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CHANGES IN FRUIT YIELD AND PHOTOSYNTHESIS PARAMETERS IN DIFFERENT OLIVE CULTIVARS (*Olea europaea* L.) UNDER CONTRASTING WATER REGIMES

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ABSTRACT

The evergreen tree olive (*Olea europaea* L.) is the only species of the genus *Olea* that produces edible fruits with high ecological and economic value. This tree species has developed a series of physiochemical mechanisms to tolerate drought stress and grow under adverse climatic environments. One of these mechanisms is photosynthesis activities, so that as yet little information achieved about the relations between olive production and photosynthetic parameters under drought conditions. An experiment was carried out during two consecutive years (2015–2017) to study the response of 20 different olive tree cultivars (*Olea europaea* L.) to drought stress. Several parameters like net photosynthetic rate (PN), stomatal conductance (GS), transpiration rate (TE), photosynthetic pigments (total chlorophyll, chlorophyll a, b and carotenoid) and fruit yield were measured. The results of combined analysis of variance for fruit yield and other measured traits showed that year, drought treatment, cultivar main effects and their interactions were highly significant. The results indicated that drought stress reduced all traits, however GS (42.80%), PN (37.21%) and TE (37.17%) significantly affected by drought. Lower reduction in photosynthetic performance (PN, GS and TE) in the cultivar T7 compared to other olive cultivars allowed them to maintain better fruit yield. Principal component analysis (PCA) identified two PCs that accounted for 82.04 and 83.27% of the total variation in photosynthetic parameters under optimal and drought stress conditions, respectively. Taken together, mean comparison, relative changes due to drought and biplot analysis revealed that cultivars 'T7', 'Roghani', 'Koroneiki', 'Korfolia' and 'Abou-satl' displayed better response against drought stress. According to our results, one olive cultivar namely 'T7', could be used in olive breeding programs to improve new high yielding cultivars with drought tolerance for use in the drought-prone environments.

Key words: chlorophyll content, drought stress, fruit yield, olive, photosynthetic performance

INTRODUCTION

The evergreen tree olive (*Olea europaea* L.) is considered as one of the oldest plants cultivated in the Mediterranean basin. This plant is the only species of the genus *Olea* that produces edible fruits with high ecological and economic value [Sorrentino et al. 2016]. According to food agriculture organization

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(FAO) report', the olives production is persistently increasing in recent years worldwide by 20.3 million tons in 2013, the second highest production level ever accomplished [FAOSTAT 2015]. Olive trees mainly are grown in arid and semi-arid areas, where plants are frequently endangered to water stress and high temperatures. During the summer, Mediterranean crops' are often subjected to periods of severe water stress that may cause significant yield losses [Boussadia et al. 2008]. Drought as the main edaphic stress affects plant growth and dramatically limits agricultural productivity in many areas [Comas et al. 2013, Ahmadi et al. 2018]. This stress can simultaneously affect many qualitative and quantitative traits and ultimately reduce yield performance [Cochard et al. 2002].

In olive tree similar to other plants, water stress can decrease photosynthesis rate, limit stomatal conductance, reduce photosynthetic pigments content and oxidative stress [Dias et al. 2018]. Under drought conditions, a higher photosynthetic rate is an important factor for better drought tolerance in olive cultivars, and differences in drought tolerance among cultivars can be related to various physiological factors [Bacelar et al. 2006]. Most works focusing on olive responses to water stress conditions have emphasized photosynthetic and growth aspects [Giorio et al. 1999, Moriana et al. 2002, Boussadia et al. 2008, Ahmed et al. 2009, Dias et al. 2018]. Among traits related to photosynthetic capacity, stomatal conductance (*Gs*) is a major physiological parameter to optimize the use of water in drought conditions. This parameter estimates the rate of gas exchange through the degree of physical resistance to the movement of gases between the interior of the leaf and the air [Pour-Aboughadareh et al. 2017]. Giorio et al. [1999] reported the good positive association between stomatal conductance and leaf water potential under drought stress. Furthermore, it is demonstrated damage to photosynthetic pigments as a result of drought stress [Bouchemal et al. 2016]. Chlorophyll content (including both chlorophyll *a* and *b*) is susceptible to drought stress, the effects of which may affect plant performance. Because higher chlorophyll content has been associated to drought tolerance, the selection of cultivars based on increased or stable chlorophyll content may inhibit yield losses under drought stress [Kadkhodaie et al. 2014]. Also, the analysis of chlorophyll fluorescence is considered as a crucial technique for evaluating the impeccability of the internal mechanism within leaf during the photosynthetic events, and provides an accurate way for estimating the damage to light reaction systems in photosynthetic systems and discovery of plants tolerant to drought stress [Percival and Sheriffs 2002]. Recently, Dias et al. [2018] evaluated chlorophyll fluorescence and biochemical responses to drought stress in the different olive cultivars, so that their results revealed positive relationships between drought tolerance and the photosynthetic pigments content and fluorescence. In other words, they reported that in the tolerant cultivar, pigments content, maximum and quantum yield of photosystem II (PSII) less affected by drought stress.

Although many studies that were focused on olive tree responses to drought conditions demonstrated considerable genetic variation for drought stress tolerance, little information achieved about the relations between olive drought tolerance and photosynthetic parameters. So, we assumed that photosynthetic indices associated with different genotypic drought tolerance levels in olive cultivars. Hence, the main objectives of this study were (i) to determinate relationships among fruit yield and photosynthetic parameters under drought conditions and (ii) grouping of the different olive cultivars in terms of their responses to drought stress.

