height varied among genotypes; UIN-66 exhibited the minimum decrease (8.44%), and the maximum decrease was observed in UIN-73 (50.32%). The maximum reduction in stem diameter was found in UIN-72 (46.98%), and the minimum reduction was noted in UIN-66 (24.81%). The highest root length reduction was observed in UIN-70 (40.23%), and the lowest root length reduction was found in UIN-57 (1.08%). The highest reduction of dry shoot weight occurred in UIN-055 (78.97%), and the lowest reduction was observed in UIN-64 (43.49%). UIN-64 and UIN-59 genotypes exhibited the lowest and the highest reduction of root dry weight, respectively. The number of fruits reduced from 36.12% in UIN-72 to 100% in UIN-55 and UIN-70. The highest reduction in fruit weight per plant was found in UIN-055 and UIN-070 (100%), and the lowest reduction was observed in UIN-072 (42.53%).

Plant height, stem diameter, root length, root width, shoot fresh weight, shoot dry weight, fresh root weight, root dry weight, the number of fruit, and fruit weight per plant were significantly decreased under drought stress conditions compared with the normal conditions (Table 3). The highest reduction was observed in fruit weight per plant (86.14%), followed by the number of fruit (82.48%), and the root length had the lowest reduction (13.64%).

This study results are consistent with Budiyati et al. (2017), who reported that drought stress significantly reduced the growth, biomass, and yields in several varieties of red curly. Furthermore, a significant decrease in plant height and stem diameter under drought stress compared to control treatment was also reported by Pérez-Gutiérrez et al. (2017) in *Capsicum chinense* Jacq. and Phimchan et al. (2012) in some cultivars of hot pepper. The reduction in plant height and stem diameter under drought stress could be caused by the loss or reduction of water from the protoplasm, which contributes to reduced cell turgor pressure and cell division (Mehraban et al. 2018). In addition, drought stress also disrupts the process of mitosis and cell elongation resulting in poor plant growth (Fahad et al. 2017). Furthermore, Baccari et al. (2020) explained that poor water flow from the xylem to surrounding cells caused inhibiting cell elongation.

Table 1. Level and categories of drought tolerance of curly pepper genotypes based on $\bar{G}$ and SD of MFVD

Level	G	Categories
1	$G_i \geq \bar{G}$ + 1.64SD	Highly drought tolerant
2	$\bar{G}$ + SD $\leq G_i < \bar{G}$ + 1.64SD	Drought tolerant
3	$\bar{G}$ - SD $\leq G_i < \bar{G}$ + SD	Moderate drought tolerant
4	$\bar{G}$ - 1.64SD $\leq G_i < \bar{G}$ - SD	Susceptible
5	$G_i < \bar{G}$ - 1.64 SD	Highly susceptible

Table S1. Growth, biomass, and yield parameters under normal and drought stress conditions of curly pepper genotypes

