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Original Article

Physiological and Growth Responses of Several Genotypes of Common Purslane (*Portulaca oleracea* L.) under Mediterranean Semi-arid Conditions

Anestis C. KARKANIS*, Spyridon A. PETROPOULOS

*University of Thessaly, Department of Agriculture Crop Production and Rural Environment, Fytokou St., 38446, Volos, Greece; anekark80@yahoo.gr (*corresponding author); fangio57gr@gmail.com*

Abstract

Common purslane (*Portulaca oleracea* L.) is a drought-tolerant weed cultivated for its fresh leaves and stems. In the present study, a field experiment was conducted to determine plant development and photosynthesis of several common purslane genotypes in a high-density planting system. The experiment was carried out according to randomized complete block design with four replications per treatment. Four local populations and two commercial cultivars of common purslane were studied. During the experiment, plant biomass, plant height, leaf relative chlorophyll content (SPAD values), stomatal conductance (gs) and photosynthetic rate (A) were recorded. From the results of our study significant differences in plant height and biomass were observed among the studied genotypes. The lowest height and biomass were found in genotype 'Domokos' whose growth was prostrate to semi-prostrate, whereas all the other genotypes had erect growth. Differences were also observed in physiological parameters. In particular, the relative chlorophyll content (SPAD value) was the highest for genotype 'Domokos', whereas stomatal conductance and photosynthetic rates were the lowest for the same genotype. Biomass yield had also positive and significant correlation with photosynthetic rate and plant height. Our results indicate that the tested genotypes had significant differences in growth habit and physiological parameters. Comparing the tested genotypes, it could be suggested that apart from genotype 'Domokos' which had lower biomass yield due to its growth habit, the rest of the genotypes could be suitable for commercial purposes and proposed as an alternative crop in semi-arid regions of the Mediterranean basin.

Keywords: common purslane, high-density planting, genotypes, edible weed, yield

Introduction

Common purslane (*Portulaca oleracea* L.) is cultivated as a vegetable and medicinal plant but it can also be a troublesome weed in spring vegetables and other crops (Doohan and Felix, 2012; Gharneh and Hassandokht, 2012; Karkanis *et al.*, 2012; Alam *et al.*, 2014a). World Health Association (WHO) has listed purslane among the most common used plants for medicinal purposes (Naeem and Khan, 2013). It is an annual summer weed widely distributed throughout Europe, Asia and other parts of the world. Common purslane plants can be propagated from seeds, whereas Proctor *et al.* (2011) reported that vegetative reproduction can also occur from stem cuttings. Steinmaus *et al.* (2000) also reported that common purslane germination rates increased linearly with temperature between 15 and 30 °C.

A great potential exists in using weeds [i.e. milk thistle (*Silybum marianum* L. Gaertn.), cow cockle (*Vaccaria hispanica* [Mill.] Rauschert), common purslane], either as medicinal plants (Karkanis *et al.*, 2011; Efthimiadou *et al.*, 2012) or as edible greens and fodder for human and animal nutrition, respectively (Aydin and Dogan, 2010; Egea-Gilabert *et al.*, 2014; Petropoulos *et al.*, 2016). Wild edible plants are well-known for their rich content in bioactive compounds such as tocopherols, vitamins, phenolic compounds and omega-3 fatty acids, which have been reported to have several health benefits when included in human diet (Simopoulos, 2008; Nebel and Heinrich, 2009; Petropoulos *et al.*, 2016). Common purslane has been reported to contain several bioactive compounds such as omega-3 fatty acids and especially alpha-linolenic acid (Simopoulos *et al.*, 1992; Gharneh and Hassandokht, 2012; Naeem and Khan, 2013; Stroescu *et al.*, 2013), while its use in human diet as a vegetable is known for centuries (Bosi *et al.*, 2004; Nebel and Heinrich, 2009; Danin *et al.*, 2014).

