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EFFECTS OF WATER STRESS ON GROWTH, OIL YIELD, FATTY ACID COMPOSITION AND MINERAL CONTENT OF *SESAMUM INDICUM*

A. Ozkan[1*] and M. Kulak[2]

[1]Department of Gastronomy and Culinary Arts Faculty of Fine Arts, Gaziantep University 27000, Gaziantep, Turkey
[2]Kilis 7 Aralık University, Faculty of Arts and Sciences, Department of Biology, 79000, Kilis, Turkey
[*]Corresponding author: aozkan27@gmail.com

ABSTRACT

Effects of water deficit on herbal growth, oil yield, fatty acid composition and mineral content in *Sesamum indicum* L. (Cultivars Cumhuriyet and Özberk) aerial and edible parts were investigated in greenhouse conditions in 2012. Plants were subjected to the different levels of water deficiency; control (FC, Field Capacity), moderate water deficit (1/2 of FC) and severe water deficit (1/4 of FC). The experiments were arranged as a factorial, using a randomized complete design with three replications. Plant growth parameters were significantly reduced by 1/4 FC and consequently caused reductions in seed yield and yield parameters. Drought did not influence the oil yield. With the increasing water deficit treatments, oleic acid content of both cultivars decreased but it was more pronounced for cv. Cumhuriyet. However, linoleic acid percentage of cv. Cumhuriyet was not influenced with the decreasing field capacity whereas it was positively affected with the treatment for cv. Özberk. Minor fatty acid compounds such as arachidic acid, linolenic acid, lignoceric acid, and behenic acid were not statistically affected for both cultivars when exposed to different level of treatment except cis-11-eicosenoic acid. Besides, mineral contents (Ca, Mg, K, Na) showed variation depending on cultivars and water deficit treatments except Na content.

Keywords: Sesame, water deficit, fatty acid, mineral content, plant growth

INTRODUCTION

Water shortage is considered to be one of the most adverse abiotic stress factors influencing plant growth and their physiological and biochemical aspects in addition to the adverse impacts on social and economic life of mankind (Anjum *et al.,* 2012), as well as impairing crop production (Hamrouni *et al.* 2001). Plant behavior can change with respect to the secondary metabolite synthesis, production, secretion, and storage when subjected to water deficit stress (Hamrouni *et al.* 2001, Laribi *et al.* 2009). However, secondary metabolite synthesis, enzyme activities and soluble substances accumulation have been positively affected by water stress (Singh-Sangwan *et al.* 2001). These are consequences of plant adaptive strategies in response to drought through establishing some changes allowing the plant to span its life under a low water potential (Hamrouni *et al*., 2001).

Sesame (*Sesamum indicum* L.) is a drought tolerant plant, however; it is sensitive to drought at germination and seedling stages (Bahrami *et al.* 2012). *Sesamum indicum* L. (Pedaliaceae) is one of the oldest and important oil seed crops. It is usually cultivated in arid and semi-arid regions of the world for its quality edible oil (Desphande *et al.,* 1996; Eskandari *et al.,* 2009) and it is very responsive to the changing environmental conditions.

Many reports stated that growth was adversely affected with increasing drought level, (Bahrami *et al.* 2012, Bor *et al.* 2009, Hassanzadeh *et al.* 2009, Orruno and Morgan 2007; Turk *et al.* 2004). The different irrigation intervals cause in stunted growth and decreased seed yield of sesame through effect on photosynthesis process in addition to the yield, oil and protein contents (Al-Palsan *et al.,* 2001; Mensah *et al.,* 2006). However, to respond the changing environmental and growing conditions, plant behavior can change regarding the biosynthesis of bioactive compounds when subjected to abiotic constraints (Hamrouni *et al*., 2001; Laribi *et al*., 2009) instead of yield parameters. This work targets to investigate influence of water deficiency on growth parameters, lipid composition, and mineral contents of *Sesamum indicum* L. seeds. Up to our the best knowledge, no data have been proposed concerning sesame seed oil yield, fatty acid content and mineral content changes under water deficiency conditions. Hence, in this paper, some biochemical responses of sesame were, for the first time, examined when exposed to different levels of irrigation.