MATERIALS AND METHODS

Site description and experimental design. The study was carried out during two consecutive years (2015–2017) in the Tarom Research Orchard (Latitude 36°47, Longitude 49°6, Altitude 335 m a.l.s.), located in the Zanjan province, from the 100 Km Zanjan City, Iran. The climate was characterized by mean annual precipitation of 145 mm per year, annual minimum temperature of 12.5°C, annual maximum temperature of 19.5°C, and mean of annual evaporations 1229.4 mm. The experiment was a two-way factorial arranged in a randomized complete blocks design with three replications. Two levels of irrigation–including full irrigation (100% FC) field capacity (control) and drought stress conditions (50% FC) – were selected as the first factor. Duration of each irrigation, the second factor was 18-year-old trees of twenty olive cultivars

Table 1. List of the studied olive cultivars in the present work

No	Cultivar	Origin	No	Cultivar	Origin
1	'T2'	Iran	11	'Zard'	Iran
2	'T6'	Iran	12	'Roghani'	Iran
3	'T7'	Iran	13	'Mari'	Iran
4	'T10'	Iran	14	'Beladi'	Lebanon
5	'T17'	Iran	15	'Mission'	USA
6	'T19'	Iran	16	'Manzanilla'	Spain
7	'T20'	Iran	17	'Koroneiki'	Greece
8	'T21'	Iran	18	'Kalamata'	Greece
9	'T18'	Iran	19	'Korfolia'	Spain
10	'T24'	Iran	20	'Abou-satl'	Syria

(including 10 new promising genotypes, 3 local cultivars and 7 commercial cultivars). Detailed information on the tested cultivars is in Table 1. During the growth period of the trees until the endocarp stage (until August 3), drought treatments were applied based on 50% of the field capacity (FC = 50%) for each tree. The FC for each plot was estimated according to Gholami et al. [2016]. Each plot consisted of six tress, and distance among them was 8 m. From each olive cultivar, two trees were selected to sampling and several parameters were record as detailed below.

Net photosynthetic rate (P_N), stomatal conductance (*Gs*) and transpiration rate (T_E). The P_N, G_S and T_E parameters of the leaves were measured using plant photosynthesis meter (LCi Analyser, ADC BioScientific Ltd., England). The measurements were recorded on the 10 leaves of each cultivar, and the data were averaged.

Photosynthetic pigments and fruit yield. Chlorophyll and carotenoid contents were measured according to the method of Lichtenthaler and Wellburn [1983] with little modification. Briefly, 250 mg leaves ground in 10 mL of 80% (v/v) acetone. The solution was centrifuged at 6,000 *g* for 10 min. The supernatant was analyzed by spectrophotometry (HALO DB-20 UV/VIS) at 470, 646 and 663 nm to obtain the concentrations of chlorophyll *a*, chlorophyll *b* and carotenoid using the following equations:

$$\text{Chlorophyll } a \text{ (mg g}^{-1}\text{ FW)} = $$
$$= (12.21 \times \text{Abs } 663) - (2.81 \times \text{Abs } 646)$$

$$\text{Chlorophyll } b \text{ (mg g}^{-1}\text{ FW)} = $$
$$= (20.13 \times \text{Abs } 646) - (5.03 \times \text{Abs } 663)$$

$$\text{Total chlorophyll (mg g}^{-1}\text{ FW)} = $$
$$= \text{Chlorophyll } a + \text{Chlorophyll } b$$

$$\text{Total carotenoid (mg g}^{-1}\text{ FW)} = $$
$$= [(1000 \times \text{Abs } 470) - 3.27 \text{ (mg chlorophyll } a) -$$
$$- 104 \text{ (mg chlorophyll } a)] / 229$$

To estimate fruit yield (kg tree^{-1}), six trees from each plot were harvested at the repining time.

Statistical analysis

Prior to data analysis, the fulfillment of the ANOVA requirements like becoming the data and the residuals normal distribution as well as the homogeneity of variance was analyzed. Combined analysis of variance (ANOVA) was performed suing SAS software (SAS Institute, Cary, NC, USA). Significant differences among the means of treatments were determined by Least Significant Differences (LSD) test at $P < 0.05$.

To discover correlations among different photosynthetic traits and fruit yield, principal component analysis (PCA) was performed using the XLSTAT package (Addisonsoft XLSTAT, Paris).

RESULTS

Net photosynthetic rate (P_N), stomatal conductance (Gs) and transpiration rate (T_E). Drought stress significantly affected P_N, *Gs* and T_E, with significantly differences among years and cultivars. The all interaction between years, drought stress, cultivars were significant (Supplemental Tab. S1). The overall means across 20 olive cultivars for P_N, *Gs* and T_E reduced by 37.21, 42.80 and 37.17%, respectively (Tab. 2). Net photosynthetic rate ranged from 0.31 to 11.35 μmol m^{-2} s^{-1} with 6.50 and 4.08 μmol m^{-2} s^{-1} under optimal and drought conditions, respectively (Tab. 2). Under drought stress, the lowest reduction of net photosynthetic rate was recorded to 'Koroneiki' followed by 'T7' and 'T10' cultivars (Tab. 3). Stomatal conductance varied between 0.01 and 0.18 mol m^{-2} s^{-1} with an average of 0.07 and 0.04 mol m^{-2} s^{-1} under optimal and drought stress condition, respectively (Tab. 2). Among different cultivars, 'Mari' in the optimal condition had the highest *Gs*, while cultivar 'T24' showed the lowest value. However, cultivars 'T7', 'T10' and 'Koroneiki' disclosed the lowest reduction than other cultivars (Tab. 3). The studied cultivars also showed the high variation in transpiration rate. Across two studied years, T_E ranged from 0.16 to 4.26 mg m^{-2} s^{-1}, with an average of 1.57 mg m^{-2} s^{-1} under drought condition. The minimum and maximum values were recorded for cultivars 'T24' and 'T18' under drought and optimal conditions, respectively (Tab. 2). Similarly, three cultivars 'Koroneiki', 'T10' and 'T7' with the lowest reduction were identified as the best cultivars (Tab. 3).