Genotypes	EC	PH	SD	RL	RW	SFW	SDW	RFW	RDW	NF	FWPP
UIN-41	NC	124.50	11.74	51.50	19.50	648.00	217.98	116.50	83.75	62.59	101.8
	DS	74.00	7.33	54.33	11.67	194.43	60.89	20.20	11.54	10.63	5.41
	% R	40.56	37.56	-5.50	67.14	70.00	72.07	82.66	86.22	83.01	94.69
UIN-48	NC	178.50	12.34	33.00	29.50	485.00	166.76	80.47	48.27	66.00	36.18
	DS	112.67	7.61	37.33	12.89	180.80	47.96	13.68	6.59	16.48	3.15
	% R	36.88	38.33	-13.1	56.31	62.72	71.24	83.00	86.34	75.03	91.29
UIN-52	NC	107.50	10.54	43.00	12.50	242.00	88.67	36.28	16.33	23.76	11.01
	DS	90.67	7.48	39.67	8.83	155.65	50.17	10.97	6.60	6.96	2.96
	% R	15.66	29.03	7.75	41.51	35.68	43.42	69.77	59.57	70.72	73.12
UIN-55	NC	100.00	10.43	53.50	19.50	667.00	250.5	63.14	34.50	29.35	8.70
	DS	89.00	6.72	33.67	12.83	132.40	52.69	10.95	6.11	0.00	0.00
	% R	11.00	35.57	37.07	51.95	80.14	78.97	82.65	82.29	100.00	100.00
UIN-57	NC	109.00	9.33	15.50	20.00	318.00	107.90	20.98	13.24	56.54	204.38
	DS	83.67	6.36	15.33	11.33	112.38	41.66	4.66	2.97	7.61	7.38
	% R	23.24	31.83	1.08	76.47	64.66	61.39	77.80	77.57	86.54	96.39
UIN-58	NC	127.50	10.81	51.00	20.00	516.00	202.14	127.28	88.54	30.32	20.00
	DS	87.67	7.28	32.00	10.17	159.37	59.96	14.01	7.40	6.96	0.95
	% R	31.24	32.66	37.25	96.72	69.11	70.34	88.99	91.64	77.04	95.25
UIN-59	NC	116.00	9.95	33.00	19.00	514.00	153.18	81.55	41.49	64.00	296.95
	DS	75.33	6.83	19.83	8.00	144.3	41.64	5.30	3.47	12.79	16.62
	% R	35.06	31.36	39.90	137.5	71.93	72.82	93.50	91.65	80.02	94.40
UIN-64	NC	109.00	9.30	40.00	14.25	244.96	104.56	10.87	8.35	32.32	72.40
	DS	86.33	7.17	35.67	10.83	117.92	59.09	17.67	7.75	2.12	3.00
	% R	20.80	22.90	10.83	31.54	51.86	43.49	-62.53	7.15	93.45	95.86
UIN-65	NC	93.00	10.45	41.50	16.00	339.00	105.06	16.67	8.29	59.78	181.29
	DS	75.67	6.74	35.67	12.17	108.64	54.54	16.78	6.48	11.99	27.34
	% R	18.63	35.50	14.06	31.51	67.95	48.09	-0.66	21.83	79.94	84.92
UIN-66	NC	75.00	10.68	44.50	24.75	281.00	109.23	51.94	36.68	85.04	352.76
	DS	68.67	8.03	43.33	15.00	136.14	49.53	22.51	9.09	27.69	24.10
	% R	8.44	24.81	2.62	65.00	51.55	54.66	56.66	75.23	67.44	93.17
UIN-67	NC	68.50	9.19	19.50	15.00	317.00	111.67	18.11	11.02	56.06	106.78
	DS	53.67	6.30	28.33	13.17	137.88	38.96	5.79	2.83	3.33	2.37
	% R	21.65	31.45	-45.3	13.92	56.50	65.11	68.03	74.29	94.05	97.78
UIN-70	NC	144.00	14.33	29.00	14.00	542.00	132.07	40.84	32.39	22.45	74.58
	DS	112.67	8.06	17.33	9.00	102.64	32.52	8.85	3.76	0.00	0.00
	% R	21.76	43.75	40.23	55.56	81.06	75.38	78.34	88.38	100	100.00
UIN-71	NC	77.00	9.80	29.00	8.50	110.00	37.64	18.79	8.09	78.57	71.80
	DS	63.00	6.70	26.33	8.10	100.73	21.09	5.89	1.82	42.68	26.93
	% R	18.18	31.63	9.20	4.94	8.43	43.97	68.64	77.54	45.68	62.49
UIN-72	NC	140.00	14.05	35.00	20.50	263.00	131.38	52.54	20.3	60.80	189.37
	DS	84.67	7.45	27.00	9.17	121.21	45.59	10.84	5.53	38.40	108.83
	% R	39.52	46.98	22.86	55.27	53.91	65.30	79.37	72.76	36.12	42.53
UIN-73	NC	102.00	11.87	25.50	15.00	370.00	100.15	30.47	9.68	57.61	47.12
	DS	50.67	7.35	24.50	10.33	96.14	27.71	5.08	2.48	36.67	16.89
	% R	50.32	38.08	3.92	45.16	74.02	72.33	83.32	74.35	36.35	64.16

Table 2. Summary of analysis of variance for the effect of stress conditions, genotypes, and the interaction between stress conditions and genotypes on morphological traits

Variation source	df	Mean of squares									
		PH	SD	RL	RW	SFW	SDW	RFW	RDW	NF	FWPP
S	1	17161.86 **	263.39 **	440.05 *	873.78 **	1189240.7 ***	142548.45 **	28153.58 **	11337.77 **	57845.34 **	187073.7 ***
G	14	2376.79 ***	4.90 ***	495.99 **	51.41 **	38319.40 ***	4749.14 ***	1798.71 ***	935.18 ***	11774.45 **	16807.22 **
S*G	14	413.00 *	1.96 *	80.51 ns	22.28 ns	27185.08 ***	2906.68 **	1472.85 ***	728.36 ***	6736.28 **	11553.23 **

Note: SOV: Source of variance, S: stressed treatment, G: Genotypes, S*G: interaction between stressed condition and genotypes, df: degree of freedom, PH: plant height, SD: stem diameter, RL: root length, RW: root width, SFW: shoot fresh weight, SDW: shoot dry weight, RFW: root fresh weight, RDW: root dry weight, NF: number of fruit, FWPP: fruit weight per plant. ns : not significant; *,**, and ***: significant at $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$, respectively

Table 3. Mean values and percentage reduction of morphological traits under control and drought stress conditions

Traits	Conditions		Reduction (%)
	Control	Drought	
Plant height (cm)	111.43a	80.56b	27.70
Stem Diameter (mm)	10.99a	7.16b	34.85
Root length (cm)	36.30a	31.35b	13.64
Root width (cm)	17.87a	10.90b	39.00
Shoot fresh weight (g)	390.46a	133.38b	65.84
Shoot dry weight (g)	134.59a	45.60b	66.12
Root fresh weight (g)	51.10a	11.55b	77.40
Root dry weight (g)	30.73a	5.63b	81.68
Number of Fruit	68.73a	12.04b	82.48
Fruit weight per plant (g)	118.34a	16.40b	86.14

One of the plant adaptation strategies under drought stress conditions is to increase root length. Plants extend their roots to find water sources to avoid dehydration (Zhan et al. 2015). However, the effects of drought stress on the root length and width in this study has not been consistent. Some studies reported an increase in root length under drought stress compared to well-watered conditions (Baccari et al. 2020; Chun et al. 2021). Other studies, on the other hand, reported no significant difference in root length between plants exposed and not exposed to drought stress conditions (Mustikarini et al. 2022). The decrease in root length under drought stress conditions is caused by a decline in both cell division and cell expansion (Yusuf and Hamed 2021) and limited distribution of assimilate to root organs, resulting in shorter root length.