MATERIALS AND METHODS

Plant material and different levels of irrigation: Effect of water deficiency on sesame varieties (Cumhuriyet and Özberk) were conducted based on the method proposed by Bettaieb *et al.* (2009). Briefly, before sowing, seeds were surface sterilized with hypochlorite (1% NaOCl) for 5 minutes. One hundred seeds were put into each pot and were irrigated every other day. During the first 35 days of pre-treatment, plants were sufficiently irrigated and then, applied to various levels of irrigation: control (FC), moderate water deficit (1/2 of FC) and severe water deficit (1/4 of FC) of field capacity (FC). The experiments were conducted in pots and arranged as a factorial, using a randomized complete design with three replications. Experimental soil was a sandy-clay-loam texture, and composed of potassium content (313.75 ppm), organic matter (% 1. 53), and salt contents (0.059) and pH (8.1). Experiments were conducted in a greenhouse with a 14 h photoperiod and lasted 4 months from May to August, 2012. Mean temperature and relative humidity were 26-30 ◦C during day and 16-20 ◦C at night, 60 % respectively. After harvest, seeds were air-dried and stored at 4 ◦C until use for further analysis.

Growth and yield parameters measurement: For each treatment, measurement of plant height, seed number per capsule, capsule number, 1000-seed weight, total weight per pod, and single plant yield were evaluated by harvests of four randomly selected plants from each pot.

Sample preparation and measurement for mineral content: Mineral contents of the samples were ascertained with ICP-OES. Briefly, dried and powdered samples were incinerated with 5 ml HNO_3 65 % and 2 ml H_2O_2 30 %. Afterwards, they were cooled at room temperature for 45 minutes. The samples were completed to 25 ml with distilled water for analysis.

Oil extraction and fatty acid composition analysis: Oils were extracted from sesame seeds (each 2 g sample) with n-hexane for four hours using a Soxhalet extraction apparatus. Then the solvent was evaporated under reduced pressure and temperature using a Rotary evaporator (Heidolph). Sesame oil 0.1 g was added, 2 ml n-heptanes into a screw-capped tube for esterification. The fatty acid analyses were conducted according to the official method COI/T.20/Doc.no.24 2001. 0.1 g of sesame oil was taken into screw-capped tube. Two ml n-heptanes added to it and shaken. After 0.2 ml methanolic potassium hydroxide was added for esterification, tubes were vigorously shaken for 30 sec after the vials were closed. The supernatant of the solution was taken followed after one hour of incubation at room temperature. Then, the supernatant was put in 2 ml vials for injection.GC-FID analyses of fatty acids methyl esters was carried out on a Shimadzu gas chromatography (GC-2010 series).

Statistical Analysis: SPSS 17.00 statistical program was used to determine statistical significance levels by employing The independent one-way ANOVA followed by Duncan multiple range test and the differences between individual averages were considered to be statistically important at $p<0.05$. The results were expressed as mean ± standard error (SE).

RESULTS AND DISCUSSION

Impact of water deficiency on growth and yield parameters: The results showed that water deficiency adversely influenced all growth parameters of both the cultivars (Cumhuriyet and Özberk) and this effect was more pronounced with the severe water deficit (1/4 FC).Between varieties plant height varied between 29.58-54.68 cm. There were no significantly differences with respect to the plant height under moderate water deficit (1/2 FC) and control (C) group for both cultivars. However, the plant height was more adversely affected under severe water deficit (1/4 FC), and was inhibited by 43,30 % and 41,75 % compared with control for Cunhuriyet and Özberk, respectively. Water deficiency often decreased stem growth and plant height because of shrinkage in output changes in cellular water status (Prasad and Staggenborg 2008; Ahmad *et al.*, 2013).