Photosynthetic pigments. The drought stress treatments significantly affected total chlorophyll (Chl *T*), chlorophyll *a* (Chl *a*) and chlorophyll *b* (Chl *b*) contents and the amount of total carotenoids (CAR) (Tab. 2). Differences in these pigments were

Table 2. Combined analysis of variance, mean values and percentage change in measured traits in 20 different olive cultivars

Source of variation	df	Mean square							
		P_N	G_S	T_E	Chl *a*	Chl *b*	Chl *T*	CAR	Yield
Year (Y)	1	51.20**	0.034**	4.88**	181.79**	6.99**	260.11**	2052.22**	5782.01**
R/Y	4	0.5	0.0001	0.04	0.56	0.002	0.611	113.32	68.34
Drought (D)	1	350.57**	0.61**	51.81**	20.59**	35.98**	111.03**	71354.08**	1135.35**
Y × D	1	14.48**	0.004**	1.54**	0.11*	0.19**	0.61**	1.69^{ns}	72.60^{ns}
Cultivar (C)	19	22.15**	0.003**	2.11**	34.31**	1.89**	50.44**	2488.37**	1793.93**
Y × C	19	11.38**	0.002**	1.08**	0.18**	0.01**	0.27**	2.13^{ns}	1520.85**
S × C	19	8.07**	0.002**	0.96**	35.81**	2.60**	55.98**	5208.35**	110.94*
Y × D × C	19	8.28**	0.002**	1.58**	0.19**	0.014**	0.31**	2.24^{ns}	69.88^{ns}
Error	156	1.159	0.0001	0.09	0.02	0.002	0.028	14.62	62.97
Coefficient of variance (%)		20.36	18.79	15.16	1.34	1.77	1.19	2.44	18.8
Mean for optimal condition		6.50	0.07	2.50	12.04	2.69	14.73	174.21	44.39
Mean for drought condition		4.08	0.04	1.57	11.46	1.92	13.37	139.73	40.04
Percentage of change due to drought		37.21	42.80	37.17	4.87	28.77	9.23	19.80	9.80

^{ns} Non-significant. * Significant at 0.05 probability levels. ** Significant at 0.01 probability levels. P_N – net photosynthetic rate (mol m^{-2} s^{-1}), G_S – stomatal conductance (mol m^{-2} s^{-1}), T_E – transpiration rate (mg m^{-2} s^{-1}), Chl *a* – chlorophyll *a* content (mg g^{-1} FW), Chl *b* – chlorophyll *b* content (mg g^{-1} FW), Chl *T* – the total chlorophyll content (mg g^{-1} FW), CAR – the total carotenoid content (mg g^{-1} FW), Yield – fruit yield (kg $tree^{-1}$)

Table 3. Mean values and percentage changes due to drought stress on measured traits in the 20 olive cultivars under optimal and drought stress conditions across two years

Year	Cultivar	P_N			Gs			T_E			Fruit yield		
		C	D	R	C	D	R	C	D	R	C	D	R
1st	'T2'	7.03	3.99	43.17	0.07	0.04	44.83	2.36	1.44	38.92	57.00	52.67	7.60
	'T6'	5.27	4.28	18.87	0.06	0.04	26.09	2.07	1.80	13.15	33.67	27.67	17.82
	'T7'	5.20	4.78	8.08	0.06	0.05	13.79	2.11	2.05	3.08	64.67	54.00	16.49
	'T10'	5.51	4.66	15.43	0.06	0.05	13.64	2.16	1.94	10.29	32.67	31.00	5.10
	'T17'	5.90	3.16	46.50	0.07	0.03	55.56	2.39	1.02	57.23	40.00	39.00	2.50
	'T18'	6.65	3.92	40.99	0.09	0.04	52.94	3.00	1.68	44.13	31.17	24.50	21.39
	'T19'	4.90	3.74	23.72	0.06	0.04	39.13	2.40	1.56	35.04	50.17	42.50	15.28
	'T20'	5.53	3.23	41.58	0.05	0.04	33.33	2.14	1.47	31.38	35.17	32.00	9.00
	'T21'	4.83	2.96	38.82	0.06	0.03	47.83	1.97	1.34	31.98	26.33	24.83	5.70
	'T24'	3.71	1.62	56.34	0.03	0.02	38.46	1.42	0.59	58.66	29.00	20.33	29.89
	'Zard'	7.05	1.40	80.20	0.08	0.03	59.38	2.50	1.15	54.05	69.83	49.67	28.88
	'Roghani'	10.33	6.55	36.66	0.11	0.07	30.95	3.52	2.13	39.33	51.50	49.50	3.88
	'Mari'	7.46	3.60	51.74	0.11	0.02	82.22	2.87	1.01	64.72	43.83	31.33	28.52
	'Bleydi'	7.18	2.98	58.55	0.09	0.03	62.86	3.35	1.50	55.12	49.00	40.67	17.01
	'Mission'	7.77	5.00	35.65	0.09	0.05	45.95	3.01	1.76	41.49	45.83	40.33	12.00
	'Manzanilla'	4.84	4.27	11.87	0.05	0.04	25.00	1.89	1.39	26.59	45.50	43.33	4.76
	'Koroniki'	6.33	6.15	2.84	0.08	0.08	3.85	2.45	2.39	2.55	47.17	43.00	8.83
	'Kalamata'	7.74	2.46	68.21	0.09	0.02	76.11	2.64	0.92	65.22	27.67	24.83	10.24
	'Korfoliya'	9.19	6.80	26.03	0.11	0.08	31.82	3.04	2.32	23.66	57.67	54.67	5.20
	'Abou-satl'	8.11	5.47	32.57	0.09	0.05	43.24	2.78	1.98	28.83	63.83	60.17	5.74
	LSD (0.05)	2.467			0.016			0.497			12.80		

