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DROUGHT TOLERANT INDICES OF LOWLAND TOMATO CULTIVARS

Indeks Toleransi Kekeringan Kultivar Tomat Dataran Rendah

Amalia Tetrani Sakya[*a], Endang Sulistyaningsih[b], Benito Heru Purwanto[b] and Didik Indradewa[b]

[*a]*Department of Agrotechnology, Universitas Sebelas Maret*
Jalan Ir. Sutami 36 A, Kentingan, Surakarta, 57126, Indonesia
[b]*Department of Agronomy, Gadjah Mada University*
Jalan Flora Bulaksumur, Yogyakarta 55281, Indonesia

** Correspondence author: amaliatetrani@staff.uns.ac.id*

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ABSTRACT

The released lowland tomato cultivars are known for their resistance to plant diseases and high temperatures. The study aimed to identify the drought tolerance of lowland tomato cultivars based on the drought tolerant indices. The study was arranged in a split plot design, using seven lowland tomato cultivars (Zamrud, Permata F1, Ratna, Mirah, Tombatu F1, Tyrana F1, and Tymoti F1) as the main plot and watering (standard conditions and once every eight days as the drought conditions) as the subplot. Parameters observed were morpho physiological characters (plant height, leaf area, biomass, root length, root surface area, shoot root ratio, relative moisture content, membrane stability index, chlorophyll levels, and proline levels). The parameters observed in each character included the sensitivity stress index (SSI), stress tolerance index (STI), and yield stability index (YSI). Results showed that four cultivars (Tyrana F1, Tymoty F1, Mirah, and Tombatu F1) were drought tolerance, and three cultivars (Ratna, Permata F1, and Zamrud F1) were susceptible. The water stress decreased agronomic and physiological traits performance, but the drought-tolerant cultivars were less affected to the stress and produced higher fruit weight. The study implies that the drought-tolerant cultivars could be used as a promising source for drought tolerant genotypes.

[**Keywords:** morpho physiological characters, stress sensitivity index, stress tolerance index, yield stability index]

ABSTRAK

Kultivar tomat dataran rendah yang dikembangkan di Indonesia merupakan kultivar yang tahan terhadap penyakit dan suhu tinggi. Penelitian dilakukan untuk mengidentifikasi toleransi kultivar tomat dataran rendah terhadap kekeringan. Penelitian diatur berdasarkan rancangan petak terpisah,dengan menggunakan tujuh kultivar tomat dataran rendah (Zamrud, Permata F1, Ratna, Mirah, Tombatu F1, Tyrana F1, dan Tymoti F1) sebagai petak utama dan penyiraman (kondisi normal dan penyiraman 8 hari sekali yang mereprentasikan kondisi cekaman kekeringan) sebagai anak petak. Parameter yang diamati yaitu karakter morfofisiologi (tinggi tanaman, luas daun, berat kering, panjang akar, luas permukaan akar, rasio akar pucuk, kadar air relatif, indeks stabilitas membran, kadar klorofil, dan kadar prolin). Pada masing-masing karakter dihitung nilai indeks sensitivitas cekaman (ISC), indeks toleransi cekaman (ITC), dan indeks stabilitas hasil (ISH). Empat kultivar (Mirah, Tombatu F1, Tyrana F1, dan Tymoty F1) menunjukkan toleransi terhadap kekeringan, sementara tiga kultivar (Ratna, Zamrud F1 dan Permata F1) bersifat rentan. Cekaman air menurunkan performa karakter agronomis dan fisiologis, tetapi kulitvar toleran kekeringan kurang terpengaruh oleh cekaman tersebut dan produksi buah tetap tinggi. Penelitian ini menunjukkan bahwa kultivar tomat toleran kekeringan merupakan sumber yang menjanjikan untuk genotipe toleran kekeringan.

[**Kata kunci:** indeks sensitifitas cekaman, indeks toleransi cekaman, indeks stabilitas hasil, karakter morfofisiologis]

INTRODUCTION

Tomato (*Lycopersicum esculentum* Mill.) is a versatile horticultural commodity and has many health benefits. It contains carotene, especially lycopene, polyphenol, and some mineral (Agarwal and Rao 2000; Martí et al. 2016; Narváez-Ortiz et al. 2018). Consumption of tomato regularly decreases the risk of heart disease and cancer, and improves eye and skin health (Lippi and Targher 2011; Palozza et al. 2011). Besides being consumed fresh and as a spice, tomato is also often used for industrial raw materials. Thus, tomatoes are classified as commercial commodities and have a high economic value.

Minister of Agriculture (2019) reported that Indonesia's tomato production is not inferior to other countries in Asia, which occupies third place after India and the Philippines, above Malaysia and Thailand. The average tomato production in 2019 was 1,020,333. Based on the National Socio-Economic Survey 2018, tomato consumption in 2019 amounted to 0.24 kg per capita per year, and the use of tomatoes as a foodstuff reached 892,000 tons. The use of these tomatoes increased by 1.66% year on year (BPS 2018). Tomato is also one of the vegetable commodities contributing to exports along with cabbage, carrots, and potatoes (BPS 2017).

Tomatoes can be planted, either on low, medium, or high altitude, depending on the variety used. However, most farmers grow tomatoes on medium or high altitudes. Along with the increasing need for tomatoes, tomatoes also began to be widely planted in the lowlands. Superior cultivars of lowland tomato developed in Indonesia include Opal, Mirah, Zamrud, Permata F_1, Tombatu F_1, Ratna, Tyrana F_1, and Tymoti F_1. These superior cultivars are resistant to high temperature and wilt (Purwati 2007), but there is no information regarding cultivars' resistance to drought. Along with environmental changes such as increased temperatures and water scarcity that can be a real threat to global agricultural production, it is necessary to know drought-tolerant tomato cultivars.

Several studies have shown that drought stress in tomatoes results in morphological, physiological, and biochemical characters changes. Growth characters such as plant height, dry weight, leaf number, root development, as well as total leaf area are lower in drought stress than those in optimal conditions (Nahar and Gretzmacher 2002; Nahar and Gretzmacher 2011; Shao et al. 2008; Pervez et al. 2009; Abou-shleel and El Saka 2016). Some physiological changes also occur in drought stress tomato plants, such as reduced nitrate assimilation in cultivars sensitive to drought (Sánchez-Rodríguez et al. 2010). Another research showed that in severe drought-stress conditions, there was a significant decrease in rubisco activity (Castrillo et al. 2001; Calcagno et al. 2011) and carbonic anhydrase (Sun et al. 2016). Furthermore, a decreased photosynthesis rate due to limited incoming CO_2 caused by stomatal closure occurs in moderate and severe drought-stress tomatoes (Castrillo et al. 2001; Khan et al. 2015). Decreased morphological and physiological characters seen in plants on drought stress conditions will ultimately reduce the yield. The relative growth rate felt from 1.37 to 0.57 g week^{-1} from average to drought conditions (Khan et al. 2015). Other researchers pointed out that the maximum fluorescence value and effective PS-II quantum yield of tomato seedling declined by 9.7% and 43.6%, respectively, under drought conditions (Liang et al. 2020). Reducing both of the characters dropped the electron transport of PS II and inhibited the photosynthetic carbon metabolism, thus decreasing tomato yield. Drought stress at the fruit development phase and the fruit ripening phase reduced the fruit weight by 26% (Cui et al. 2020). The fruit weight of tomatoes per plant decreased from 3% to 150% on seven tomato cultivars in irrigation interval of eight times a day (Sakya et al. 2018).