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Significant genetic variation exists among purslane genotypes in terms of agronomic traits (Egea-Gilabert *et al.*, 2014) and physiological characteristics (Alam *et al.*, 2015). Moreover, common purslane is tolerant to drought and high levels of salinity (Ren *et al.*, 2011; Teixeira and Carvalho, 2009; Bilalis *et al.*, 2014), which is an important agronomic feature for farming in the Mediterranean basin. Various purslane genotypes responded differently in saline conditions (Alam *et al.*, 2014b), while according to Alam *et al.* (2014c) it can be grown under various soils conditions and types. These reasons, as well as the fact that it is a species with rather short growth cycle (from sowing to harvest), make purslane an important crop under semi-arid conditions, while it can also be cultivated in regions where the availability of irrigation water is low and cultivation of conventional crops is not feasible.

In order to propose purslane as an alternative vegetable crop for cultivation under Mediterranean semi-arid conditions, it is crucial to evaluate the performance and adaptability of various genotypes of different origin under these conditions. The available genetic diversity with different purslane genotypes and/or ecotypes can serve as a vast gene pool to be used in plant breeding programs for the development of high yielding purslane cultivars. Therefore, the aim of this study was to determine plant morphology and physiology traits, as well as the performance (total yield) of six purslane genotypes in a high-density planting, in order to evaluate the potential of commercial growing of the species under Mediterranean semi-arid conditions.

Materials and Methods

Study site

The experiment was carried out at the experimental field of University of Thessaly, at Velestino (central Greece) in 2016. The soil was sandy clay loam (48% sand, 29% silt and 23% clay), with pH 7.4 (1:1 soil/H_20) and organic matter 1.3%. Climatic conditions of the experimental site during the growing period are presented in Fig. 1. The field was moldboard plowed to a depth of 20-25 cm followed by two rotary-harrowing's. Common purslane was sown late, on 15th of June 2016, in rows 40 cm apart, within the rows at 2.5 cm and at a depth of 1 cm. Seedling emergence was recorded about 4-6 days after sowing (DAS). A sprinkler irrigation system was used, while irrigation was applied immediately after sowing and three more times at 10 days intervals for crop establishment. Weed control was applied two times by hand hoeing at 15 days intervals, while the fungicide boscalid+pyraclostrobin (0.4+0.1 kg a.i. ha^{-1}, Signum® 26.7/6.7 WG) was applied to control white rust.

Experimental design

The experimental layout was a randomized complete block design with four replications per treatment (genotype). The tested genotypes were two commercial cultivars ('Glystrida 0425' and 'Purslane Dark Green'), three local populations originating from Iran ('Sari', 'Gorgan', 'Aliabad') and one local population from Greece ('Domokos').

The experimental field was set up over an area of 497.8 m^2 (27.5 × 18.1 m), with plots of 4 m wide and 4 m long, while the corridors between plots were 0.7 m wide.

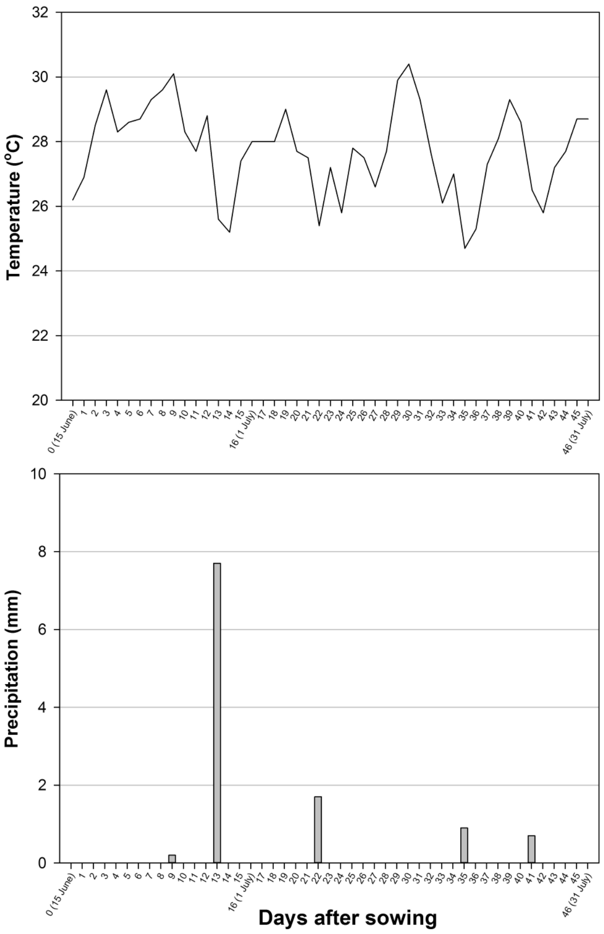

Fig. 1. Precipitation (mm) and mean daily temperature (°C) at the experimental site during the growing season (15th of June-31st of July 2016)