Year	Cultivar	Chl *a*			Chl *b*			Chl *T*			CAR		
		C	D	R	C	D	R	C	D	R	C	D	R
2nd	'T2'	16.95	15.72	7.24	4.04	2.65	34.30	20.98	18.37	12.45	218.22	147.58	32.37
	'T6'	13.55	12.89	4.87	2.85	2.28	19.83	16.40	15.17	7.47	178.51	153.52	14.00
	'T7'	12.38	9.31	24.80	2.00	1.80	10.24	14.38	11.11	22.77	155.92	155.61	0.20
	'T10'	14.19	12.99	8.45	2.80	2.14	23.63	16.99	15.13	10.95	167.47	155.88	6.92
	'T17'	10.36	10.30	0.58	1.98	1.63	17.74	12.34	11.93	3.33	135.86	120.03	11.65
	'T18'	11.89	10.25	13.77	2.37	1.63	31.24	14.26	11.88	16.68	157.98	116.29	26.39
	'T19'	13.90	11.60	16.53	2.47	2.43	1.67	16.37	14.03	14.29	168.75	135.14	19.92
	'T20'	11.29	10.38	8.02	2.20	1.98	10.16	13.49	12.36	8.37	146.54	143.23	2.26
	'T21'	12.35	8.52	30.98	2.59	1.46	43.43	14.94	9.99	33.14	173.61	141.96	18.23
	'T24'	17.93	10.38	42.10	3.49	2.11	39.52	21.42	12.49	41.68	211.37	143.51	32.10
	'Zard'	10.99	10.35	5.81	2.44	1.92	21.36	13.43	12.27	8.64	160.08	148.43	7.28
	'Roghani'	12.51	11.23	10.21	2.56	1.95	23.65	15.07	13.19	12.49	166.08	135.93	18.15
	'Mari'	10.60	9.48	10.53	2.75	2.12	22.85	13.35	11.61	13.07	158.71	147.70	6.94
	'Bleydi'	15.85	9.20	41.93	3.89	1.56	59.80	19.73	10.77	45.45	225.63	133.39	40.88
	'Mission'	11.92	7.49	37.16	2.63	1.05	59.89	14.55	8.55	41.27	185.35	104.67	43.53
	'Manzanilla'	11.45	9.97	12.88	3.68	1.68	54.53	15.13	11.65	23.02	211.47	133.52	36.86
	'Koroniki'	12.27	10.00	18.46	2.57	1.50	41.50	14.83	11.50	22.45	185.75	124.06	33.21
	'Kalamata'	11.39	6.63	41.83	2.53	1.03	59.38	13.92	7.65	45.02	179.53	99.51	44.57
	'Korfoliya'	12.76	10.74	15.83	2.84	1.96	31.19	15.60	12.69	18.63	184.82	144.20	21.98
	'Abou-satl'	14.42	10.03	30.44	3.40	1.23	63.90	17.82	11.26	36.82	206.67	116.29	43.73
	LSD (0.05)	1.633			1.614			1.629			8.048		

C – optimal condition, D – drought stress condition, R – relative change due to drought stress, P_N – net photosynthetic rate (mol m^{-2} s^{-1}), G_S – stomatal conductance (mol m^{-2} s^{-1}), T_E – transpiration rate (mg m^{-2} s^{-1}), Chl *a* – chlorophyll *a* content (mg g^{-1} FW), Chl *b* – chlorophyll *b* content (mg g^{-1} FW), Chl *T* – the total chlorophyll content (mg g^{-1} FW), CAR – the total carotenoid content (mg g^{-1} FW), Yield – fruit yield (kg $tree^{-1}$)

observed among years and cultivars. The interaction between drought stress treatments and cultivars was significant for all traits. However, the interactions between years, drought stress treatment and cultivars were only significant for Chl *a*, Chl *b* and Chl *T*. Drought stress decreased Chl *a* compared to the optimal condition (4.87%), with an overall mean of 12.04 and 11.46 mg g^{-1} FW (leave fresh weight) in the optimal and drought-stressed plants, respectively. Drought stress induced the most reduction of Chl *a* in cultivars 'T24', 'Kalamata' and 'Beleydi', whereas 'T6', 'T17' and Zard showed the lowest reduction in the Chl *a* (Tab. 3). Under drought stress, the Chl *b* and Chl *T* averaged across all cultivars declined about 28.77 and 9.23% compared to the optimal condition. The Chl b ranged from 0.95 to 4.34 mg g^{-1} FW and the lowest reduction was recorded for 'T19' followed by 'T20' and 'T7'. Moreover, the Chl *T* varied between 7.09 and 23.01 mg g^{-1} FW with an average of 13.37 and 14.73 mg g^{-1} FW under drought and optimal conditions, respectively. Among different tested cultivars, 'T6', 'T17' and 'T20' showed the lowest reduction in comparison with others. Similarly, the total carotenoid decreased from 229.60 to 97.87 mg g^{-1} FW. The overall mean of the 20 cultivars for this pigment decreased by 19.80%, under drought condition (Tab. 2), and 'T7', 'T10' and 'T20' showed the lowest reduction of carotenoid contents (Tab. 3).