A drought tolerant variety needs to be created to reduce yield loss due to drought conditions. The initial step in developing superior tomato varieties is to obtain or select drought resistant cultivars. One of the stress tolerance screening can be done by using a tolerance indicator through stress tolerance indices. Several indices have been used to identify or to predict plant tolerance to stress such as stress susceptibility index (SSI) (Fischer and Maurer 1978), average productivity (MP), and tolerance (TOL) (Rosielle and Hamblin 1981), yield stability index (YSI) (Bouslama and Schapaugh 1984), superiority index (PI) (Lin and Binns 1988), stress tolerance index (STI), average productivity geometry (GMP) and harmonic average (HM) (Fernandez 1992), and yield index (YI) (Gavuzzi et al. 1997). The drought tolerance index has also been used for screening drought-tolerant tomatoes by some researchers. Zdravković et al. (2013) used a stress susceptibility index (SSI) based on the plant height and shoot-root ratio in determining tomato tolerance to drought. Other researchers determined drought stress tolerance of 28 tomato accessions based on the percentage of fruit formation in stress and non-stress conditions (Bacallao et al. 2016).

There are still a few reports of tomato screening in drought conditions in Indonesia. The study aimed to identify the drought tolerance of seven lowland tomato cultivars based on the drought tolerance indices based on morphological and physiological characters.

MATERIALS AND METHODS

Experimental Site

The study was conducted in the experimental farm of Faculty of Agriculture, Gadjah Mada University (UGM) in Banguntapan, Yogyakarta, at ±115 m above sea level. The temperatures of the study site ranged between 29 and 34.6^{0}C and humidity from 76 to 95%.

Plant Materials and Soil Properties

Seven lowland tomato cultivars were used, i.e., Zamrud, Permata F_1, Ratna, Mirah, Tombatu F_1, Tyrana F_1, and Tymoti F_1. Zamrud, Ratna, and Mirah were obtained from the Indonesian Vegetables Research Institute, and others were the collection of East-West Seed, Indonesia.

The soil used in this study was Entisol. The soil used has the 5.84 pH H_20, 13% moisture content, 0.69% organic C, 0.07% N total, 64 ppm P_2O_5, 0,19 me 100^{-1} g available K, and 5.7 me 100^{-1} g cation exchange capacity (CEC).

Field Experiment

The study used a complete randomized block design with eight replications arranged in a split plot design—the drought conditions as main plots and cultivars as subplots. The drought conditions consisted of two levels, namely watering every day (standard conditions) and watering every eight days (drought stress conditions). Watering was done according to the treatment by giving water to field capacity by flushing until all pores are filled and waited until water dripping from the polybags.

Entisol soil as much as 8 kg per polybag was used as a planting medium. The polybags were arranged according to research design and placed in the greenhouse. The soil has a moisture content of 34.30% field capacity (FC), and a permanent wilting point was 11.08% FC. Cultivation was carried out according to recommendations by applying 10 tons ha^{-1} (50 g $polybag^{-1}$) compost, 200 kg ha^{-1} SP-36 (0.36 g P $polybag^{-1}$), 200 kg ha^{-1} urea (0.45 g N $polybag^{-1}$), and 100 kg ha^{-1} KCl (0.1 g K $polybag^{-1}$). Compost and P fertilizers were given one week before planting. Urea (nitrogen) and KCl (potash) were applied at 1 and 4 weeks after transplanting (WAT), ½ each dose. Watering was done every day until the field capacity for 3 WAT. Then, watering was given according to treatment. Pests were controlled manually while disease was managed as necessary. The first harvest was done when the fruit has shown a full red color and a 10% volume of tomato fruit, or around 69-75 days after planting.

Variable Observation and Data Analysis

Variables observed consisted of morphological and physiological characters. The measured morphological characters included plant height, leaf area, root length, root surface area, biomass, shoot root ratio, fruit number, and fruit weight per plant. These characters were measured at 13 WAT.

Physiological characters included relative water content, membrane stability index (root and leaf), chlorophyll content (chlorophyll a, b, total and chlorophyll ratio), and proline content measured at nine weeks after transplanting. The relative water content was measured and calculated as described by Hayat et al. (2008). The relative water content of the leaves was measured by weighing the fresh weight of the leaves (FW), then immediately soaked in distilled water for 48 hours to gain turgid weight (TW), after which the leaves were dried with an oven to get dry weight (DW). Relative water content was calculated by the formula: RWC = (FW-DW)/(TW-DW).

Membrane stability index was measured based on Almeselmani et al. (2011). A 0.1 g of leaves or roots was cut into pieces with uniform size and put in a test tube containing 10 ml distilled water in two sets. Each set was measured its electrical conductivity after being incubated at 40° C for 30 minutes (C1) and 100° C for 15 minutes (C2). The membrane stability index was calculated using the formula [1 - (C1/C2)] x 100.

The chlorophyll content was analyzed as defined by Islam et al. (2009). One g of leaf samples was cut into pieces and crushed in a mortar then added 20 ml of 80% acetone. The solution was filtered with Whatman filter paper no. 42. The filtrate was inserted into the cuvette until the boundary line and then measured with spectrophotometers at λ 645 and 663 nm. Chlorophyll levels were determined using the formula: chlorophyll a = (12.7 x λ 663 – 2.69 x λ 645) x (20 ml/1000 x 1 g); chlorophyll b = (22,9 x λ 645 – 4,68 x λ 663) x (20 ml/1000 x 1 g) and chlorophyll total = (20.2 x λ 645 + 8.02 x λ 663) x (20 ml/1000 x 1 g).

Proline was measured following the Bates method (Bates et al. 1973). A 0.5 g of leaves was extracted in 10 ml of 3% sulfuric acid (b/v) and filtered with filter paper. A 1.25 g of ninhydrin was dissolved in a mixture of 30 ml of glacial acetic acid and 20 ml 6 M of H_3PO_4 warm until dissolved. It was then cooled and stored at a temperature of 40° C. A 2 ml of filtrate was reacted with 2 ml of ninhydrin acid solution and 2 ml of glacial acetic acid in the test tube for 1 hour at a temperature of 100° C. Then the reaction process ends in an "ice bath." The mixture was then extracted with 4 ml of toluene and firmly soaked using a "test-tube stirrer" for 15-20 seconds. It was then measured at 520 nm with a spectrophotometer. For blank solution used toluene solution. The proline concentration was determined by the standard curve of pure proline and calculated based on fresh weight.

All variables were observed under normal and stress conditions to calculate the level of drought tolerance based on the stress susceptibility index (SSI), stress tolerance index (STI), and yield stability index (YSI). The drought tolerance index was observed for each variable using the following formula:

$$SSI = \left(1 - \left({}^{Y_s}\!/_{Y_p}\right)\right) / \left(1 - \left({}^{mY_s}\!/_{mY_p}\right)\right)$$

$$SSI = \left(1 - \left({}^{Y_s}\!/_{Y_p}\right)\right) / \left(1 - \left({}^{mY_s}\!/_{mY_p}\right)\right)$$

(Fischer and Maurer 1978)

$$STI = {}^{(Y_s \; x \; Y_p)}\!/_{mY_p{}^2}$$ $$STI = {}^{(Y_s \; x \; Y_p)}\!/_{mY_p{}^2}$$

(Fernandez 1992)

$$YSI = {}^{Y_s}\!/_{Y_p}$$ $$YSI = {}^{Y_s}\!/_{Y_p}$$

(Bouslama and Schapaugh 1984)

Notes: Ys = character value of a cultivar under stress conditions (8-day watering); Yp = character values of a cultivar in non-stress conditions (1-day watering); mYs = average of a character under stress conditions; mYp = the average of a character in normal (non-stress) conditions.