Sampling, measurements and methods

For plant height determination, 5 plants were randomly selected in each plot. The measurements were repeated twice, at 26 and 45 days after sowing (DAS). Stem diameter, internode length (3rd node from the base of plant), leaf width, length and thickness (4th pair of leaves from the apex) was also measured at the day of harvest (45 DAS). In order to record the fresh and dry weight (kg ha^{-1}) of common purslane, an area of 2 m^2, corresponding to the central area of each plot was hand harvested. The dry weight was determined after drying at 72 °C until constant weight (approximately after 72 h). The days from sowing to 50% flowering were also calculated.

Moreover, measurements of stomatal conductance (mol H_20 $m^{-2}s^{-1}$) and photosynthetic rate (μmol CO_2 $m^{-2}s^{-1}$) were recorded between 10.30 a.m. and 14.30 p.m., with 2 measurements per plot, at 26 and 40 days after sowing. These parameters were measured with the Portable Photosynthesis System LI-6400 (LI-COR Biosciences, Inc., Lincoln, Nebraska) at the 4th pair of leaves from the apex. The chlorophyll content index (SPAD values) was measured twice during the growing period, at 26 and 40 days after sowing at the 4th pair of leaves from the apex, by using the portable SPAD-502 chlorophyll meter (Konica Minolta Inc., Osaka, Japan).

Statistical analysis

The data were subjected to statistical analysis according to the randomized complete block design. The statistical analysis was realized using the Statgraphics Plus 5.1 logistic package. Data were evaluated by analysis of variance and the means of values were compared by Fisher's Least Significant Difference (LSD) test at $P<0.05$. Pearson's correlation analysis was also performed to examine the relationships between various physiological traits and crop parameters.

Results and Discussion

Physiological traits

Concerning the relative chlorophyll content (SPAD values) there were significant differences between genotypes (Table 1). At 26 DAS, genotype 'Domokos' showed the highest values, while the lowest values were found in genotypes 'Aliabad', 'Glystrida 0425' and 'Purslane Dark Green'. At the second assessment (40 DAS), the highest value (48.70) was found in genotype 'Domokos', while no significant differences were observed between genotypes 'Sari', 'Glystrida 0425' and 'Purslane Dark Green'. Egea-Gilabert *et al.* (2014) have reported similar SPAD values (25.2-38.3), while they have also recorded significant differences between twelve common purslane accessions. Similarly, Alam *et al.* (2014c) have also reported SPAD values in the range between 26.2 and 39.52.

Regarding the stomatal conductance of leaves (Table 2), there were significant differences between the genotypes at both measurements (26 and 40 DAS). Therefore, at both assessments the lowest value of stomatal conductance was found in genotype 'Domokos' and the highest in genotype 'Glystrida 0425'. At 26 DAS, the lowest values of photosynthetic rates were recorded in genotype 'Domokos' (21.95 μmol CO_2 $m^{-2}s^{-1}$). Furthermore, at 40 DAS, genotype 'Glystrida 0425' showed the highest values of photosynthetic rate (23.82 μmol CO_2 $m^{-2}s^{-1}$) being statistically different from the other genotypes, whereas the lowest values were recorded in genotype 'Domokos' (8.64 μmol CO_2 $m^{-2}s^{-1}$). Differences in photosynthetic activity between purslane genotypes have been previously reported by Alam *et al.* (2014c), who also found significant differences between purslane accessions in photosynthetic rates which ranged between 20.8-28.73 μmol CO_2 $m^{-2}s^{-1}$.