Drought stress also generated a negative effect on plant biomass. Drought-induced inhibition of the development of root and shoot of curly pepper, thus, negatively affected shoot and root biomass (Table 3). Significant differences in shoot dry weight and root dry weight between stressed and control plants indicated that drought stress has inhibited plant growth and reduced assimilate production in the tested curly peppers. Evidence also shows that drought stress reduces dry matter in curly peppers (Okunlola et al. 2017; Widuri et al. 2020). Many researchers stated that drought tolerance genotypes have a small decline in dry weight under drought stress conditions (Ahmed et al. 2020). In our study, UIN-064 showed a small decline in dry weight under drought-stress conditions compared to normal conditions, so this genotype is drought-tolerant. A significant reduction in fruit weight per plant was observed in drought-stress treatment (Table 3). Our results are consistent with previous reports (Phimchan et al. 2012). Reduction in yield under drought stress conditions might be due to many factors, including increased pollen sterility (Rosmaina et al. 2019b), disturbed assimilate distribution, and decreased photosynthesis rate (Abreha et al. 2022). Drought stress at the flowering stage of the plants is crucial because it can increase pollen sterility and results in low fruit set and high flower abortion. Rosmaina et al. (2018) reported that drought stress at the flowering stage in curly pepper caused yield reduction significantly due to high flower abortion.

Chlorophyll contents

The result of the variance analysis of chlorophyll content is presented in Table 4. The genotype factor significantly affected the chlorophyll a (Chl a), chlorophyll b (Chl b), and chlorophyll total (Chl T). Still, the stress condition factor did not significantly affect the chlorophyll contents, while interaction between genotypes and stress conditions had only significant effect on the chlorophyll b. The mean Chl a, Chl b, and Chl T for normal conditions were 3.55 mg/g FW, 1.46 mg/g FW, and 5.01 mg/g FW, respectively, while the mean Chl a, Chl b, and Chl T for drought stress conditions were 3.54 mg/g FW, 1.44 mg/g FW, and 4.97 mg/g FW, respectively. Reduction of Chl a, Chl b, and Chl T under drought stress conditions compared to control conditions was 0.28%, 2.70%, and 0.80%, respectively (Table 5). Under drought stress conditions, chlorophyll contents of each genotype were varied, as shown in Table S2. Eight genotypes displayed increasing chlorophyll a and nine genotypes exhibited increasing chlorophyll b.

Chlorophyll is one of the main components of chloroplast for photosynthesis. The decrease in chlorophyll content is a common phenomenon observed under drought stress conditions (Chen et al. 2016). The reduction in chlorophyll content under drought stress conditions can be caused by inhibition of the biosynthesis of chlorophyll-a precursors (Batra et al. 2014; Dalal and Tripathy 2018) and toxic reactive oxygen species (ROS), such as O_2- and H_2O_2 as results from drought stress (Muhammad et al. 2021). ROS can cause lipid peroxidation, so chlorophyll breakdown. In the present study, chlorophyll a, chlorophyll b, and chlorophyll total under drought stress conditions (Table 5) have not been consistent with previous reports (Chen et al. 2016; Nio et al. 2019), but it was a line with those reported by Zhang et al. (2020), who found no change the chlorophyll contents under drought stress in *Dianthus barbatus* plants.

The highest chlorophyll a, chlorophyll b, and chlorophyll total under drought stress conditions were found in UIN-059 genotype (Table S2). Drought-resistant genotypes usually have high chlorophyll contents (Chen et al. 2016; Ahmed et al. 2020). Resistant genotypes under drought stress conditions had higher chlorophyll content than the sensitive genotypes have been reported in Maize (Khayatnezhad 2012), curly pepper (Rosmaina et al. 2018; Gaswanto and Gunaeni 2021), and hot pepper (Rajametov et al. 2021).

Gas exchange parameters

The results of variance analysis displayed that the genotypes had a highly significant effect on all gas exchanges parameters ($P<0.01$), while the stress conditions had a highly significant effect on the photosynthetic rate, stomatal conductance, transpiration rate, and ratio of intercellular CO_2 concentration and intracellular CO_2 concentration (Ci/Ca) (Table 4). The interaction between genotypes and stress conditions significantly affected the photosynthetic rate, stomatal conductance, intercellular CO_2 concentration, transpiration rate, and the ratio of intercellular CO_2 concentration and intracellular CO_2

concentration (Ci/Ca), mesophyll conductance, and intrinsic water use efficiency. Our results were similar to those reported by Vanaja et al. (2015) in *Cajanus cajan* L. and Liu et al. (2015) in *Panicum virgatum* L. Genotypes responses to drought stress were different because of differences in their genetic potential on drought tolerance.

The reduction of physiological traits in each genotype of curly pepper was varied, as shown in Table S2. Of the 15 curly genotypes tested, 12 curly genotypes showed a decrease in photosynthetic rate under drought stress conditions. The highest reduction in photosynthesis rate was observed in UIN-64 (79.70%), and the lowest reduction was found in UIN-55 (2.22%). The increase in photosynthetic rate under drought conditions was observed in the UIN-70 (73.43%), UIN-65 (27.21%), and UIN-52 (19.20%). A decrease in stomatal conductance under stress conditions was found in 13 genotypes of curly pepper; this decrease varied, ranging from 25.89% to 76.66%, depending on genotypes. The lowest stomatal conductance reduction was observed in genotype UIN-73 (25.69%), and the highest was in UIN-58.