Cultivar grouping was done based on a drought tolerance index of each morphological and physiological character using cluster analysis. The level of similarity between the drought tolerance index of morphological and physiological characters was calculated based on similarity coefficient using the Group Average Clustering method through the Unweight Pair Group Method Arithmetic (UPGMA) with hierarchical techniques, sequential, agglomerative, hierarchical, and nested clustering (SAHN) in the NTSYS program version 2.10 (Rohlf 1998). Furthermore, the grouping was displayed in the dendrogram (Trahanias and Skordalakis 1989).

RESULTS AND DISCUSSION

Environmental Conditions

The study was conducted in the greenhouse at the experimental station of the Agriculture Faculty UGM. The average temperature during the study ranged from 29 to 38.6^{o} C, while the humidity and soil pH was 76-96% and 5.85, respectively. The ideal conditions for tomato growth are 24-28^{o} C for temperature and 80% for moisture (Shamshiri et al., 2018). Tomatoes can grow in hot climates, but too high temperatures will affect flowering and fruit formation. The soil analysis as described in the methodology, showed a low N, P, and K content, suggesting fertilizer application according to the recommendations of tomato cultivation.

The dominant weed found during the study was *Imperata cylindrica*. The weed was controlled manually every week. Some tomato plants were attacked by the fungus causing withering disease at 9 weeks after treatment (WAT) and rotten ends of the fruit at the first harvest, but no control was carried out due to the small number. The dominant pests attacking tomato plants include the root nematode (*Meloidogyne* sp.) and whitefly (*Planococcus* sp.). Pest control was carried out by providing deltamethrin 25% at 3 weeks and 9 weeks after transplanting (WAT).

Cultivar Identification Based on Drought Tolerance Index

Moisture content is one of indicators that can be used to determine water availability in the soil. There was a different effect independently of each treatment. All cultivars' responses showed the same pattern, Watering every eight days reduced the soil water content in all varieties. Measurement of water content at 7 and 9 WAT showed that under normal conditions (watering every day), the average water content before watering was 34.87% and after watering was 38.4% field capacity (FC). Whereas under stress conditions, the average water content before watering was 18.32% FC and after watering was 37.25% FC. Average water content under stress conditions before watering was in the range of 50-55% FC, and plants look wilt. However, the moisture content was still between the field capacity and the permanent wilting point. Rewatering could increase the moisture content around 37.25% and refresh the plant. Moisture contents after rewatering at 7 or 9 WAT on treatment of 1 and 8 days were not significantly different. Moreover, this study revealed that at 7 and 9 WAT, which is commonly the maximum vegetative growth phase and fruit development phase, tomato required sufficient water for optimal growth. It shows that rewatering increased moisture content and the amount of water in the planting medium was relatively similar (Table 1).

Moisture content between cultivars before watering was only significantly different at 9 WAT. Ratna's moisture content at 9 WAT was the lowest and significantly different from the moisture content of Permata F1, which was the highest. It may be due to the transpiration rate, and water absorption in Permata F1 was the lowest, whereas the Ratna was higher than another cultivar. Its difference was due to the genetic factors of each cultivar in water usage available in the soil. The ability of plants to use water available in the soil was dominated by genetic variations in each plant (Shamim et al. 2014; Pereira et al. 2015; Liang et al. 2020)

Soil moisture levels after watering did not show any significant difference between cultivars both at 7 and 9 WAT. It means that after rewatering, the soil moisture content was similar. Similar condition was also reported by Khan et al. (2012) that varying watering intervals in chili cultivar returns in the optimum capacity of growing media for supporting plant growth.

Table 2 showed that in drought conditions (8-day watering interval), the morphological characters' performance was reduced, except for the root performance and shoot root ratio. Watering once every eight days resulted in a decrease in plant height, on average of 15.8%, biomass 32%, leaf area 28%, fruit number 40.4%, and fruit weight 38.8%. Stress conditions resulted in an average increase in root length of 1.9%, root surface area of 6.1%, and shoot root ratio of 15% compared to normal conditions.

Table 1. Soil moisture content before and after watering at 7 and 9 weeks after planting.

Treatment	Moistur content (%)			
	7 WAT		9 WAT	
	Before	After	Before	After
Watering interval (day)				
1	32.23 a	37.89 a	30.95 a	37.87 a
8	17.56 b	37.15 a	16.30 b	36.97 a
Cultivar				
Zamrud	26.56 a	38.67 a	25.45 abc	38.67 a
Permata F_1	26.05 a	38.78 a	26.89 a	38.12 a
Ratna	26.34 a	37.23 a	24.29 d	37.15 a
Mirah	26.21 a	37.87 a	24.87 bcd	38.24 a
Tombatu F_1	25.78 a	38.56 a	24.67 cd	38.33 a
Tyrana F_1	27.89 a	38.48 a	25.46 ab	38.20 a
Tymoti F_1	26.67 a	38.34 a	24.54 cd	37.87 a
CV (%)	5.5	4.62	6.25	7.5

WAT= weeks after transplanting.
The value followed by the same letter in the same column is not significantly different from the Duncan 5% test.
Moisture content of the field capacity = 34.30%, moisture content of the permanent wilting point = 11.08%

The change in morphological character was in line with research on tomatoes reported by Hayat et al. (2008), Brdar-Jokanović et al. (2014), and Khan et al. (2015). At the stress conditions (watering once every eight days), the highest yield was found in Tyrana F_1 cultivar and the lowest was in Ratna.

Some of the physiological characters were also decreased in drought conditions (Table 3). Watering every eight days also resulted in an average decrease in the relative water content by 15%, membrane stability index on leaves and roots by 17%, and 15%, and lowering chlorophyll a and b by 27% and 41%, respectively. The 8-day watering interval increased proline and chlorophyll ratio by 340% and 22.8%, respectively. The least damage in leaf and root membranes were found in Tyrana F_1 and Tymoty F_1. The membrane stability index showed the damage of the membrane due to drought stress. The higher the membrane stability, the less damage there was. It is in line with George et al. (2015); Aghaie et al. (2018). In this study, the most proline content was found in Ratna and the least was on Permata (Table 3). Proline is one of the organic compounds formed in plants to adjust osmotic so that there is no plasmolysis in drought conditions. Proline accumulation is one indicator of stress caused by abiotic and biotic factors (Hayat et al. 2012; Chun et al. 2018), but not all plants produce them, including drought-tolerant species.

Overall, the response of lowland tomato cultivars to watering was almost the same, except for Tymoty F_1, Mirah, and Tombatu F_1. Tymoty F_1 showed different responses on plant height, root length, root surface area, and chlorophyll a/b ratio. Mirah and Tombatu F_1 also showed different responses on the root surface area with other cultivars. It indicates the different abilities of each cultivar to deal with drought stress. Several other researchers also reported differences in tomato responses to drought stress conditions. Wahb-Allah et al. (2011) reported different responses on the vegetative and fruit characters of ten hybrid tomatoes grown on different irrigations. Sánchez-Rodríguez et al. (2010) also found differences in relative water content, antioxidant content (MDA, H_2O_2), proline, and phenolic content of five cherry tomatoes grown under moderate stress conditions. Another researcher showed differences in antioxidant composition (lycopene, total phenolic, and flavonoids) and antioxidant activity of four tomatoes grown under drought stress conditions (Klunkin and Savage 2017).