Moreover, photosynthetic rate at 40 DAS was lower than that at 26 DAS for all the tested genotypes. The main reasons for higher photosynthetic rate at 26 DAS may be attributed to temperature, since temperatures at 40 DAS were always higher than those at 26 DAS and could induce stomatal closure and lower photosynthetic activity due to stress conditions. Lara *et al.* (2003) and D' Andrea *et al.* (2014) also reported that common purslane is a C4 plant but it may shift its photosynthetic metabolism into crassulacean acid metabolism (CAM) under drought

Table 1. Relative chlorophyll content (SPAD values) at 26 and 40 days after sowing (DAS), in relation to purslane genotype

Genotypes	Relative chlorophyll content (SPAD values)	
	26 DAS	40 DAS
'Sari'	38.90bc	40.87d
'Gorgan'	37.15cd	45.00b
'Aliabad'	36.30d	43.20c
'Domokos'	41.50a	48.70a
'Glystrida 0425'	36.50d	40.27d
'Purslane Dark Green'	35.20d	39.52d
Mean	37.59	42.92
CV% (Coefficient of Variation)	6.57	8.04
$LSD_{5\%}$	2.26	1.91
F values	9.343***	30.274***

Means in each column followed by same letter are not significantly different according to LSD ($P<0.05$) test. ***Significant differences at $P<0.001$

Table 2. Stomatal conductance (mol H_2O m^{-2} s^{-1}) and photosynthetic rate (μmol CO_2 m^{-2} s^{-1}) at 26 and 40 days after sowing (DAS), in relation to purslane genotype

Genotypes	Photosynthetic rate		Stomatal conductance	
	26 DAS	40 DAS	26 DAS	40 DAS
'Sari'	34.27a	17.43b	0.455bc	0.419a
'Gorgan'	28.86b	12.20c	0.368cd	0.257b
'Aliabad'	27.12b	12.62c	0.327cd	0.232b
'Domokos'	21.95c	8.64d	0.277d	0.177b
'Glystrida 0425'	34.75a	23.82a	0.601a	0.425a
'Purslane Dark Green'	29.30b	14.27c	0.519ab	0.234b
Mean	29.37	14.84	0.424	0.291
CV% (Coefficient of Variation)	17.62	35.30	32.97	37.88
$LSD_{5\%}$	4.657	3.345	0.142	0.093
F values	9.503***	22.385***	6.802**	11.375***

Means in each column followed by the same letter are not significantly different according to LSD ($P<0.05$) test. **Significant differences at $P<0.01$; ***Significant differences at $P<0.001$.

conditions, which is mostly the case when it is grown as a rain-fed weed. Considering that in our study, no fertilizers were applied, while irrigation was applied only three times and up to 30 DAS after sowing, it could be suggested that plants were grown under conditions similar to weeds. This argument may be supported by the study of Jin *et al.* (2016), who found that heat (high temperatures) combined with drought may severely affect purslane physiological parameters (i.e. chlorophyll content). Other plants that can be grown under semi-arid conditions are some *Amaranthus* species which are also cultivated for their edible leaves and stems, as well as for seed production. These species have been reported to be tolerant under drought and high temperatures conditions, while its crop growth cycle is similarly short (Rastogi and Shukla, 2013; Sogbohossou *et al.*, 2015).

Morphological and agronomic traits

The selection of genotype determines common purslane growth parameters. In our study, no significant differences were observed between genotypes in seedlings emergence, whereas the studied purslane genotypes differed in their morphological characters. Regarding the number of days to flowering, there were significant differences between the studied genotypes. Genotype 'Domokos' presented the earliest flowering at 29 DAS (Table 3). In contrast, genotype 'Purslane Dark Green' had the latest flowering at 38 DAS, whereas no significant differences between genotypes 'Sari', 'Gorgan', 'Aliabad' and 'Glystrida 0425' were observed. The difference in the number of days to flowering should be taken into consideration for commercial cultivation of purslane, since early flowering and seed production may be the limiting factors in purslane production (Szalai *et al.*, 2010), especially under semi-arid conditions.