The curly pepper genotypes' transpiration rates (Tr) value ranged from 1.066 to 3.890 mmolH_2O $m^{-2}s^{-1}$ under normal conditions and 0.48 to 2.617 mmolH_2O $m^{-2}s^{-1}$ under stress conditions (Table S2). Thirteen curly pepper genotypes showed a decrease in transpiration rate under stress conditions. The highest decrease in transpiration rate was observed in genotype UIN-41 (70.57%), and the lowest decrease in transpiration rate was observed in genotype UIN-73 (15.96%). This decreased transpiration rate of these genotypes was in line with the decline in stomatal conductance. The increase in transpiration rate under stress conditions was observed in three curly pepper genotypes, namely UIN-65 (56.60%), UIN-55 (13.24%), and UIN-57 (23.68%). The mean value of Ci of the genotypes of curly ranged from 94.66 to 353.94 µmolCO_2 $mmol^{-1}$ under normal conditions and ranged from 179.22 to 337.14 µmolCO_2 $mmol^{-1}$ under stress conditions (Table S2). Nine genotypes showed a decrease in the Ci value under stressed conditions, which decrease in the Ci value of these genotypes was parallel with the decrease in stomatal conductance. Eleven genotypes in this study showed a decrease in mesophyll conductance under stress conditions, and four genotypes showed an increase in mesophyll conductance under drought stress conditions.

Gas exchange parameters experienced decreasing under drought stress conditions compared to control conditions (Table 5). The highest reduction was observed in mesophyll conductance (56.00%), followed by stomatal conductance (50%), transpiration rate (46%), and photosynthesis rate (40%) whereas the lowest reduction was observed in intercellular CO_2 concentration (3.00%). Stomatal limitation increased (9.00%) under drought stress conditions compared to the control conditions. The present study exhibited a negative effect of drought stress conditions on the photosynthesis rate, stomatal conductance, and transpiration rate of curly pepper (Table 5). This result was consistent with Seleiman et al. (2021), who reported that the photosynthesis rate, stomatal conductance, and transpiration rate were reduced significantly under drought-stress conditions. It was clear from the results that photosynthetic rates declined due to partial stomatal closure. Thus, it reduced CO_2 supply from the atmosphere to the chloroplast, inhibiting photosynthetic enzymes (e.g., Rubisco) and synthesis of ATP (Zlatev and Lidon 2012). Transpiration plays a pivotal physiological role in maintaining the water loss in the plant.

In general, our study's concentration of CO_2 intercellular (Ci) tends to decrease (Table S2). The result is compatible with Allahverdiyev et al. (2015), who found a decrease in Ci value under drought stress in two wheat genotypes. Two genotypes (UIN-64 and UIN-57) showed a significant increase in the concentration of CO_2 intercellular value under drought stress than in control treatments, even though stomatal conductance decreased. The concentration of intercellular CO_2 increase was estimated due to both genotypes experiencing severe drought stress conditions, indicating that the stress treatment (45% of field capacity) applied for these genotypes is considered severe. This result agrees with Wang et al. (2018), who found that the Ci value tended to increase under severe drought conditions.

Meanwhile, an increased Ci value when the potential water decreases indicated the reduction in CO_2 assimilation activity and a decrease in carboxylation efficiency (Baath et al. 2020). Flexas et al. (2018) explained that the increase in Ci value indicated the dominance of photosynthesis inhibition due to non-stomata limitations. Genotypes that experienced an increase in Ci values under drought stress conditions also experienced an increase in the Ci/Ca values. The increase in the Ci/Ca ratio is closely related to the decrease in stomatal conductance, which in this study occur a decrease in stomatal conduction up to 50% under water deficit conditions.

Stomatal and non-stomatal limitations can cause a decrease in the photosynthetic rate. The combination of Ls and Ci values was the main criterion to decide whether decreasing the photosynthesis rate due to stomatal or non-stomatal limitation. The stomatal limitation would dominate when the Ls value increase and the Ci value decrease; conversely, the non-stomatal limitation would dominate when the Ls value decrease, accompanying the Ci value increase (Liang et al. 2020). Our result found a significant decrease in photosynthesis rate in the UIN-57 and UIN-64 caused by the non-stomatal factors. In contrast, decreasing photosynthesis rate in other genotypes is caused by stomatal limitation. The non-stomatal factors controlling the photosynthesis rate included mesophyll conductance and biochemical limitations. Mesophyll conductance determines the rate of diffusion of CO_2 from the air space between cells to the carboxylation site, which is located in the chloroplast stroma. In contrast, the biochemical inhibiting of the photosynthesis rate is largely determined by Rubisco's carboxylation capacity (Perdomo et al. 2017). The mesophyll conductance value of UIN-57 and UIN-64 genotypes decreased significantly under drought stress conditions compared to control conditions (Table S2); thus, CO_2 flow was blocked, so plant photosynthesis rates decreased significantly.