Generally, tolerance determination is based on the decreasing yield under stress conditions. The higher the yield reduction, the cultivars are sensitive to stress. However, plant response to drought was shown by yield decreasing; each cultivar's morphological and physiological characters also showed different responses to drought conditions. Duca (2015) stated that plant resistance is the plants' ability to grow and produce in an unfavorable environment. The capacity could be showed in morphological and physiological characters. Morphological or physiological responses of plants to stress conditions show how an adaptive genotype deals with stress. Those characters might be used as a tool to get varieties with high stability and yield and as a basis for determining plant resistance to stress. Some researchers have shown that identification of plant tolerance to stress is determined by the yield and other characters. Bacallao et al. (2016) used the fruit formation percentage, Brdar-Jokanovic et al. (2014) chose the character of maximum vegetative growth in determining the drought tolerance of a variety. Sakya et al. (2018) reported that on drought conditions there was

Table 2. Drought tolerance index of morphological and physiological characters of some lowland tomato cultivars.

Character	Cultivar	Condition		Drought indices					
		Normal	Stress	SSI	T/S*	STI	T/S*	YSI	T/S*
Plant height (cm)	Zamrud	42.23	30.75	1.72	S	0.46	S	0.73	S
	Permata F_1	49.61	36.90	1.62	S	0.64	S	0.74	S
	Mirah	60.02	56.17	0.41	T	1.19	T	0.94	T
	Tombatu F_1	59.86	45.92	1.47	S	0.97	T	0.77	S
	Tyrana F_1	57.61	57.40	0.02	T	1.16	T	1.00	T
	Ratna	54.12	35.67	2.16	S	0.68	S	0.66	S
	Tymoti F_1	49.66	51.28	-0.21	T	0.90	T	1.03	T
	Mean	53.30	44.87	1.03		0.86		0.84	
Biomass (g)	Zamrud	44.19	32.82	1.16	S	0.84	T	0.74	S
	Permata F_1	45.99	33.15	1.26	S	0.88	T	0.72	S
	Mirah	42.65	31.95	1.14	S	0.79	S	0.75	S
	Tombatu F_1	36.00	25.31	1.34	S	0.53	S	0.70	S
	Tyrana F_1	47.67	34.93	1.21	S	0.96	T	0.73	S
	Ratna	30.49	28.49	0.30	T	0.50	S	0.93	T
	Tymoti F_1	44.61	40.53	0.41	T	1.04	T	0.91	T
	Mean	41.66	32.45	0.98		0.79		0.78	
Leaf area (cm^2)	Zamrud	1034.10	798.85	1.00	T	0.90	T	0.77	T
	Permata F_1	895.40	546.30	1.71	S	0.53	S	0.61	S
	Mirah	1008.17	690.14	1.39	S	0.76	T	0.68	S
	Tombatu F_1	890.47	602.72	1.42	S	0.59	S	0.68	S
	Tyrana F_1	949.13	698.53	1.16	T	0.73	T	0.74	T
	Ratna	785.13	635.84	0.84	T	0.55	S	0.81	S
	Tymoti F_1	1131.37	798.57	1.29	S	0.99	T	0.71	T
	Mean	956.25	681.56	1.26		0.72		0.71	
Root length (cm)	Zamrud	11.70	10.07	-7.09	T	0.94	T	0.86	S
	Permata F_1	9.34	5.46	-21.13	T	0.41	S	0.58	S
	Mirah	14.83	14.86	0.10	S	1.76	T	1.00	S
	Tombatu F_1	10.22	10.89	3.31	S	0.89	S	1.07	T
	Tyrana F_1	12.00	11.64	-1.54	S	1.12	T	0.97	S
	Ratna	12.85	12.58	-1.08	S	1.29	T	0.98	S
	Tymoti F_1	7.41	14.40	47.99	T	0.85	S	1.94	T
	Mean	11.19	11.41	2.94		1.04		1.06	
Root surface area (cm^2)	Zamrud	1536.05	1104.61	4.60	S	0.99	T	0.72	S
	Permata F_1	882.04	228.97	12.12	S	0.12	S	0.26	S
	Mirah	1904.18	2105.11	-1.73	T	2.34	T	1.11	T
	Tombatu F_1	844.88	978.90	-2.60	T	0.48	S	1.16	T
	Tyrana F_1	1237.26	905.51	4.39	S	0.65	S	0.73	S
	Ratna	1686.48	1647.92	0.37	T	1.62	T	0.98	S
	Tymoti F_1	1074.44	1634.63	-8.54	T	1.02	S	1.52	T
	Mean	1309.33	1229.38	1.23		1.03		0.92	
Root shoot ratio	Zamrud	0.1240	0.1375	0.69	T	1.09	S	1.11	S
	Permata F_1	0.1080	0.1538	2.67	S	1.07	S	1.42	S
	Mirah	0.1500	0.1670	0.72	T	1.61	T	1.11	S
	Tombatu F_1	0.1042	0.1408	2.21	S	0.94	S	1.35	T
	Tyrana F_1	0.1209	0.1218	0.05	T	0.95	S	1.01	S
	Ratna	0.1527	0.1733	0.85	T	1.70	S	1.13	S
	Tymoti F_1	0.1137	0.1180	0.24	T	0.86	S	1.04	S
	Mean	0.12	0.14	1.06		1.17		1.17	
Fruit number	Zamrud	11.67	5.00	1.41	S	0.29	S	0.43	S
	Permata F_1	10.00	8.00	0.49	T	0.40	S	0.80	T
	Mirah	7.67	6.33	0.43	T	0.24	S	0.83	T
	Tombatu F_1	13.33	6.33	1.30	S	0.43	S	0.48	S
	Tyrana F_1	23.33	17.33	0.63	T	2.04	T	0.74	T
	Ratna	8.33	2.33	1.78	S	0.10	S	0.28	S
	Tymoti F_1	24.33	13.33	1.12	S	1.63	T	0.55	S
	Mean	14.10	8.38	1.02		0.73		0.59	
Fruit weight (g)	Zamrud	335.17	136.07	1.53	S	0.16	S	0.41	S
	Permata F_1	314.11	304.41	0.08	T	0.33	S	0.97	T
	Mirah	507.33	300.61	1.05	S	0.53	S	0.59	S
	Tombatu F_1	705.06	459.35	0.90	T	1.12	T	0.65	T
	Tyrana F_1	784.53	556.43	0.75	T	1.51	T	0.71	T
	Ratna	232.61	101.81	1.45	S	0.08	S	0.44	S
	Tymoti F_1	885.66	445.99	1.28	S	1.37	T	0.50	S
	Mean	537.78	329.24	1.01		0.73		0.61	

Note SSI: stress susceptibility index, STI: stress tolerance index, YSI: yield stability index. * S and T compare with the drought index value in each category. For SSI: S = susceptible (value > mean in each character) T= tolerant, value < mean in each character). For STI and YSI: S = susceptible (value < mean in each character) T= tolerant, value > mean in each character).

Table 3. Drought tolerance index of physiological character of some lowland tomato cultivars.