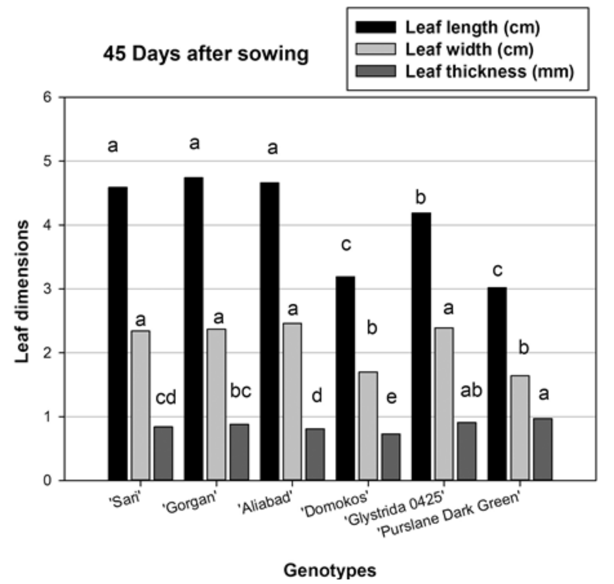

Fig. 2. The effect of purslane genotypes on leaf length (cm), leaf width (cm) and leaf thickness (mm), at 45 days after sowing (DAS). For each leaf parameter, bars followed by different letters indicate significant differences according to Fisher's Least Significant Difference (LSD) test (P<0.05). $LSD_{5\%}$ values were 0.34, 0.22 and 0.07 for leaf length, width and thickness, respectively

Genotypes 'Sari', 'Gorgan' and 'Aliabad' from Iran were susceptible to white rust (*Albugo portulaceae,* synonym *Wilsoniana portulacae*), since lack of resistance to this pathogen could be due to adaptation to different growing conditions. Vrandečić *et al.* (2011) have also reported that common purslane is a host for *Wilsoniana portulacae*. At 30 DAS, the recommended rate of boscalid+pyraclostrobin was applied to control this disease.

Concerning the leaf length, at 45 DAS, there were also significant differences between genotypes (Fig. 2). The highest leaf length was found in genotypes 'Sari', 'Gorgan' and 'Aliabad' (4.59, 4.74 and 4.66 cm, respectively), without significant differences being observed among these genotypes. Furthermore, at 45 DAS, the lowest leaf width was recorded in genotypes 'Domokos' and 'Purslane Dark Green' (1.70 and 1.64 cm, respectively), whereas there were no significant differences among genotypes 'Sari', 'Gorgan', 'Aliabad' and 'Glystrida 0425'.

Regarding the leaf thickness, the lowest value was recorded in genotype 'Domokos' (0.73 mm). At the final assessment (45 DAS), the lowest internode length was found in genotypes 'Domokos', 'Glystrida 0425' and 'Purslane Dark Green', while the highest stem diameter was found in genotypes 'Sari', 'Gorgan' and 'Aliabad'. Concerning the stem diameter, there were also significant differences between genotypes (Fig. 3). Alam *et al.* (2014c) have also found significant differences among 45 purslane accessions in morphological parameters (i.e. plant height, numbers of branches, leaves and nodes number, internode distance and stem diameter). Differences in leaves' size have been also reported by Salah and Chemli (2004) who evaluated morphological features of several purslane populations.

From the results of our study significant differences in plant height (Table 3) were observed during cultivation, with all genotypes having upright growth, apart from genotype 'Domokos' whose growth was prostrate to semi-prostrate. These genotypes showed similar growth habit when planted in lower plant density, according to our previous study with the same genotypes (Petropoulos *et al.*, 2015). Salah and Chemli (2004) also observed that some purslane populations tends to have an upright growth habit and larger leaves, while others show prostrate growth. At the first assessment (26 DAS), genotypes 'Sari', 'Gorgan' and 'Glystrida 0425' had the highest height in comparison to the other genotypes. However, at the second assessment (45 DAS), genotype 'Glystrida 0425' had the highest height (70 cm), being significantly different from most studied genotypes, including those with similar growth habits ('Sari', 'Aliabad' and 'Purslane Dark Green'). The height for all the genotypes was higher than that reported in our previous study (Petropoulos *et al.*, 2015), probably due to higher plant density implemented in the present study. In a recent study, Egea-Gilabert *et al.* (2014) also found significant differences between purslane accessions in plant height.