Table S2. Gas exchange parameters under normal and drought stress conditions of curly pepper genotypes

Genotypes	**EC**	**Chl a**	**Chl b**	**Chl T**	***Pr***	***gs***	***Tr***	***Ci***	***Ci/Ca***	**gm**	**iWUE**	**Ls**
UIN-41	NC	3.11	1.27	4.37	3.92	82.41	2.99	300.53	0.75	0.013	47.69	0.25
	DS	3.31	1.39	4.70	2.25	24.43	0.88	250.69	0.61	0.01	87.58	0.39
	% R	-6.43	-9.45	-7.55	42.60	70.36	70.57	16.58	18.67	23.08	-83.64	-56.00
UIN-48	NC	3.38	1.50	4.87	2.61	60.21	1.65	318.79	0.79	0.008	43.76	0.22
	DS	3.04	0.60	3.64	1.90	23.29	0.78	244.19	0.60	0.008	90.23	0.40
	% R	10.06	60.00	25.26	27.20	61.32	52.73	23.40	24.05	0.00	-106.19	-81.82
UIN-52	NC	3.59	0.30	3.90	2.24	79.59	1.89	353.94	0.85	0.006	28.08	0.15
	DS	2.59	0.74	3.33	2.67	26.90	0.99	225.12	0.55	0.012	99.23	0.44
	% R	27.86	-146.7	14.62	-19.20	66.20	47.62	36.40	35.29	-100.00	-253.38	-193.33
UIN-55	NC	3.10	1.29	4.39	3.15	32.95	1.36	223.80	0.56	0.014	95.60	0.43
	DS	3.17	0.60	3.78	3.08	40.71	1.54	233.90	0.59	0.014	89.78	0.41
	% R	-2.26	53.49	13.90	2.22	-23.55	-13.24	-4.51	-5.36	0.00	6.09	4.65
UIN-57	NC	3.76	1.59	5.35	5.93	35.72	1.14	122.87	0.30	0.049	165.59	0.70
	DS	3.49	1.57	5.07	1.58	36.90	1.41	307.83	0.76	0.005	47.14	0.24
	% R	7.18	1.26	5.23	73.36	-3.30	-23.68	-150.53	-153.33	89.80	71.53	65.71
UIN-58	NC	3.47	1.51	4.98	7.90	121.4	4.14	266.05	0.68	0.03	65.05	0.32
	DS	3.07	1.33	4.37	3.09	28.34	1.07	208.70	0.51	0.015	110.56	0.49
	% R	11.53	11.92	12.25	60.89	76.66	74.15	21.56	25.00	50.00	-69.96	-53.13
UIN-59	NC	4.78	2.26	7.05	3.37	61.18	2.16	284.54	0.71	0.012	58.95	0.29
	DS	4.32	1.95	6.26	1.96	33.90	1.31	280.19	0.70	0.007	60.72	0.30
	% R	9.62	13.72	11.21	41.84	44.59	39.35	1.53	1.41	41.67	-3.00	-3.45
UIN-64	NC	4.17	1.84	6.00	7.88	43.51	1.58	94.66	0.24	0.083	181.61	0.77
	DS	4.40	1.99	6.38	1.60	21.14	0.85	248.66	0.62	0.007	83.34	0.38
	% R	-5.52	-8.15	-6.33	79.70	51.41	46.20	-162.69	-158.33	91.57	54.11	50.65
UIN-65	NC	4.68	2.20	6.88	2.72	29.85	1.06	234.61	0.59	0.012	91.29	0.41
	DS	4.27	1.89	6.12	3.46	41.98	1.66	241.54	0.60	0.016	85.07	0.40
	% R	8.76	14.08	11.05	-27.21	-40.64	-56.60	-2.95	-1.69	-33.33	6.81	2.44
UIN-66	NC	3.46	1.58	5.04	4.07	116.5	3.89	316.96	0.78	0.013	42.41	0.22
	DS	3.76	1.73	5.49	3.23	59.36	1.85	291.5	0.72	0.012	58.82	0.28
	% R	-8.67	-9.84	-8.93	20.64	49.04	52.44	8.03	7.69	7.69	-38.69	-27.27
UIN-67	NC	2.96	1.19	4.15	3.57	79.78	2.53	304.66	0.77	0.012	45.68	0.23
	DS	3.27	1.49	4.78	3.08	36.87	1.49	241.25	0.60	0.014	87.08	0.40
	% R	-10.47	-25.21	-15.18	13.73	53.79	41.11	20.81	22.08	-16.67	-90.63	-73.91
UIN-70	NC	3.19	1.35	4.54	1.43	65.86	1.89	333.43	0.83	0.004	30.82	0.17
	DS	4.06	1.78	5.82	2.48	20.65	0.73	179.22	0.45	0.015	127.64	0.55
	% R	-27.27	-31.85	-28.19	-73.43	68.65	61.38	46.25	45.78	-275.00	-314.15	-223.53
UIN-71	NC	2.56	1.09	3.64	4.52	75.08	2.64	274.97	0.68	0.017	67.28	0.32
	DS	3.30	1.44	4.74	1.40	41.88	1.34	337.14	0.82	0.004	33.63	0.18
	% R	-28.91	-32.11	-30.22	69.03	44.22	49.24	-22.61	-20.59	76.47	50.01	43.75
UIN-72	NC	4.03	1.55	5.58	3.86	85.49	2.64	314.85	0.77	0.014	44.88	0.23
	DS	3.86	1.78	5.63	2.29	31.50	0.79	244.72	0.59	0.011	95.84	0.41
	% R	4.22	-14.84	-0.90	40.67	63.15	70.08	22.27	23.38	21.43	-113.55	-78.26
UIN-73	NC	3.04	1.32	4.36	5.72	53.64	1.88	164.20	0.42	0.059	131.03	0.59
	DS	3.18	1.39	4.57	3.52	39.86	1.58	240.24	0.59	0.015	89.88	0.41
	% R	-4.61	-5.3	-4.82	38.46	25.69	15.96	-46.31	-40.48	74.58	31.41	30.51