The capsule number, which is of the essential criteria for phenotypic selection, changed between 5.17-9.92 (capsule/plant). The highest capsule number (9.92) was determined under Control group for Özberk and under 1/2 FC for Cumhuriyet concerning on capsule number. It was immediately pronounced to be reduced under 1/2 FC and 1/4 FC for Özberk cultivar. Furthermore, seed numbers per capsule and 1000-seed weight were severely influenced by water deficit for both cultivars. Concomitant with the decrease in capsule number per plant under 1/4 FC, seed yield per plant (g) and seed yield per pot (g) decreased for both cultivars (Table 1). Accordingly, there was a positive correlation between plant growth and seed yield as reported by Laribi *et al*. (2009). The effects of drought on whole-plant processes are variable and can influence seed growth, seed yield, and seed quality but sometimes the adverse influence during one phase or trait can be atoned by recovery and excess growth of other organ or trait. Hence, decline in grain yield can be atoned by increased grain quality and it should be understood that post harvest quality is much more important than total yield (Prasad and Staggenborg 2008). Once cultivars are evaluated with respect to the seed number per capsule under all experimental applications, the cultivar Cumhuriyet showed better agronomic performances concerned with total yield.

Concerning on seed yield per plant, no statistically significant differences were found under 1/2 FC and C-treatments. However, differences were more pronounced under 1/4 FC. Accompanying with the decrease in seed yield per plant, seed yield per pot declined for the cultivar Özberk, but the moderate water deficit (1/2 of FC) application increased better than control group. Oil content (%), which is the crop characteristics of sesame, did not vary by water-deficit treatments. To respond the changing environmental and growing conditions, plant behavior can change with respect to secondary metabolites when subjected to this constraint (Hamrouni *et al.* 2001, Laribi *et al.* 2009) instead of yield parameters.

Effects of water deficit on fatty acids and oil content: Sesame, which is of the oldest and important oil seed crops, was majorly characterized with the content of oleic, stearic, palmitic and linoleic acid. Oil yield of sesame varieties studied herein were not significantly affected with the water deficit treatments. Our results were in agreement with those obtained by Zarei *et al.* (2010). It was noted that the irrigation regimes or levels did not influence cultivar seed oil content (Zarei *et al.* 2010). These findings were also in harmony with the report by Al-Barrak (2006). It did not induce an effect on seed oil percentage (Table 2).But, according to the report proposed by Al-Palsan *et al*. (2001) revealed that water constraints reduced oil percentage of sesame crops. However, to respond the changing environmental and growing conditions, plant behavior can change regarding the biosynthesis of bioactive compounds when subjected to abiotic constraints (Hamrouni *et al*., 2001; Laribi *et al*., 2009) instead of yield parameters.

Accordingly statistically significant differences were found at 1 % probability level in terms of palmitic acid oleic acid, linoleic acid, cis-11-eicosenoic acid among varieties. In the reports proposed by Laribi *et al.* (2009), palmitic acid proportion increased with water limitation but decreased in sage (Bettaieb *et al.,* 2009) whereas oleic acid decreased in caraway. However, water limitation did not elicit any change on palmitic acid in cv. Cumhuriyet but palmitic acid decreased with severe water in cv. Özberk.

Accordingly statistically significant differences were found at 5 % probability level in terms of palmitoleic acid among varieties. No statistical differences were determined among varieties concerning on myristic acid, heptadecanoic, cis-10-heptadecanoic acid and stearic acid, arachidic acid, linolenic acid, behenic acid, lignoceric acid (Table 2).

The content of palmitic acid, of which content was desired to be low for health due to the its saturated properties, varied between 8.66-9.34 % among compared cultivars. No statistically differences were obtained with 1/4 FC and 1/2 FC treatments with respect to the ranges of palmitic acid but decreased once compared to the control for Özberk cv. However, there was no statistically significant variation among water deficit treatments for Cumhuriyet cv. Oleic acid was to be 39.75-44.21 % for cultivars. Higher contents of oleic acid were found to be in Özberk cv. than Cumhuriyet cv for oleic acid. However, the ranges of linoleic acid (39.85-44.27 %) were higher in Cumhuriyet cv. than Özberk cv. Both cultivars include unsaturated fatty acid with an average of 85 %. While there was statistical significance at the 5 % probability level for palmitoleic acid, no differences were determined for the other fatty acids between cultivars.

With the increasing water deficit treatments, oleic acid content of both cultivars decreased but it was more pronounced for Cumhuriyet cv. However, linoleic acid percentage of Cumhuriyet cv. were not influenced with the decreasing field capacity whereas it was positively affected with the treatment for Özberk cv. Minor fatty acid compounds such as arachidic acid, linolenic acid, lignoceric acid, and behenic acid were not statistically found to be vary for both cultivars when exposed to different level of treatment except cis-11-eicosenoic acid.