Character	Cultivar	Condition		Drought Indices					
		Normal	Stress	SSI	T/S*	STI	T/S*	YSI	T/S*
Relative water content (%)	Zamrud	88.54	73.50	1.10	S	0.86	T	0.83	S
	Permata F_1	91.57	75.54	1.13	S	0.91	T	0.82	S
	Mirah	86.13	78.90	0.54	T	0.89	T	0.92	T
	Tombatu F_1	87.13	79.38	0.58	T	0.91	T	0.91	T
	Tyrana F_1	85.77	65.29	1.55	S	0.74	S	0.76	S
	Ratna	85.59	76.89	0.66	T	0.87	T	0.90	T
	Tymoti F_1	85.25	66.31	1.44	S	0.74	S	0.78	S
	Mean	87.14	73.69	1.00		0.85		0.85	
Index stability membrane (leaf) (%)	Zamrud	73.2	61.7	0.91	T	0.71	S	0.84	T
	Permata F_1	74.2	65.3	0.70	T	0.76	S	0.88	T
	Mirah	86.7	69.5	1.16	S	0.94	T	0.80	S
	Tombatu F_1	83.2	69.1	0.99	T	0.90	T	0.83	S
	Tyrana F_1	83.1	73.6	0.67	T	0.96	T	0.89	T
	Ratna	74.2	53.3	1.64	S	0.62	S	0.72	S
	Tymoti F_1	85.4	71.4	0.96	T	0.95	T	0.84	T
	Mean	80.00	66.27	1.00		0.83		0.83	
Index stability membrane (toot) (%)	Zamrud	77.02	61.08	1.37	S	0.72	S	0.79	T
	Permata F_1	74.01	64.76	0.83	T	0.73	S	0.88	S
	Mirah	86.86	75.12	0.90	T	1.00	T	0.86	S
	Tombatu F_1	84.84	72.64	0.95	T	0.94	T	0.86	S
	Tyrana F_1	83.78	72.38	0.90	T	0.92	T	0.86	S
	Ratna	73.61	60.16	1.21	S	0.68	S	0.82	T
	Tymoti F_1	86.66	75.10	0.88	T	0.99	T	0.87	S
	Mean	80.97	68.75	1.01		0.85		0.85	
Chlorophyll a content (mg g^{-1})	Zamrud	0.541	0.349	1.32	S	0.81	T	0.64	S
	Permata F_1	0.527	0.374	1.08	S	0.85	T	0.71	S
	Mirah	0.494	0.389	0.79	T	0.83	T	0.79	T
	Tombatu F_1	0.436	0.333	0.87	T	0.63	S	0.77	T
	Tyrana F_1	0.477	0.401	0.58	T	0.82	T	0.84	T
	Ratna	0.439	0.271	1.42	S	0.51	S	0.62	S
	Tymoti F_1	0.461	0.346	0.92	T	0.69	S	0.75	T
	Mean	0.48	0.35	1.00		0.73		0.73	
Chlorophyll b content (mg g^{-1})	Zamrud	0.366	0.157	1.37	S	0.53	S	0.43	S
	Permata F_1	0.299	0.159	1.12	S	0.44	S	0.53	S
	Mirah	0.398	0.229	1.02	S	0.85	T	0.58	S
	Tombatu F_1	0.473	0.176	1.51	S	0.77	T	0.37	S
	Tyrana F_1	0.313	0.243	0.54	T	0.71	T	0.78	T
	Ratna	0.206	0.118	1.03	S	0.22	S	0.57	S
	Tymoti F_1	0.243	0.258	-0.15	T	0.58	S	1.06	T
	Mean	0.328	0.192	0.92		0.58		0.62	
Total chlorophyll content (mg g^{-1})	Zamrud	0.907	0.506	1.39	S	0.70	T	0.56	S
	Permata F_1	0.826	0.533	1.11	S	0.67	S	0.65	S
	Mirah	0.892	0.618	0.96	T	0.84	T	0.69	S
	Tombatu F_1	0.908	0.509	1.38	S	0.70	T	0.56	S
	Tyrana F_1	0.790	0.645	0.58	T	0.78	T	0.82	T
	Ratna	0.645	0.389	1.25	S	0.38	S	0.60	S
	Tymoti F_1	0.703	0.663	0.18	T	0.71	T	0.94	T
.	Mean	0,810	0.552	0.98		0.68		0.69	
Chlorophyll ratio a/b	Zamrud	1.478	2.223	2.21	S	1.4	T	1.50	T
	Permata F_1	1.759	2.343	1.45	S	1.68	T	1.33	S
	Mirah	1.242	1.696	1.61	S	0.86	S	1.37	S
	Tombatu F_1	0.922	1.897	4.64	S	0.71	S	2.06	T
	Tyrana F_1	1.521	1.650	0.37	T	1.02	S	1.08	S
	Ratna	2.134	2.303	0.35	T	2.01	T	1.08	S
	Tymoti F_1	1.900	1.341	-1.29	T	1.04	S	0.71	S
	Mean	1.56	1.92	1.33		1.24		1.30	
Proline (µg g^{-1})	Zamrud	5.772	24,695	0.96	S	7.14	T	4.28	S
	Permata F_1	6.194	11,888	0.27	S	3.69	S	1.92	S
	Mirah	3.159	14,756	1.08	S	2.34	S	4.67	S
	Tombatu F_1	2.554	18,739	1.86	T	2.40	S	7.34	T
	Tyrana F_1	5.733	23,623	0.92	T	6.79	T	4.12	S
	Ratna	5.859	28,477	2.63	S	4.08	S	9.96	T
	Tymoti F_1	5.001	15,649	0.62	T	3.92	S	3.13	S
	Mean	4.47	19.69	1.19		4.34		5.06	

Note SSI: stress susceptibility index, STI: stress tolerance index, YSI: yield stability index. * S and T compare with the drought index value in each category. For SSI: S = susceptible (value > mean in each character) T= tolerant, value < mean in each characteristic). For STI and YSI: S = susceptible (value < mean in each character) T= tolerant, value > mean in each character).

a high correlation between the membrane stability index and the yield, which could be as an indicator for selecting varieties on drought stress. Shamim et al. (2014) showed that the percentage of germination is not a useful indicator for determining drought tolerance.

Tomato plant tolerance in this study was measured based on a stress susceptibility index (SSI), stress tolerance index (STI), and yield stability index (YSI) of 16 morpho-physiological characters of tomato plants. The three drought indexes are important to picture changes in growth and yields both in normal and stress conditions. The three indexes would be more precised compared to one index that only provides a picture of changes in development in one of the conditions.

In this study, each index of the character's average value was used to determine drought sensitivity for each cultivar. According to Fernandez (1992), the cultivar is categorized as more drought tolerant. Therefore, a cultivar that has a lower SSI value and a higher STI and YSI values than the average value of each index of each character is categorized as a drought-tolerant cultivar. The more morphophysiological characters of a cultivar, which has a low SSI, high STI, and YSI value, show that these cultivars are tolerant to drought stress. The SSI, STI, and YSI value of some tomato cultivar's 16 morphophysiological characters are presented in Tables 2 and 3.

SSI determines the decrease in morphological and physiological characters in stress conditions compared to normal conditions. High SSI values indicate more significant character changes and lower character stability under different conditions. Cultivars with high SSI values can be considered as drought-sensitive cultivars. The cultivars showed a more substantial reduction in stressful situations (Zdravković et al., 2013; Adhikari et al., 2019).

Based on the SSI values, Zamrud, Permata F1, Ratna, and Tombatu F1 had more characters with higher SSI values than the average SSI in each character. These cultivars had 9-12 morphological characters out of 16 characters measured with a higher SSI value than the average SSI value in each character. The more characters with high SSI values, the more sensitive cultivars are to environmental stress. It indicates that Zamrud, Permata F1, Ratna, and Tombatu F1 are more susceptible to drought than Mirah, Tyrana F1, and Tymoty F1. It is in line with Zdravković et al. (2013), which used SSI based on plant height and shoot root ratio. The use of SSI to identify sensitive and tolerant cultivars was also widely applied to other plants (Ilker et al., 2011; Naghavi et al., 2013; Arunachalam and Kannan 2013; Kumar et al. 2014; Bündig et al. 2017; Ben Naceur et al. 2018).