Note: Chl a : chlorophyll a; Chl b: chlorophyll b; Chl T: chlorophyll total; Pr: photosynthetic rates; gs: stomatal conductance; Tr: transpiration rates; Ci: intercellular CO_2 concentration; Ci/Ca: ratio of intercellular CO_2 concentration and intracellular CO_2 concentration; g_m: meshophyll conductance; iWUE: intrinsic water use efficiency; Ls. stomatal limitation; EC: Experimental conditions; NC: normal conditions; DS: drought stressed; %R: percentage of reduction

Table 4. Summary of analysis of variance for the effect of stress conditions, genotypes, and the interaction between stress conditions and genotypes on physiological traits

SOV	**df**	**Mean of squares**										
		Chl a	**Chl b**	**Chl T**	**P_N**	**gs**	**Tr**	**Ci**	**Ci/Ca**	**gm**	**iWUE**	**Ls**
S	1	0.01 ns	0.03 ns	0.01 ns	76.96 ***	31692.91 ***	28.02 ***	2157.72 ns	0.019 ns	0.003 ***	0.001 ns	0.02 ns
G	14	1.36 ***	0.74 ***	4.05 ***	6.84 ***	1832.64 ***	1.91 ***	12706.47 ***	0.074 ***	0.001 ***	0.004 ***	0.07 ***
S*G	14	0.29 ns	0.17 *	0.65 ns	8.15 ***	1224.64 ***	1.53 ***	16339.35 ***	0.099 ***	0.001 ***	0.006 ***	0.10 ***

Note: Source of variance (SOV), stressed treatment (S), Genotypes (G), the interaction between stressed condition and genotypes (S*G), degree of freedom (df), photosynthetic rates (P_N), stomatal conductance (g_s), transpiration rates (T_r), intercellular CO_2 concentration (Ci), the ratio of intercellular CO_2 concentration and intracellular CO_2 concentration (Ci/Ca), Meshophyll conductance (g_m), water use efficiency (WUE), and stomatal limitation (L_S). *** significant at P≤ 0.001 ** significant at P≤ 0.01, * significant at P ≤ 0.05, ns: non significant at P ≤ 0.05

Table 5. The average values of physiological traits under control and drought stress conditions

Traits	Conditions		Reduction (%)
	Control	Drought	
Chlorophyll a (mg/g Fresh Weight)	3.55	3.54	0.28
Chlorophyll b (mg/g Fresh Weight)	1.48	1.44	2.70
Chlorophyll total (mg/g Fresh Weight)	5.01	4.97	0.80
Photosynthesis rate (µmol CO_2 $m^{-2}s^{-1}$)	4.27a	2.55b	40.00
Stomatal conductance (mmol H_2O $m^{-2}s^{-1}$)	69.04a	34.66b	50.00
Transpiration rate (mmol H_2O $m^{-2}s^{-1}$)	2.28a	1.24b	46.00
Ci (µmolCO_2 $mmol^{-1}$ H_2O)	260.59	253.66	3.00
The ratio of intercellular CO_2 and intracellular CO_2 concentrations	0.65	0.62	5.00
Mesophyll conductance (mmol $m^{-2}s^{-1}$)	0.025a	0.011b	56.00
Intrinsic water use efficiency (µmol CO_2 mol^{-1} HO_2)	82.67	76.75	7.00
Stomatal limitation	0.35	0.38	-9.00

The variation in mesophyll conductance values among genotypes was obtained in this study. It was also consistent with those previously reported for soybean (Tomeo and Rosenthal 2017), wheat (Jahan et al. 2014); chickpeas (Shrestha et al. 2018). Mesophyll conductance variability within and among species is associated with leaf structure and anatomical properties, particularly the surface area of chloroplast exposed to the intercellular spaces, cell wall, and thickness of chloroplast (Shrestha et al. 2018). Therefore, mesophyll conductance can be used as an indicator selection to improve crop water use efficiency (Flexas et al. 2013).

Intrinsic water use efficiency (iWUE) is an essential parameter for plants under drought conditions. Each genotype displays different intrinsic water use efficiency under normal and stress conditions. A significant increase in water use efficiency under drought stress conditions was observed in the genotype of UIN-70 and UIN-52 (Table S2). Both genotypes are also capable of increasing photosynthesis rate and decreasing transpiration values. This result is consistent with Li et al. (2017), who reported that genotypes of wheat resistant to drought exhibited an increased photosynthetic rate, a decreased transpiration value, and high water use efficiency (iWUE). Under drought stress conditions, the more efficiently the plants use water (high WUE value), the more plants will survive than plants with low WUE values (Hatfield and Dold 2019). Therefore, summarized that the UIN-70 and UIN-52 are droughts resistant physiologically based on this character.

Determination of traits for selecting drought tolerance genotypes

In the present study, the principal component analysis (PCA) was used to identify the reliability of morphological and physiological traits in determining drought tolerance genotypes with an understanding of each character's contribution to the observed total variation. The result of PCA analysis based on the drought tolerance coefficient of morphological and physiological traits is shown in Table 6. Overall, PC1-PC2 explained 62.40% of the observed total variation. The PC1 explained 41.51% of the total variation in which the most significant contributing characteristics were stomatal limitation, mesophyll conductance, stomatal conductance, root length, and photosynthesis rate. The PC2 explained 20.89% of the total variation. The highest contribution characters were fruit weight per plant, mesophyll conductance, chlorophyll b, photosynthesis rate, number of fruits, and transpiration rate.