Dry matter content was also affected by the genotype. At 26 DAS, the lowest dry weight was found in genotype 'Domokos' (6.20%), while there were no significant differences among the other genotypes ranging from 8.56% (genotype 'Gorgan') to 9.44% (genotype 'Sari'). Dry matter content had positive and significant correlation with photosynthetic rate (r=0.601, P<0.01) and stomatal

Table 3. Plant height (cm), dry matter content (%) at 26 and 45 days after sowing (DAS), and days to 50% flowering of common purslane, in relation to purslane genotype

Genotypes	Plant height (cm)	Dry matter content (%)	Plant height (cm)	Dry matter content (%)	Days to 50% flowering
	26 DAS		45 DAS		
'Sari'	40.70c	9.44a	63.25b	6.61d	35b
'Gorgan'	45.00b	8.56a	64.50ab	6.26d	35b
'Aliabad'	39.25c	9.19a	56.75c	6.70d	35b
'Domokos'	7.50e	6.20b	17.00d	9.66a	29c
'Glystrida 0425'	48.00a	8.95a	70.00a	8.36b	35b
'Purslane Dark Green'	35.50d	9.01a	60.75bc	7.34c	38a
Mean	36.00	8.56	55.38	7.49	34.5
CV% (Coefficient of Variation)	38.04	13.92	33.05	16.71	8.25
$LSD_{5\%}$	1.90	0.761	6.08	0.557	0.806
F values	539.05***	22.21***	91.55***	49.18***	121.08***

Means in each column followed by the same letter are not significantly different according to LSD (P<0.05) test. ***Significant differences at P<0.001

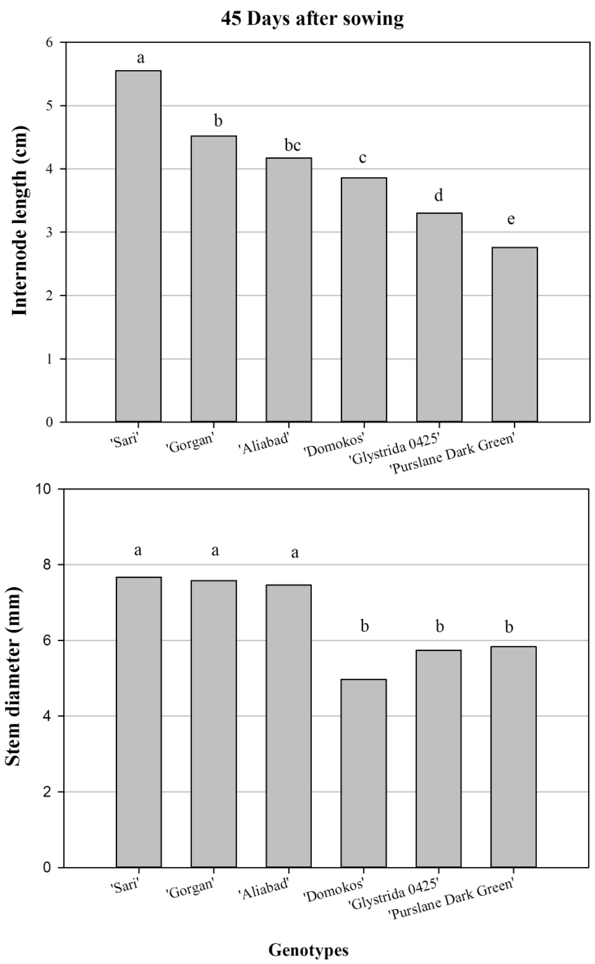

Fig. 3. The effect of purslane genotypes on stem diameter (mm) and internode length (cm), at 45 days after sowing (DAS). For each trait, bars followed by different letters indicate significant differences according to Fisher's Least Significant Difference (LSD) test (P<0.05). $LSD_{5\%}$ values were 1.00 and 0.42 for stem diameter and internode length, respectively

conductance (r=0.478, P<0.05). In contrast, at 45 DAS, the lowest values of dry matter content were found in three genotypes from Iran ('Sari', 'Gorgan' and 'Aliabad') while the highest values was determined in genotype 'Domokos'.