STI and YSI in this study were to support the evaluation of characters in stress and normal conditions. As proposed by Bouslama and Schapaugh (1984), Gavuzzi et al. (1997), and Fernandez (1992), YSI and STI are used to measure the yield stability and identify genotypes that provide high yield under normal and stress conditions. Based on Tables 2 and 3, Permata F_1, Ratna, and Zamrud had 9-11 characters with lower STI and YSI than the average values in each character. This results indicates that those cultivars provide low values of corresponding traits in both normal and stress conditions. Based on STI and YSI, Zamrud, Permata F1, and Ratna were more sensitive to drought than Tombatu F1, Tymoti F1, Mirah, and Tyrana F1. Bacallao et al. (2016) also used STI, YSI, and other tolerance indexes to identify drought tolerance based on the percentage of flower formation. Several researchers took into account both indexes to classify genotype resistance and tolerance to drought through various morphological or physiological characters (Mahdi 2012; Orcen and Altinbas 2014; Negarestani et al. 2019; Muthuramu and Ragavan 2020; Sanchez-Reinoso, Ligarreto-Moreno, and Restrepo-Diaz 2020).

Classification of Tomato Cultivars Based on Drought Tolerance Index

Determination of plant tolerance to stress is often based solely on decreasing crop yield under stress conditions compared to that in optimal conditions or just based on a particular character. Sometimes this will lead to inappropriate selection decisions. Therefore, the selection of cultivar tolerance to drought in this study was based not only on one character, but also based on 16 characters calculated together. It is considered because the yield and plant tolerance to stress is a complex process involving various events in plants depicted in the morphology, physiology, and biochemistry characters.

Cluster analysis is an efficient procedure to demonstrate structural relationships between tested cultivars and classify cultivars based on cultivars' similarities. The cluster analysis based on SSI, STI, and YSI of 16 morpho-physiological characters showed that all cultivars had similarity values of 42% (Figure 1). From the seven cultivars used, two groups were formed. The first group with a 55% similarity value consisted of Ratna, Zamrud, and Permata F_1 cultivars. The second group with 46% similarity value consisted of Mirah, Tombatu F_1, Tyrana F_1, and Tymoti F_1 cultivars. Ratna, Zamrud, and Permata F_1 tend to have high SSI values, low STI and YSI thus these three cultivars can represent cultivars that are not drought tolerant. Mirah, Tombatu F_1, Tyrana F_1, and Tymoty F_1 tend to have a low SSI value, high STI and YSI values thus the four cultivars are drought-tolerant cultivars.

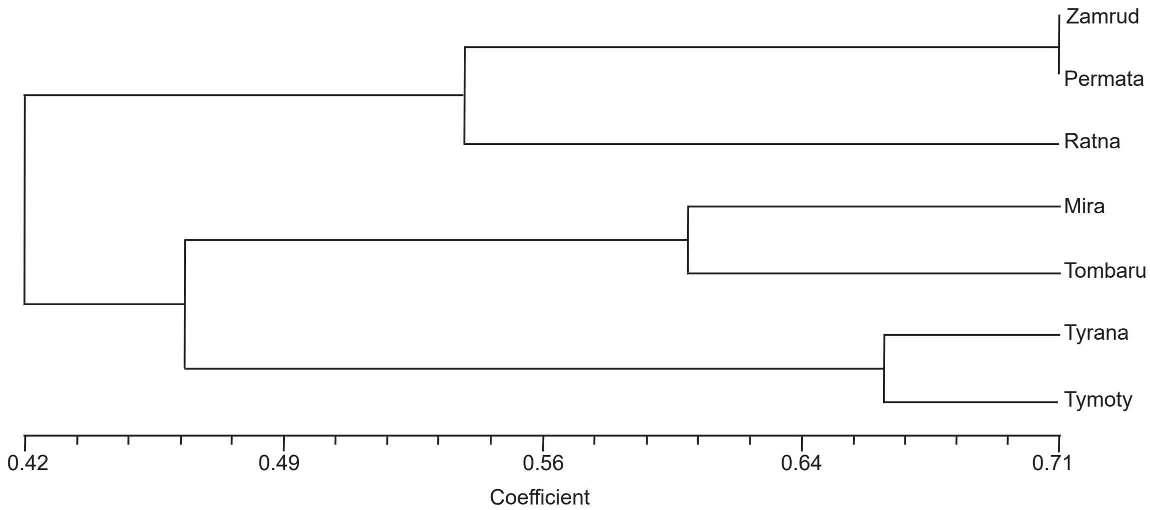

Fig. 1 Dendrogram of lowland tomato cultivars based on the similarity of drought tolerance index of morphophysiological characters

Evaluation of tomato cultivars for drought tolerance using cluster analysis was also carried out by (Aghaie et al. 2018). These researchers classified 14 tomatoes based on the drought tolerance index of growth and physiological characters into four groups: drought tolerant, moderately tolerant, sensitive, and highly sensitive cultivars. Naghavi classified eight maize cultivars into three groups based on the tolerance index: drought tolerant, semitolerant, and susceptible. The first group is a cultivar that has high STI and YSI value, and the second group is a cultivar that has an average indicator value. The third group is a cultivar that has high SSI scores, which only suitable for conditions with sufficient water (Naghavi et al. 2013). The drought tolerance index has been used as a basis to classify genotypes for drought tolerance by cluster analysis (Mahdi 2012, Gholinezhad et al. 2014; Pereira et al. 2015).

Tyrana F1, Tymoty F1, Mirah, and Tombatu F1 cultivars are drought tolerant from cluster analysis using tolerance indexes based on morphological and physiological characters. The cultivars showed a lower decrease in morphological and physiological characters in drought conditions. Tyrana F1, Tymoty F1, Mirah, and Tombatu F1 have higher plant height, leaf area, fruit number, and fruit weight. Besides, the cultivars have higher water content, chlorophyll content, proline accumulation, and lower membrane damage in drought conditions (Tables 2 and 3). Cultivars that have a higher agronomic character in drought conditions are drought tolerant. Cultivars with better seedling growth, plant height, leaf area, dry weight of plants, fruit number, and fruit weight higher in drought conditions are drought tolerant. These can be used as a promising source for drought-tolerant genotypes (Ghebremariam et al. 2013; Ghanem, Kh et al. 2016). Aghaie et al. (2018) also obtained a drought-tolerant tomato cultivar that has better plant growth, low electrolyte leakage and malondialdehyde, and high proline accumulation content.

CONCLUSION

Seven lowland tomato cultivars (Zamrud, Permata F1, Ratna, Mirah, Tombatu F1, Tyrana F1, and Tymoti F) have been evaluated for their tolerance to drought stress conditions. Four cultivars (Tyrana F_1, Tymoty F_1, Mirah and Tombatu F_1) are drought-resistant, and three cultivars (Ratna, Permata $F_{1,}$ and Zamrud F_1) are sensitive to drought. The resistant cultivars have better agronomical traits (higher plant height, leaf area, fruit number, fruit weight) and physiological characters (higher water content, chlorophyll content, proline accumulation, and lower membrane damage drought conditions). The study implies that the drought-resistant cultivars could be used as a promising source for drought tolerant genotypes.

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REFERENCES

Abou-shleel, S.M., & El Saka, ZI (2016). Evaluating different tomato genotype for drought tolerance. *Egypt Journal Plant Breeding*, 20(6), 995–1008.

Adhikari, M., Adhikari, N.R., Sharma, S., Gairhe, J., Bhandari, R.R., & Paudel, S. (2019). Evaluation of drought tolerant rice cultivars using drought tolerant indices under Water stress and irrigated condition. *American Journal of Climate Change*, 08(02), 228–236. https://doi.org/10.4236/ajcc.2019.82013.