Table 6. Eigenvalues matrix of principal component analysi

Characters	PC1	PC2
Plant height	0.071	-0.017
Stem diameter	0.028	-0.024
Root length	0.286	-0.185
Root width	-0.027	-0.016
Shoot fresh weight	0.045	-0.087
Root fresh weight	0.018	-0.159
Root dry weight	0.030	-0.109
Shoot dry weight	0.034	-0.075
Number of fruits	-0.079	0.203
Fruit weight per plant	-0.137	0.685
Chlorophyll a	-0.035	0.173
Chlorophyll b	-0.062	0.251
Chlorophyll total	-0.043	0.196
Photosynthetic rates	0.217	0.224
Stomatal conductance	0.345	-0.149
Intercellular CO_2 concentration	-0.297	-0.148
Transpiration rates	-0.114	0.201
Mesophyll conductance	0.520	0.337
The ratio of intercellular CO_2 and intracellular CO_2 concentration	-0.027	0.059
Intrinsic water use efficiency	-0.055	-0.021
Stomatal limitation	0.573	0.042
Eigenvalues	2.105	1.06
Percentage	41.51	20.89
Cumulative percentage	41.51	62.40

Table 7. MFVD values of each genotype are based on morphological and physiological traits in curly pepper genotypes

Traits	Genotypes														
	UIN 41	**UIN 48**	**UIN 52**	**UIN 55**	**UIN 57**	**UIN 58**	**UIN 59**	**UIN 64**	**UIN 65**	**UIN 66**	**UIN 67**	**UIN 70**	**UIN 71**	**UIN 72**	**UIN 73**
Root length	0.40	0.44	1.00	0.16	0.00	0.59	0.06	0.25	0.15	0.35	0.10	0.35	0.16	0.22	0.12
Number of fruits	0.03	0.11	0.03	0.00	0.15	0.07	1.00	0.03	0.6	0.61	0.01	0.00	0.13	0.35	0.18
fruit weight per plant	0.00	0.01	0.00	0.00	0.10	0.00	0.30	0.01	1.00	0.10	0.01	0.00	0.03	0.12	0.03
Chlorophyll b	0.40	0.00	0.11	0.12	0.57	0.55	1.00	0.54	0.81	0.50	0.61	0.64	0.27	0.33	0.23
Photosynthetic rate	0.24	0.34	0.65	0.51	0.04	0.12	0.25	0.00	0.70	0.39	0.43	1.00	0.07	0.25	0.27
Stomatal conductance	0.70	0.09	1.00	0.07	0.22	0.19	0.00	0.35	0.13	0.27	0.16	0.61	0.03	0.01	0.24
Transpiration rates	0.03	0.17	0.20	0.67	0.75	0.00	0.27	0.22	1.00	0.17	0.24	0.10	0.19	0.03	0.45
Mesophyll conductance	0.20	0.25	0.53	0.26	0.01	0.12	0.16	0.00	0.37	0.24	0.31	1.00	0.05	0.22	0.05
Stomatal limitation	0.42	0.52	0.92	0.20	0.00	0.40	0.24	0.05	0.21	0.32	0.47	1.00	0.07	0.51	0.12
Average MFVD	0.27	0.21	0.49	0.22	0.20	0.23	0.36	0.16	0.55	0.33	0.26	0.52	0.11	0.23	0.19
Category	M	M	T	M	M	M	M	M	HT	M	M	HT	S	M	M

Note: HT: Highly drought tolerant; T: drought tolerant; M: moderate drought tolerant, S: susceptible, and HS: highly susceptible. MFVD: membership function values

Based on the PCA analysis above, we proposed that the root length, number of fruit, and fruit weight per plant characters can be used as the main indicator for screening drought tolerance based on morphological characters. At the same time, the physiological characteristics were the main indicators for the stomatal limitation, mesophyll conductance, stomatal conductance, photosynthesis rate, chlorophyll b, and transpiration rate. The finding of nine traits from PCA analysis could be used as indicators to select drought tolerance curly pepper genotypes in the future. Sun et al. (2021) found five traits, e.g., plant height, effective fruit branch number, single boll weight, transpiration rate, and chlorophyll content in cotton species, as the main indicators for screening drought tolerance based on PCA analysis. Afsar et al. (2020) have successfully identified nine characters based on PCA analysis for screening salt tolerance in *Eruca sativa* Mill. germplasm.

Identification of drought tolerance genotypes by MFVD

Nine selected characters from PCA analysis were used to screen the drought tolerance genotypes based on the index of membership function values of drought tolerance (MFVD). The MFVD values of each genotype are exhibited in Table 7. The mean and standard deviation values of overall MFVD were 0.29 and 0.14, respectively. The highest mean MFVD value was observed in UIN-65 (0.55), while the lowest mean MFVD was found in UIN-71 (0.11). The higher mean MFVD indicated higher drought tolerance of genotype and vice versa. Among fifteen curly pepper genotypes, two genotypes (UIN-65 and UIN-70) were classified as highly drought tolerant (MFVD > 0.51); one genotype (UIN-52) was drought tolerant ($0.43 \leq$ MFVD < 0.51); one genotype (UIN-72) showed drought susceptible category ($0.067 \leq$ MFVD < 0.15); and rest genotypes showed moderately drought tolerant category ($0.15 \leq$ MFVD < 0.43).