Drought stress decreased fruit yield. The drought stress treatments significantly affected fruit yield (Tab. 2). Differences in this trait were also observed among years and cultivars. The all interactions between years and drought stress treatments, years and cultivars as well as drought stress treatment and cultivars were significant. Drought stress significantly affected fruit yield which decreased by 9.80% across the 20 cultivars from 79.33 kg $tree^{-1}$ in the optimal to 16.33 kg $tree^{-1}$ under drought stress. With regard to mean comparison, the cultivars 'T19' in the optimal and 'T24' under drought stress condition showed the highest and lowest fruit yield, respectively. Comparing the reduction values of all cultivars under the drought condition, it is obvious that 'T17' followed by 'Roghani', 'Manzanilla' and 'T10' with the lowest reduction are the best tolerant cultivars (Tab. 3).

Association among photosynthetic traits and identification of the tolerant cultivars. Principal component analysis (PCA) was performed to discover association among the different photosynthetic traits and fruit yield. Associations among traits were considered from the angle between the traits vectors on the biplot. For example, an acute angle displays a strong positive association and an obtuse angle indicates a weaker relationship; a 180° angle results if there is a negative correlation, whereas a 90° angle indicates no correlation between indices. The results of the PCAs are shown in Tab. 4. Under optimal condition, the two first PCs accounted 82.04% of the total variation. In this treatment, PC1 accounted for 46.20% of the total variation and was strongly influenced by chlorophyll components; thus, it was termed 'photosynthetic potentials'. PC2 explained 35.83% of the total variation and correlated positively with all the studied traits; hence, this component was termed 'fruit yield and gas exchange capacity'. Also, as shown in Figure 1A, photosynthetic pigments created a distinct group. Fruit yield and other traits grouped together in the same group. Angles of traits vector showed fruit yield positive significantly correlated with other traits. Under drought stress, the two first PCs, explained 83.27% of the total variation. The first PC justified 45.97% of the total variation and significantly influenced by photosynthetic pigments traits; hence this PC was named 'chlorophyll potential'. The second PC accounted for 37.30% of the total variation and positively correlated with G_S, T_E, P_N and yield; thus this PC was termed 'fruit yield potential'. Relationships among studied traits showed similar pattern of correlation. As shown in Figure 1B, correlations among photosynthetic pigments with each other, and fruit yield with P_N, T_E and G_s were positive. In light of this information, the selection of superior drought-tolerant cultivars should be based on high PC1 and low PC2 scores. Accordingly, cultivars 'T7', 'Roghani', 'Koroneiki', 'Korfolia' and 'Abou-satl' were identified as the most tolerant cultivars than others.

DISCUSSION

Drought is one of the most edaphic stress that reduces olive yield in tropical and subtropical climates where these regions characterized by low rainfall and low high potential evaporation during the growing season [Guerfel et al. 2007]. Hence, the knowledge of

Table 4. Principal components of measured traits in two optional and drought stress conditions

Traits	Optimal condition		Drought condition	
	PC1	PC2	PC1	PC2
P_N	–0.248	0.493	0.321	0.416
Gs	–0.291	0.460	0.334	0.419
T_E	–0.258	0.467	0.341	0.398
Chl *a*	0.464	0.145	0.430	–0.270
Chl *b*	0.414	0.287	0.353	–0.400
Chl T	0.477	0.186	0.426	–0.301
CAR	0.410	0.295	0.309	–0.319
Yield	–0.061	0.317	0.286	0.262
Eigenvalue	3.696	2.867	3.678	2.984
Variability (%)	46.20	35.83	45.97	37.30
Cumulative (%)	46.20	82.04	45.97	83.27

P_N – net photosynthetic rate (mol m^{-2} s^{-1}), G_S – stomatal conductance (mol m^{-2} s^{-1}), T_E – transpiration rate (mg m^{-2} s^{-1}), Chl *a* – chlorophyll *a* content (mg g^{-1} FW), Chl *b* – chlorophyll *b* content (mg g^{-1} FW), Chl *T* – the total chlorophyll content (mg g^{-1} FW), CAR – the total carotenoid content (mg g^{-1} FW), Yield – fruit yield (kg $tree^{-1}$)

the mechanisms implied in drought tolerance and identify the most tolerant cultivars can help to optimize the water supply in olive orchard [Fernandez 1997]. The current study assessed some photosynthetic responses of 20 olive cultivars to drought stress. Genotypic variation in drought tolerance and some of the parameters related to photosynthetic activity was apparent in the set of olive cultivars tested in the current study work (Tab. 2). These findings are similar with earlier results reported on different olive cultivars [Bacelar et al. 2006, Ahmed et al. 2009, Dias et al. 2018]. Knowledge of the basic plant growth processes like photosynthesis and transpiration is important for breeders to management practices influences plant growth and development of new cultivars [Holding and Streich 2013].

Under drought condition, all of the estimated traits reduced by varying degrees. The net photosynthetic rate (P_N) is one of the important parameter to be affected by drought, via declined CO_2 diffusion to the chloroplast and metabolic constraints [Pinherio and Chaves 2011]. In response to drought, rate of stomatal conductance (G_S) to CO_2 often reduce in unison, this diffusive limitations to the uptake of CO_2 reduce the concentration of CO_2 at the site of carboxylation within the chloroplast envelope causing a reduction in the P_N [Centritto et al. 2009, Lauteri et al. 2014]. Besides, stomata closure to limit water loss using transpiration is one of the key responses to drought [Ergen and Budak 2009]. Thus determination of *Gs* and T_E by leaf stomata can be estimated the degree of physical resistance to the movement of gases between the interior of the leaf and the air [Pour-Aboughadareh et al. 2017]. Our results showed T_E and P_N rates and *Gs* declined the most under drought (Tab. 2). These results are similar to those obtained by Tognetti et al. [2006], Bacelar et al. [2006] and Ahmed et al. [2009], who reported that G_S, N_P and T_E in olive trees decreased by drought stress. Among the different tested cultivars, two promising cultivars 'T7' and 'T10' along with cultivar 'Koroneiki' affected less by drought stress (Tab. 3), suggesting that leaf photochemistry in these cultivars may tolerant to drought stress.