Mineral Nutrients: Minerals are necessary to enable various enzymes for biological responses. Sustainability of life is dependent upon the body's ability to provide balance between the minerals (Prasad and Bisht 2011). The mineral content of edible parts, seeds, of sesame cultivars is presented in Table 3. The contents of calcium, potassium, magnesium and sodium in edible parts of plants were found to be 31.09±0.40 - 32.01±2.51, 26.26±1.80-29.96±0.58, 17.67±0.39 - 22.44±0.40, and 7.98±0.34-8.21±1.30 for cultivar Cumhuriyet, respectively, and 38.75±2.92-64.58±11.32, 27.18±1.18-30.68±0.54, 16.49±1.04-32.26±6.48, and 6.65±0.87 - 8.46±0.68 for cultivar Özberk, respectively. Hereunder, the higher content of Ca and Mg were determined in cultivar Özberk than Cumhuriyet under control treatment while there was statistically significant difference among cultivars with respect to the concentration under moderate water deficit and severe water deficit

Interestingly, the highest content of K was determined under 1/4 FC for cultivar Özberk whereas the lowest concentration was found under 1/4 FC for cultivar Cumhuriyet. The upward frequency and duration of drought in arid and semi-arid regions in many parts of world and the problems related to the water constraints in water- applying systems and areas may affect the bioavailability and mobility of minerals and mineral-nutrient relations in plants (Hu and Schmidhalter 2005). Potassium is of the osmosis regulating cellular enlargement and turgor-driven movements and a competitor of Na. Additionally, higher K:Na ratio will improve the resistance of plants exposed to stress conditions (Hu and Schmidhalter 2005).The availability of potassium, in general, decreased with the limiting soil water contents. Whereas, the content of K in Cumhuriyet reduced with the severe water deficit (1/4 FC) treatments, it increased with 1/4 FC conditions in Özberk, consequently higher K: Na ratio was obtained. Even though in many studies reported, the potassium increases the plant's drought through its physiological functions in stomatal regulation, osmoregulation, energy status, charge balance, and protein synthesis (Hu and Schmidhalter 2005). Agronomical parameters concerned with yield and quality in Özberk, which had higher K content, were severely affected with the water deficit levels. There were no essential differences regarding the content of Na for both cultivars.

Table 1. Water deficiency effects on growth and yield parameter of sesame cultivars

	Cumhuriyet cv.			Özberk cv.		
	FC	**1/2 FC**	**1/4 FC**	**FC**	**1/2 FC**	**1/4 FC**
Plant height	52.167±0.93[a]	45.92 ±3.99[a]	29.58±1.86[b]	54.68±1,61[a]	48.017±6.36[a]	31.85±1.09[b]
seed number	46.87±3.06[a]	33.83±2.54[ab]	37.58±6.42[ab]	35.75±1.61[ab]	26.25±4.71[b]	22.75±7.19[b]
Capsule number	7.08±0.55b[c]	8.92±0.85[ab]	5.67±0.22[c]	9.92±1.40[a]	6.17±0.44[c]	5.17±0.44[c]
1000-seed weight	3.60±0.74[ab]	3.43±0.03[ab]	2.94±0.36[ab]	3.66±0.38[a]	3.81±0.92[a]	2.66±0.56[c]
seed yield/ plant	0.66±0.073[a]	0.73±0.072[a]	0.29±0.081[b]	0.75±0.004[a]	0.69±0.039[a]	0.46±0.175[ab]
seed yield/ pot	3.32±0.37[ab]	3.68±0.62[a]	1.54±0.50[c]	3.23±0.26[ab]	2.96±0.23[abc]	1.83±0.70[bc]
Oil content (%)	24.42±1.42a	25.74±2.91[a]	26.90±4.77[a]	23.09±0.51[a]	24.92±1.66[a]	26.67±2.88[a]

Means±SE in the same column by the same letter are not significantly different to the test of Duncan (α=0.05)

Table 2. Effects of water-deficit on total fatty acid composition from sesame seeds of two cultivars