As shown in Table 7, 13.33% of the genotypes were classified as highly drought tolerant, 6.7% as drought tolerant, 73.33% as moderately drought tolerant, and 6.7% as drought susceptible. Identification of drought tolerant genotypes using MFVD proved reliable. Similarly, Chen et al. (2012) found five accesions (5.56%) and 11 accesions (12.2%) of highly drought tolerant and drought tolerant, respectively, from 90 accession tested. Wang et al. (2021) classified 53 of canola genotypes three catogories, five genotypes as drought tolerant, 16 genotypes as moderate drought tolerant, and 32 genotypes as susceptible, and Yan et al. (2020) found two accessions of soybean as highly drought tolerance, 17 genotypes as moderate drought tolerant, and one genotype as susceptible using MFVD index.

The highly drought-tolerant genotypes based on MFVD did not always produce a high fruit weight per plant (yield), such as UIN-70 and UIN-65 with 100% and 85% yield reduction, respectively, under drought stress conditions. The yield of these genotypes was not consistent with their tolerance to drought. Our result was supported by previous studies (Liu et al. 2015; Liu et al. 2017). This phenomenon is not surprising, because high yields and drought adaptation are often based on different mechanisms, and to some extent, tend to be contradictory mechanisms. In many cases, the main effect of drought is to reduce yield rather than kill the crop. Therefore, for developing drought-tolerant curly pepper genotypes, drought resistance must be incorporated with high yield potential. The drought-tolerant curly pepper genotypes found in this study can be used in crosses with high-yielding but drought-sensitive genotypes to produce drought-resistant and high-yielding genotypes. The present study successfully identified two genotypes resistant physiologically with low yields, i.e. UIN-70, UIN-65, and UIN-52 as well as one genotype (UIN-71) that has a high yield but is sensitive to drought. Therefore, this study recommended that hybridization between UIN-71 and UIN-70, or UIN-65, or UIN-52 can be carried out to produce drought-resistant and high-yielding genotypes in the future.

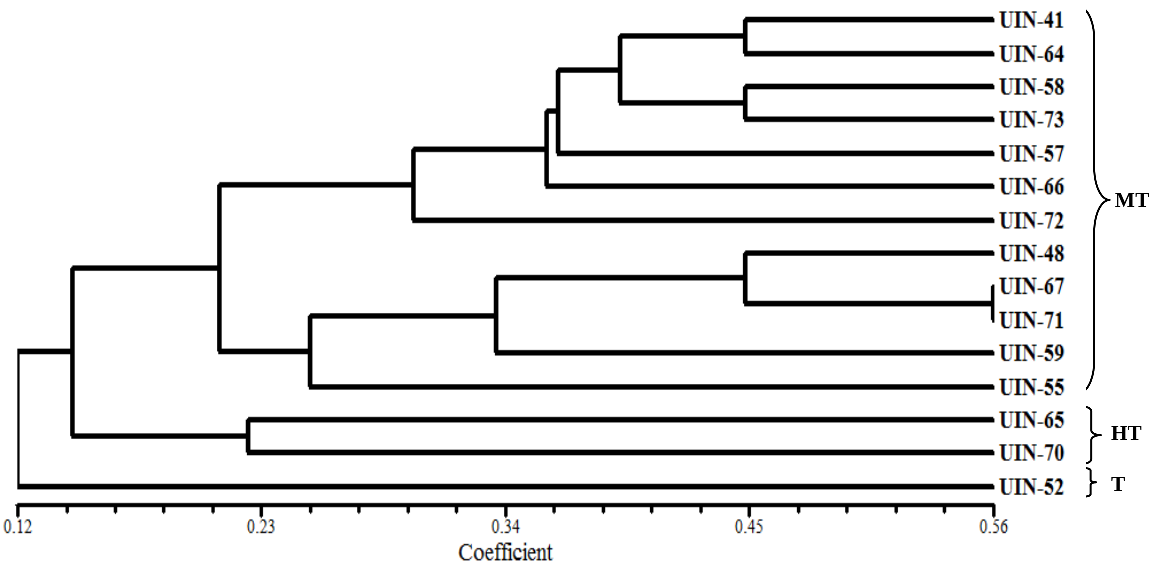

Figure 1. The UPGMA dendrogram based on the drought tolerance coefficient value of morpho-physiological characters. HT: Highly drought tolerant; T: Drought tolerant; and M: Moderately drought tolerant

The UPGMA dendrogram based on drought coefficients values is displayed in Figure 1. Fifteen curly pepper genotypes were grouped into three distinct groups. The first cluster consisted of UIN052 as a drought tolerant group, the second cluster was composed of UIN-70 and UIN-65 as a highly drought tolerant group, while the rest of the genotypes were clustered into third groups as moderately drought tolerant. The results of genotypes categorization based on MFVD values (Table 3) are broadly consistent with the genotypes grouping based on the UPGMA dendrogram. Interestingly, the sensitive genotype (UIN-71) is gropued into moderately drought tolerant group. There are slight differences between grouping genotypes based on MFV and UPGMA analysis that have also been reported in *E. sativa* accessions (Afsar et al. 2020) and *Brassica napus* L. cultivars (Mohamed et al. 2020).

In conclusion, this study found that drought stress reduced curly pepper's morphological and physiological traits. The main indicators for screening the curly pepper drought tolerance were stomatal limitation, mesophyll and stomatal conductance, root length, photosynthesis rate, fruit weight per plant, chlorophyll b, number of fruit, and transpiration rate. The genotypes UIN-65 and UIN-70 were highly drought-tolerant and can be utilized to improve curly pepper's drought tolerance in the future.

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