Agarwal, S., & Rao, A.V. (2000). Tomato lycopene and its role in human health and chronic diseases. *CMAJ*, 163(6), 739–744. https://doi.org/10.1016/j.postharvbio.2004.05.023.

Aghaie, P., Hosseini Tafreshi, S.A., Ebrahimi, M.A., & Haerinasab, M. (2018). Tolerance evaluation and clustering of fourteen tomato cultivars grown under mild and severe drought conditions. *Scientia Horticulturae*, 232, 1–12. https://doi.org/10.1016/j.scienta.2017.12.041.

Almeselmani, M., Abdullah, F., Hareri, F., Naaesan, M., Adel Ammar, M., Zuher Kanbar, O., & Alrzak Saud, A. (2011). Effect of drought on different physiological characters and yield components in different varieties of Syrian durum wheat. *Journal of Agricultural Science*, *3*(3), 127–133. https://doi.org/10.5539/jas.v3n3p127.

Arunachalam, P., & Kannan, P. (2013). Screening for drought tolerant Groundnut (*Arachis hypogaea* L.) Lines Suitable for rainfed Alfisol. *Asian Journal of Agricultural Research*, 7(1), 35–42.

Bacallao, M.F., Fundora, L.B., Rodríguez, R.M,L., Gil. M,A., Hurtado, F.D., & Scull, T.S. (2016). Evaluation of drought tolerance in tomato (*Solanum lycopersicum*) using tolerance indices. *Cultivos Tropicales*, *37*(1), 128–135. https://doi.org/10.13140/RG.2.1.3064.2804.

Bates, L.S., Waldren, R.P., & Teare, I.D. (1973). Rapid determination of free proline for water-stress studies. *Plant and Soil*, 39(1), 205–207. https://doi.org/10.1007/BF00018060.

Ben Naceur, A., Cheikh-MHamed, H., Abdelly, C., & Ben Naceu, M. (2018). Screening of North African barley genotypes for drought tolerance based on yields using tolerance indices under Water deficit conditions. *Turkish Journal of Field Crops*, 23(2), 135–145. https://doi.org/10.17557/tjFC.471686.

Bouslama, M., & Schapaugh, W.T. (1984). Stress tolerance in soybeans. I. Evaluation of three screening techniques for heat and drought tolerance 1.*Crop Science*, *24*(5), 933–937. https://doi.org/10.2135/cropsci1984.0011183x002400050026x.

B.P.S. (2017). Statistik Tanaman Sayuran dan Buah-buahan Semusim. *Statistik Indonesia*. Jakarta: Badan Pusat Statistik.

BPS (2018). Statistik Tanaman Sayuran dan Buah-Buahan Semusim Indonesia 2018. Jakarta: Badan Pusat Statistik. https://www.bps.go.id/publication/2019/10/07/9c5dede 09c805bc38302ea1c/statistik-tanaman-sayuran-dan-buah-buahan-semusim-indonesia-2018.html

Brdar-Jokanović, M., Girek, Z., Pavlović, S., Ugrinović, M., & Zdravković, J. (2014). Shoot and root dry weight in drought exposed tomato populations. *Genetika*, 46(2), 495–504. https://doi.org/10.2298/GENSR1402495B.

Bündig, C., Vu, T.H., Meise, P., Seddig, S., Schum, A., & Winkelmann, T. (2017). Variability in osmotic stress tolerance of starch potato genotypes (*Solanum tuberosum* L.) as revealed by an in vitro screening: role of proline, osmotic adjustment and drought response in pot trials. *Journal of Agronomy and Crop Science*, 203(3), 206–218. https://doi.org/10.1111/jac.12186.

Calcagno, A. M., Rivas, M., & Castrillo, M. (2011). Structural, physiological and metabolic integrated responses of two tomatoes (*Solanum lycopersicum* L.) cultivars during leaf rehydration. *Australian Journal of Crop Science*, *5*(6), 695–701.

Castrillo, M., Fernandez, D., Calcagno, A. M., Trujillo, I., & Guenni, L. (2001). Responses of ribulose-1,5-bisphosphate carboxylase, protein content, and stomatal conductance to Water deficit in maize, tomato, and bean. *Photosynthetica*. https://doi.org/10.1023/A:1013731210309.

Chun, S.C., Paramasivan, M., & Chandrasekaran, M. (2018). Proline accumulation influenced by osmotic stress in arbuscular mycorrhizal symbiotic plants. *Frontiers in Microbiology*, 9(October), 1–13. https://doi.org/10.3389/fmicb.2018.02525.

Cui, J., Shao, G., Lu, J., Keabetswe, L., & Hoogenboom, G. (2020). Yield, quality and drought sensitivity of tomato to water deficit during different growth stages. *Scientia Agricola*, 77(2), 1–7. https://doi.org/10.1590/1678-992x-2018-0390.

Fernandez, G.C.J. (1992). Effective selection criteria for assessing plant stress tolerance. In *Adaptation of Food Crops to Temperature and Water Stress.* Ed. Kuo, C.G. Proceedings of International Symposium on Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress. 257-270.

Fischer, R.A., & Maurer, R. (1978). Drought resistance in spring wheat cultivars. I. Grain yield responses. *Australian Journal of Agricultural Research*, *29*(5), 897–912. https://doi.org/10.1071/AR9780897.

Gavuzzi, P., Rizza, F., Palumbo, M., Campanile, R.G., Ricciardi, G.L., & Borghi, B. (1997). Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. *Canadian Journal of Plant Science*, *77*(4), 523–532. https://doi.org/10.4141/P96-130.

George, S., Minhas, N.M., Jatoi, S.A., Siddiqui, S.U., & Ghafoor, A. (2015). Impact of polyethylene glycol on proline and membrane stability index for Water stress regime in tomato (*Solanum lycopersicum*). *Pakistan Journal of Botany*, 47(3), 835–844.

Gholinezhad, E., Darvishzadeh, R., & Bernousi, I. (2014). Evaluation of drought tolerance indices for selection of confectionery sunflower (*Helianthus annuus* L.) landraces under various environmental conditions. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 42(1), 187–201. https://doi.org/10.15835/nbha4219394.

Hayat, S., Hasan, S. A., Fariduddin, Q., & Ahmad, A. (2008). Growth of tomato (*Lycopersicon esculentum*) in response to salicylic acid under Water stress. *Journal of Plant Interactions*, *3*(4), 297–304. https://doi.org/10.1080/ 17429140802320797.

Hayat, S., Hayat, Q., Alyemeni, M.N., Wani, A.S., Pichtel, J., & Ahmad, A. (2012). Role of proline under changing environments: A review. *Plant Signaling and Behavior*, 7(11), 1456–1466. https://doi.org/ 10.4161/psb.21949.

Ilker, E., Tatar, Ö., Aykut Tonk, F., & Tosun, M. (2011). Determination of tolerance level of some wheat genotypes to post-anthesis drought. *Turkish Journal of Field Crops*, 16(1), 59–63. https://doi.org/10.17557/tjFC.25945.

Islam, M.S., Hasanuzzaman, M., Rokonuzzaman, M., & Nahar, K. (2009). Effect of split application of nitrogen fertilizer on morphophysiological parameters of rice genotypes. *International Journal of Plant Production*, 3(1), 51–62. https://doi.org/10.22069/ijpp.2012.631.

Khan, M., Hoque, M., Farooque, A., Habiba, U., & Rahim, M. (2012). Physio-morphological features of chilli accessions under moisture stress conditions. *Bangladesh Journal of Agricultural Research*, *37*(2), 263–269. https://doi.org/10.3329/bjar.v37i2.11229.