	Cumhuriyet cv.			Özberk cv.		
	C	**1/2 FC**	**1/4 FC**	**C**	**1/2 FC**	**1/4 FC**
Myristic acid	0.015±0.00[ab]	0.018±0.00[a]	0.015±0.00[ab]	0.015±0.00[ab]	0.016±0.00[ab]	0.013±0.00[b]
Palmitic acid	9.34±0.049[a]	9.26±0.04[a]	9.22±0.01[a]	9.33±0.24[a]	8.66±0.06[b]	8.77±0.011[b]
Palmitoleic acid	0.12±0.00[ab]	0.13±0.00[a]	0.11±0.00[b]	0.12±0.,01[b]	0.12±0.00[b]	0.11±0.00[b]
Heptadecanoic acid	0.078±0.00[ab]	0.069±0.00[b]	0.081±0.00[ab]	0.079±0.01[ab]	0.090±0.01[a]	0.075±0.00[ab]
cis-10-Heptadecanoic acid	0.046±0.00[ab]	0.042±0.00[b]	0.046±0.00[ab]	0.046±0.00[ab]	0.051±0.00[a]	0.047±0.00[ab]
Stearic acid	4.94±0.08[ab]	4.98±0.08[ab]	5.14±0.02[a]	5.01±0.18[ab]	4.85±0.14[ab]	4.77±0.00[b]
Oleic acid	39.95±0.13[c]	40.49±0.74[bc]	39.75±0.63[c]	44.21±0.69[a]	42.31±0.94[ab]	42.18±0.18[b]
Linoleic acid	44.16±0.18[a]	43.63±0.80[a]	44.27±0.65[a]	39.85±1.11[b]	42.64±0.78[a]	42.71±0.20[a]
Arachidic acid	0.55±0.01[a]	0.57±0.01[a]	0.57±0.01[a]	0.57±0.03[a]	0.53±0.02[a]	0.54±0.01[a]
cis-11-Eicosenoic acid	0.18±0.00[c]	0.18±0.00[c]	0.16±0.00[d]	0.19±0.00[a]	0.18±0.00[bc]	0.19±0.00[ab]
Linolenic acid	0.42±0.00[a]	0.43±0.03[a]	0.46±0.03[a]	0.38±0.06[a]	0.38±0.00[a]	0.40±0.00[a]
Behenic acid	0.12±0.00[a]	0.13±0.00[a]	0.12±0.00[a]	0.12±0.00[a]	0.12±0.00[a]	0.12±0.00[a]
Lignoceric acid	0.075±0.00[a]	0.075±0.03[a]	0.075±0.03[a]	0.082±0.06[a]	0.079±0.00[a]	0.076±0.00[a]

Means±SE in the same column by the same letter are not significantly different to the test of Duncan (α=0.05)

Table 3. Water- deficit treatments on the mineral content

	Cumhuriyet cv.			Özberk cv.		
	C	**1/2 FC**	**1/4 FC**	**C**	**1/2 FC**	**1/4 FC**
Ca	31.64±0.36[b]	32.01±2.51[b]	31.09±0.40[b]	64.58±11.32[a]	38.75±2.92[b]	42.15±0.25[b]
K	29.96±0.58[ab]	27.80±0.93[ab]	26.26±1.80[b]	27.18±1.18[ab]	27.30±1.39[ab]	30.68±0.54[a]
Mg	22.44±0.40[b]	19.21±0.78[b]	17.67±0.39[b]	32.26±6.48[a]	17.32±0.85[b]	16.49±1.04[b]
Na	7.98±0.34[a]	7.36±1.06[a]	8.21±1.30[a]	8.46±0.68[a]	6.65±0.87[a]	7.64±1.31[a]

Means±SE in the same column by the same letter are not significantly different to the test of Duncan (α=0.05).

Conclusion: It can be concluded that growth and yield parameters of sesame cultivars (cv.Cumhuriyet and Özberk) were adversely affected with the limited water supply whereas the oil yield was not influenced. However, the percentage of major fatty acid compositions was significantly affected with the limited water supply. Overall, the changes in composition and structural modifications -but not in yield- could be expressed as tolerance mechanism towards water limited conditions.

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