Chlorophyll, as one of main components involved in the photosynthesis process, is protected in the thylakoid membranes. The loss of chlorophyll content may be due to drought-induced electrolytic leakage from thylakoid membranes and also lipid peroxidation of chloroplast membranes [Pradhan et al. 2012]. Many studies have indicated damage to photosynthetic pigments as a result of drought stress [Kadkhodaie et al.

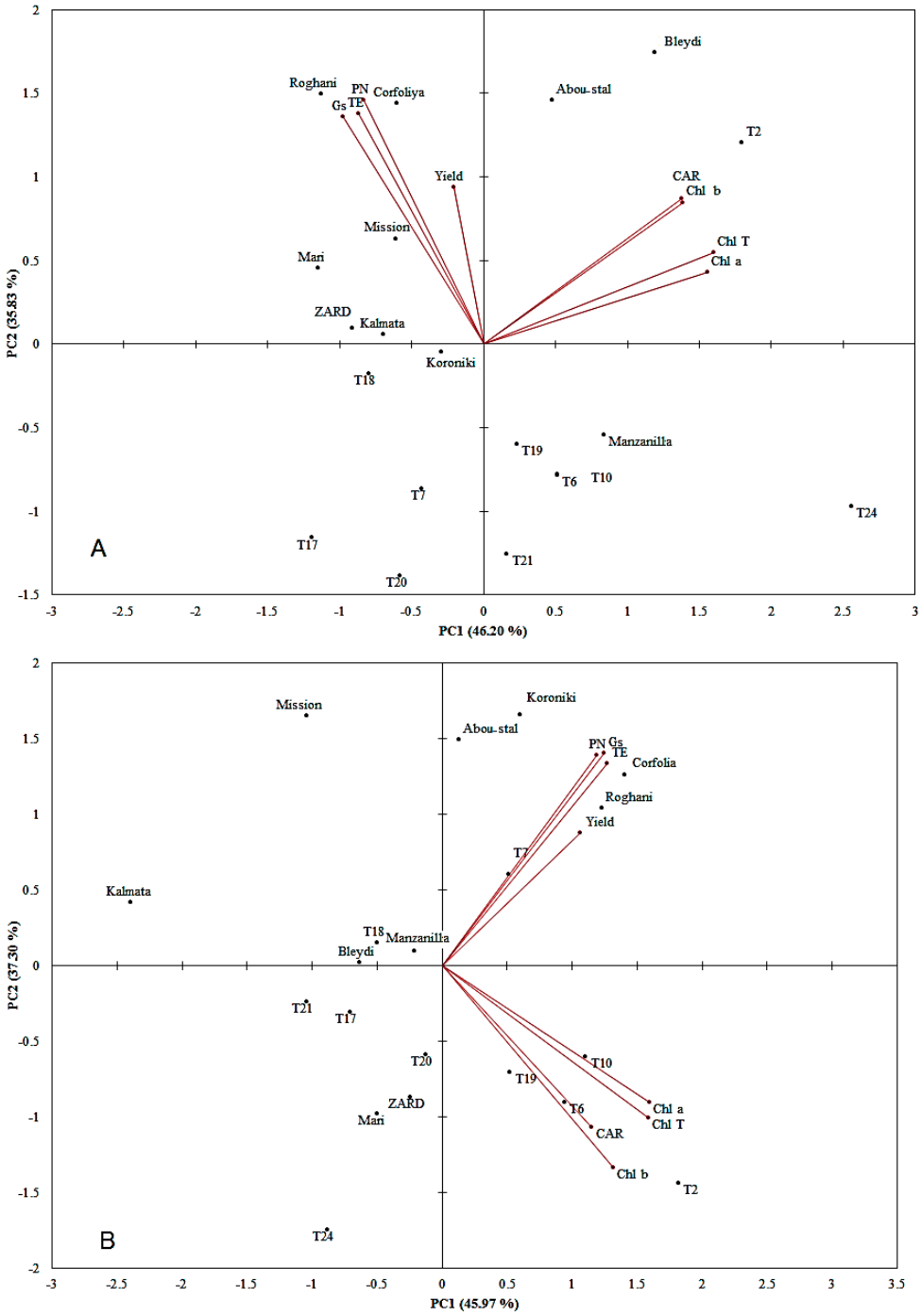

Fig. 1. The biplot display of photosynthetic-related traits of 20 olive cultivars under (A) optimal and (B) drought stress conditions. P_N – net photosynthetic rate (mol m^{-2} s^{-1}), G_S – stomatal conductance (mol m^{-2} s^{-1}), T_E – transpiration rate (mg m^{-2} s^{-1}), Chl *a* – chlorophyll *a* content (mg g^{-1} FW), Chl *b* – chlorophyll *b* content (mg g^{-1} FW), Chl *T* – the total chlorophyll content (mg g^{-1} FW), CAR – the total carotenoid content (mg g^{-1} FW), Yield – fruit yield (kg $tree^{-1}$)