Khan, S.H, Khan, A., Litaf, U., Shah, A.S., Khan, M.A.L, Bilal, M., & Ali, M. U. (2015). Effect of drought stress on tomato cv. Bombino. *Journal of Food Processing & Technology*, *06*(07), 465–470. https://doi.org/10.4172/2157-7110.1000465.

Kumar, S., Dwivedi, S. K., Singh, S.S., Jha, S.K., S, Lekshmy, Elanchezhian, R., Singh, O.N., & Bhatt, B.P. (2014). Identification of drought tolerant rice genotypes by analyzing drought tolerance indices and morpho-physiological traits. *Sabrao Journal of Breeding and Genetics*, *46*(2), 217–230.

Liang, G., Liu, J., Zhang, J., & Guo, J. (2020). Effects of drought stress on photosynthetic and physiological parameters of tomato. *Journal of the American Society for Horticultural Science*, 145(1), 12–17. https://doi.org/10.21273/JASHS04725-19.

Lin, C.S., & Binns, M.R. (1988). A superiority measure of cultivar performance for cultivar × location data. *Canadian Journal of Plant Science*, *68*(1), 193–198. https://doi.org/10.4141/cjps88-018.

Lippi, G., & Targher, G. (2011). Tomatoes, lycopene-containing foods and cancer risk. *British Journal of Cancer*, 104(7), 1234–1235. https://doi.org/10.1038/bjc.2011.59.

Mahdi, Z. (2012). Evaluation of drought tolerance indices for the selection of Iranian barley (Hordeum vulgare) cultivars. *African Journal of Biotechnology*, 11(93), 15975–15981. https://doi.org/10.5897/ajb12.2127.

Martí, R., Roselló, S., & Cebolla-Cornejo, J. (2016). Tomato as a source of carotenoids and polyphenols targeted to cancer prevention. *Cancers*, 8(6), 1–28. https://doi.org/10.3390/cancers8060058.

Muthuramu, S., & Ragavan, T. (2020). Studies on indices and morphological traits for drought tolerance in rainfed rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding*, 11(1), 1–5. https://doi.org/10.37992/ 2020.1101.001.

Naghavi, M.R., Pour-Aboughadareh, A., & Khalily, M. (2013). Evaluation of drought tolerance indices for screening some corn (*Zea mays* L.) cultivars under environmental conditions. *Notulae Scientia Biologicae*, 5(3), 388–393. https://doi.org/10.15835/nsb539049.

Nahar, K, & Gretzmacher, R. (2011). Response of shoot and root development of seven tomato cultivars in hydroponic system under Water stress. *Academic Journal of Plant Sciences*, *4*(2), 57–63.

Nahar, K. & Gretzmacher, R. (2002). Effect of Water stress on nutrient uptake, yield and quality of tomato (*Lycopersicon esculentum* Mill.) under subtropical conditions. *Bodenkultur*, *53*(1), 45–51.

Narváez-Ortiz, W.A., Becvort-Azcurra, A.A., Fuentes-Lara, L.O., Benavides-Mendoza, A., Valenzuela-García, J.R., & González-Fuentes, J.A. (2018). Mineral composition and antioxidant status of tomato with the application of selenium. *Agronomy*, 8(9), 1–16. https://doi.org/10.3390/agronomy8090185.

Orcen, N., & Altinbas, M. (2014). Use of some stress tolerance indices for late drought in spring wheat. *Fresenius Environmental Bulletin*, 23(9A), 2289–2293.

Palozza, P., Simone, R.E., Catalano, A., & Mele, M.C. (2011). Tomato lycopene and lung cancer prevention: From experimental to human studies. *Cancers*, 3(2), 2333–2357. https://doi.org/10.3390/cancers3022333.

Pereira, J.W.de L., da Silva, E.C.A., da Luz, L.N., Nogueira, R. J. M. C, Filho, P. de A.M., de Lima, L.M., & dos Santos, R.C. (2015). Cluster analysis to select peanut drought tolerance lines. *Australian Journal of Crop Science*, 9(11), 1095–1105.

Pervez, M.A, Ayub, C M., Khan, H.A, Shahid, M.A & Ashraf, I. (2009). Effect of drought stress on growth, yield and seed quality of tomato (*Lycopersicon esculentum* L.). *Pakistan Journal of Agricultural Science*, *46*(3), 174–178. https://doi.org/none.

Purwati. (2007). Varietas unggul harapan tomat hibrida (F1) dari Balitsa. *Iptek Hortikultura*, *3*, 34–40.

Rohlf, F.J. (1998). NTSYS-pc, numerical taxonomy and multivariate system. version 2.0. *Exeter Software, New York*.

Rosielle, A.A., & Hamblin, J. (1981). Theoretical aspects of selection for yield in stress and non-stress environments. *Crop Science*, *21*(Nov-Dec), 943–946.

Sakya, A.T., Sulistyaningsih, E., Indradewa, D., & Purwanto, B.H. (2018). Physiological characters and tomato yield under drought stress. IOP Conference Series: *Earth and Environmental Science*, 200(1). https://doi.org/10.1088/1755-1315/200/1/012043.

Sanchez-Reinoso, A.D., Ligarreto-Moreno, G,A., & Restrepo-Diaz, H. (2020). Evaluation of drought indices to identify tolerant genotypes in common bean bush (*Phaseolus vulgaris* L.). *Journal of Integrative Agriculture*, *19*(1), 99–107. https://doi.org/10.1016/S2095-3119(19)62620-1.

Sánchez-Rodríguez, E., Rubio-Wilhelmi, M., Cervilla, L.M., Blasco, B., Rios, J. J., Rosales, M.A., Romero, L., & Ruiz, J.M. (2010). Genotypic differences in some physiological parameters symptomatic for oxidative stress under moderate drought in tomato plants. *Plant Science*, *178*(1), 30–40. https://doi.org/10.1016/j.plantsci.2009.10.001.

Shamim, F., Saqlan, S.M., Athar, HUR, & Waheed, A. (2014). Screening and selection of tomato genotypes/cultivars for drought tolerance using multivariate analysis. *Pakistan Journal of Botany*, 46(4), 1165–1178.

Shamshiri, R.R., Jones, J.W., Thorp, K.R., Ahmad, D., Man, H.C., & Taheri, S. (2018). Review of optimum temperature, humidity, and vapour pressure deficit for microclimate evaluation and control in greenhouse cultivation of tomato: A review. *International Agrophysics*, 32(2), 287–302. https://doi.org/10.1515/intag-2017-0005.

Shao, H.B., Chu, L.Y., Jaleel, CA, & Zhao, C.X. (2008). Water-deficit stress-induced anatomical changes in higher plants. *Comptes Rendus - Biologies*, *331*(3), 215–225. https://doi.org/10.1016/j.crvi.2008.01.002.

Sun, W.H., Wu,Y.Y., Wen, X.Y., Xiong, S.J., He, H.G., Wang, Y., & Lu, GQ. (2016). Different mechanisms of photosynthetic response to drought stress in tomato and violet orychophragmus. *Photosynthetica*, *54*(2), 226–233. https://doi.org/10.1007/s11099-015-0177-3.

Trahanias, P., & Skordalakis, E. (1989). An efficient sequential clustering method. *Pattern Recognition*, *22*(4), 449–453. https://doi.org/10.1016/0031-3203(89)90053-8.

Zdravković, J., Jovanović, Z., Djordjević, M., Girek, Z., Zdravković, M., & Stikić, R. (2013). Application of stress susceptibility index for drought tolerance screening of tomato populations. *Genetika*, *45*(3), 679–689. https://doi.org/10.2298/GENSR1303679Z.