In another study, Oliveira *et al.* (2009) also observed that water was the major constituent in purslane leaves (91.13-92.27%) and stems (89.19-91.13%). Yield (fresh weight) was affected by genotype as clearly shown in Fig. 4. In addition, the lowest yield (15.233 kg ha^{-1}) was recorded in genotype 'Domokos' whose growth was prostrate to semi-prostrate. The yield for all the genotypes except for genotype 'Sari' was higher than that reported in our previous study (Petropoulos *et al.*, 2015), probably due to higher plant density implemented in the present study. Yield had positive and significant correlation with

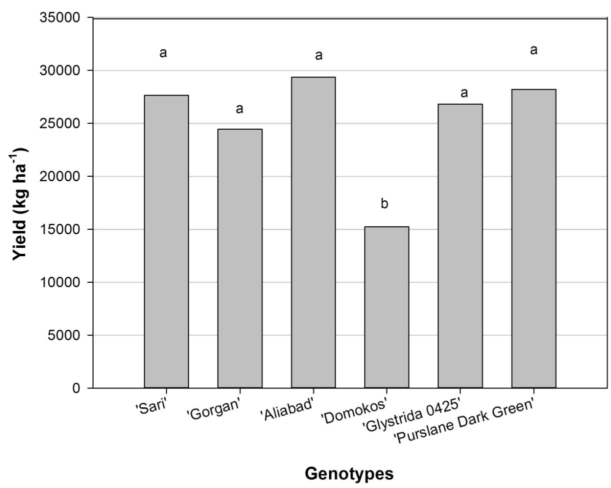

Fig. 4. The effect of purslane genotypes on biomass yield (fresh weight, kg ha^{-1}) at 45 days after sowing (DAS). Bars followed by different letters indicate significant differences according to Fisher's Least Significant Difference (LSD) test (P<0.05). $LSD_{5\%}$ and CV% (Coefficient of Variation) values were 5928 and 23.4, respectively

Table 4. Pearson correlation coefficients[1] between the main physiological traits and crop parameters

Parameters	SH	Y	SC	PR
Height (H)	0.556**	0.695***	0.680***	0.761***
Stem diameter (SH)	-	0.461*	ns	ns
Yield (Y)		-	ns	0.446*
Stomatal conductance (SC)			-	0.887***
Photosynthetic rate (PR)				-

[1]r was calculated using the linear equation. Significant at *P<0.05, **P<0.01 and ***P<0.001, respectively. Ns: not significant

photosynthetic rate (r=0.446, P<0.05, Table 4) and plant height (r=0.695, P<0.001). In the study of Alam *et al.* (2014c), a positive and significant correlation was also found between fresh weight and plant height (r=0.48, P<0.001).

Our results revealed that significant variation exists among purslane genotypes for the studied agronomic characteristics, physiological traits and yield potential. Similarly, Ren *et al.* (2011) have also reported high genetic diversity among purslane accessions collected by different geographical areas. Therefore, the fact that purslane is a wide spread species throughout the Mediterranean basin and various microclimate conditions, creates a vast genetic pool to be exploited in future breeding programs.

Conclusions

Our results indicate that the tested genotypes had significant differences in growth habit and morphological features. At final assessment (45 DAS), the lowest leaf length and width were recorded in genotypes 'Domokos' and 'Purslane Dark Green'. By comparing the six genotypes, it was also found that genotype 'Aliabad' had higher yield than the other tested genotypes, which is an agronomic trait of major importance when considering purslane cultivation for commercial purposes. In addition, yield had positive and significant correlation with photosynthetic rate and plant height. Therefore, it could be suggested that apart from genotype 'Domokos' which had lower biomass yield due to its growth habit, the rest of the genotypes could be suitable for commercial cultivation and could be suggested as an alternative vegetable crop under Mediterranean semi-arid conditions, while erect growth is essential for mechanizing cultivation practices under commercial farming. Moreover, apart from growth habits and yield, chemical composition has also to be considered under commercial farming, especially regarding oxalic acid and oxalates content which may have adverse effects on human health.

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