2014, Bouchemal et al. 2016]. Both chlorophyll *a* and *b* elements are susceptible to drought, the effects of which may affect plant production and quality. Similar to other plant in olive higher chlorophyll content is related to drought tolerance and the selection of cultivars based on stable chlorophyll content may limit fruit yield under drought condition [Filippou et al. 2007]. In the present study, cultivars studied showed a high variation for chlorophyll components. Our results revealed that drought-stressed trees of 'T17' and 'T6' as new promising cultivars had lowest reduction of chlorophyll *a* and the total chlorophyll contents than the other cultivars, suggesting that these cultivars had a good capacity of chlorophyll pigments, which can be used in the future programs. However, as shown in Tab. 3, the promising cultivar 'T20' showed a lowest reduction in chlorophyll b and the total chlorophyll contents under drought condition. We surmise, the higher chlorophyll contents in this cultivar drought condition may be due to the increased carotenoid contents. Because carotenoid plays an important role in response to drought conditions and may help plants to tolerate drought stress [Jaleel et al. 2009]. The trend of reduction of the total carotenoid content showed that the cultivar 'T20' had the lowest reduction under drought condition. Hence, it seems that stability in carotenoid content in this cultivar is likely associated with the absorption of excessive light to avoid photooxidative damage to photosystem II (PSII) [Deng et al. 2003]. Additionally, carotenoids are directly involved in reducing chlorophyll, which inhibits the generation of singlet oxygen and oxidative damage [Deng et al. 2003].

As expected, the fruit yield in olive plants changed significantly from optimal to drought-stress conditions. Similar to other traits, this trait is considerably affected by drought stress (Tab. 2). This reduction as mainly due to lower fruit weight as has been reported by Fernandes-Silva et al. [2010] for drought stress conditions. Moreover, Flexas and Medrano [2002] stated that this decrease can be explained by inhabitations to biochemical and photosynthesis processes, which are controlled by drought stress. In the present study, the decreasing trend in yield due to drought was in the order of 'T17' < 'Roghani' < 'Manzanilla' < 'T10' < remaining cultivars (Tab. 4). Of these, two ne promising cultivars 'T17' and 'T10' also revealed the lowest reductions in other photosynthetic parameters and pigments. This demonstrated that photosynthetic parameters and chlorophyll content are suitable biochemical traits which could be used to screen and select cultivars for drought-stress tolerance. This result can be supported by correlation coefficients between yield and photosynthetic parameters and chlorophyll content under drought stress (Fig. 1B). Due to the difficulty in identifying drought-tolerance cultivars based on a single trait, we used the biplot-based principal component analysis to select superior drought-tolerant. Taking into account this biplot, cultivar 'T7', 'Roghani', 'Koroneiki', 'Korfolia' and 'Abou-satl' as superior drought-tolerant cultivars (Fig. 1B). Hence, these cultivars especially 'T7' can be used in olive breeding programs to improve new high yielding cultivars with drought tolerance for use in the drought-prone environments.

CONCLUSIONS

Changes in photosynthetic process may be one of the important steps for enhancing olive cultivation, particularly in tropical and subtropical regions suffering from limited water resources. The high genotypic variation in photosynthetic parameters and fruit yield observed in this work indicates to relate to the selection of more drought-tolerant cultivars. Our results revealed that some of new promising cultivars like 'T7', 'T10' and 'T20' responded better to drought by low decreasing traits involving in photosynthesis process and fruit yield. These results suggest that these cultivars may cope better with drought and could be more suited to be cultivated in drought-prone zones.

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Table S1. Mean values for measured traits in the 20 olive cultivars under optimal (N) and drought stress (S) conditions in 2015–2016 and 2016–2017

Year	Genotype	P_N		G_S		T_E		Chl *a*		Chl *b*		Chl *T*		CAR		Yield	
		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1st	‘T2’	3.36	6.75	0.03	0.06	0.86	2.12	16.88	18.20	2.85	4.34	19.73	22.54	143.68	213.97	47.33	48.67
	‘T6’	4.55	4.40	0.05	0.04	2.20	2.08	14.56	13.85	2.45	3.06	17.01	16.91	150.16	175.29	17.33	22.00
	‘T7’	2.66	4.96	0.03	0.05	1.28	2.41	13.30	10.00	1.93	2.15	15.23	12.15	152.86	153.28	72.33	67.33
	‘T10’	3.42	4.46	0.03	0.03	1.52	1.64	15.24	13.95	2.29	3.00	17.53	16.96	163.96	152.64	27.00	25.33
	‘T17’	2.87	3.19	0.02	0.03	0.97	1.18	11.13	11.11	1.75	2.13	12.88	13.23	117.47	133.29	39.00	40.00
	‘T19’	4.44	4.35	0.05	0.05	1.72	1.75	11.01	12.77	1.75	2.55	12.76	15.31	113.75	155.02	26.33	34.33
	‘T20’	5.21	3.48	0.05	0.03	2.22	1.48	14.93	12.47	2.61	2.66	17.54	15.12	131.69	165.85	67.33	79.33
	‘T21’	4.66	6.25	0.05	0.06	1.94	2.41	12.12	11.15	2.37	2.13	14.49	13.28	143.73	140.65	45.00	35.67
	‘T18’	2.94	5.33	0.03	0.05	1.14	2.02	9.16	13.26	1.57	2.78	10.73	16.05	139.84	170.53	30.00	31.33
	‘T24’	2.93	1.69	0.03	0.01	1.01	0.84	19.26	11.15	3.76	2.27	23.01	13.42	206.91	140.93	24.33	40.67
	‘Zard’	1.61	5.10	0.02	0.05	0.78	2.59	11.12	11.80	2.06	2.62	13.18	14.42	145.86	157.34	63.33	76.00
	‘Roghani’	5.01	9.32	0.04	0.10	1.74	3.65	13.44	12.06	2.10	2.75	15.54	14.81	132.83	163.27	67.67	64.67
	‘Mari’	2.20	4.23	0.02	0.05	1.41	2.81	15.15	10.19	2.96	2.28	18.11	12.47	155.19	145.33	40.00	54.33
	‘Beladi’	3.60	9.30	0.04	0.12	1.55	4.07	9.89	17.02	1.68	4.17	11.56	21.20	131.11	221.66	51.00	46.33
	‘Mission’	3.95	6.75	0.03	0.07	1.45	2.73	8.05	12.80	1.13	2.82	9.18	15.63	102.82	182.37	55.00	59.33
	‘Manzanilla’	4.10	4.14	0.04	0.04	1.14	1.04	10.71	12.29	1.80	3.96	12.51	16.25	131.05	208.57	58.00	61.00
	‘Koroneiki’	4.83	4.85	0.05	0.05	2.23	2.15	10.74	13.17	1.61	2.76	12.36	15.93	121.58	182.69	19.67	24.00
	‘Kalamata’	2.48	8.87	0.02	0.09	1.02	2.69	7.12	12.23	1.10	2.72	8.22	14.95	97.87	176.68	21.33	22.00
	‘Korfolia’	6.57	8.39	0.07	0.08	2.37	2.58	11.53	13.70	2.10	3.05	13.63	16.76	141.53	181.63	72.00	70.00
	‘Abou-satl’	5.94	10.01	0.05	0.12	1.63	3.31	10.77	15.49	1.32	3.65	12.09	19.14	113.81	203.06	66.00	72.67

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2nd	‘T2’	5.05	4.63	0.04	0.06	1.49	2.03	17.54	14.56	3.59	2.46	21.14	17.01	178.83	151.48	48.00	58.00
	‘T6’	4.47	4.01	0.04	0.04	2.14	1.41	14.21	12.55	2.75	2.11	16.96	14.67	162.72	156.88	19.67	38.00
	‘T7’	3.81	7.76	0.04	0.09	1.85	2.81	11.65	11.47	2.04	1.66	13.69	13.13	153.07	158.99	69.83	57.00
	‘T10’	3.94	5.90	0.03	0.07	1.58	2.36	14.60	13.14	2.65	1.98	17.25	15.12	158.30	170.98	26.17	35.00
	‘T17’	3.03	3.45	0.02	0.04	1.07	1.08	11.12	9.59	1.94	1.51	13.05	11.10	125.38	122.59	39.50	41.00
	‘T19’	4.39	3.41	0.05	0.04	1.73	1.64	11.89	9.49	2.15	1.51	14.04	11.00	134.39	118.83	30.33	22.67
	‘T20’	4.35	2.27	0.04	0.02	1.85	0.90	13.70	12.87	2.64	2.25	16.33	15.12	148.77	138.59	73.33	17.67
	‘T21’	5.45	1.80	0.06	0.02	2.18	0.99	11.64	10.45	2.25	2.04	13.88	12.49	142.19	149.35	40.33	25.33
	‘T18’	4.13	2.98	0.04	0.04	1.58	1.54	11.21	7.89	2.18	1.36	13.39	9.25	155.19	144.07	30.67	19.67
	‘T24’	2.31	0.31	0.02	0.02	0.93	0.16	15.20	16.60	3.01	3.24	18.22	19.84	173.92	215.84	32.50	16.33
	‘Zard’	3.36	1.18	0.03	0.05	1.69	1.52	11.46	9.58	2.34	1.78	13.80	11.36	151.60	151.00	69.67	36.00
	‘Roghani’	7.16	8.09	0.07	0.11	2.69	2.53	12.75	11.59	2.42	1.81	15.18	13.40	148.05	139.03	66.17	31.33
	‘Mari’	3.21	5.00	0.04	0.02	2.11	0.62	12.67	13.06	2.62	2.55	15.29	15.61	150.26	162.22	47.17	22.67
	‘Beladi’	6.45	2.36	0.08	0.03	2.81	1.46	13.45	8.52	2.93	1.45	16.38	9.97	176.38	135.67	48.67	30.33
	‘Mission’	5.35	6.06	0.05	0.07	2.09	2.08	10.42	6.94	1.98	0.98	12.40	7.91	142.60	106.52	57.17	25.67
	‘Manzanilla’	4.12	4.44	0.04	0.04	1.09	1.64	11.50	9.23	2.88	1.55	14.38	10.79	169.81	136.00	59.50	28.67
	‘Koroneiki’	4.84	7.84	0.05	0.11	2.19	2.55	11.96	9.26	2.19	1.39	14.14	10.65	152.14	126.53	21.83	66.33
	‘Kalamata’	5.67	2.45	0.06	0.03	1.85	0.82	9.68	6.14	1.91	0.95	11.59	7.09	137.28	101.15	21.67	28.33
	‘Korfolia’	7.48	7.03	0.07	0.09	2.48	2.28	12.62	9.94	2.58	1.81	15.19	11.75	161.58	146.86	71.00	37.33
	‘Abou-satl’	7.97	5.01	0.08	0.06	2.47	2.32	13.13	9.29	2.48	1.14	15.61	10.42	158.44	118.76	69.33	54.33

P_N – net photosynthetic rate (mol m^{-2} s^{-1}), G_S – stomatal conductance (mol m^{-2} s^{-1}), T_E – transpiration rate (mg m^{-2} s^{-1}), Chl *a* – chlorophyll *a* content (mg g^{-1} FW), Chl *b* – chlorophyll *b* content (mg g^{-1} FW), Chl *T* – the total chlorophyll content (mg g^{-1} FW), CAR – the total carotenoid content (mg g^{-1} FW), Yield – fruit yield (kg $tree^{-1}$)