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EFFECT OF SOIL WATER CONTENT ON THE PHYSIOLOGICAL PARAMETERS, PRODUCTION AND ACTIVE SUBSTANCES OF SUMMER SAVORY (*Satureja hortensis* L.)

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Abstract. Effect of water supply on *Satureja hortensis* L. (summer savory) 'Budakalászi' cultivar was investigated. Three saturation levels (70–50–30%) of soil water capacity (SWC) applied in climatic chamber resulted in significant changes of physiological parameters of savory plants. Compared to the control treatment (70% of SWC) the driest condition (30% SWC) caused more than 20% decrease of the relative water content (RWC) of plants and an almost 5-fold lower water potential. SPAD values indicated 45% higher chlorophyll content in the lowest watering regime. The reduction of SWC (30%) significantly affected the production of savory: fresh weight was reduced by 54% while dry weight decreased by 46%. No changes were detected in the leaf mass/total shoot mass ratio. The highest essential oil (EO) concentration of leaves (5.300 ml·100 g^{-1}) was measured in plants of moderate drought stress (50% SWC) while the control plants and plants exposed to severe water stress treatment showed lower essential oil accumulation (4.922 and 4.782 ml·100 g^{-1}, respectively). The EO production calculated from the values of fresh yield, and the EO concentration were the lowest in the case of plants grown in pots of lowest soil water content. The main components of the oil were carvacrol (56.7–60.6% EO) and γ-terpinene (29.7–32.3% EO) in each treatment. Water supply did not modify significantly the quantitative composition of the EO, however, it influenced noticeably the headspace volatiles (HS). In contrast with the former practice we found that without a proper water supply the cultivation of summer savory cannot be efficient.

Key words: water capacity, drought stress, essential oil, SPME, water potential, SPAD

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Abbreviations:

SWC	soil water capacity
RWC	relative water content
HS-SPME	head space – solid phase microextraction
GC	gas chromatography
MS	mass spectrum
EO	essential oil

INTRODUCTION

Summer savory (*Satureja hortensis* L.) is a widely known annual herbaceous plant from the Lamiaceae plant family. It is traditionally used as a spice and nowadays the demand is increasing because of its wide application potential as natural antioxidant and antimicrobial agent [Madsen et al. 1996, Exarchou et al. 2002, Pank et al. 2004]. The essential oil (EO) concentration varies between 0.5 and 3.5 ml·100 g^{-1} dry weight (DW) [Pank et al. 2004, Hadian et al. 2007]. However, without the stem fraction a higher EO concentration (5.9%) was detected [Seidler-Łożykowska et al. 2009]. The main components of the essential oil are carvacrol and γ-terpinene [Svoboda and Greenaway 2003, Pank et al. 2004]. Until now the EO composition has mainly been identified after hydrodistillation with the use of GC-MS or GC-FID techniques. Despite the headspace solid phase microextraction (HS-SPME) method is known as a technique for fast identification of EO components, this technique was only rarely used to identify the volatile compounds of summer savory. Novak et al. [2006] reported a high ratio of carvacrol and γ-terpinene in the individual glands of *Satureja hortensis*.

Several papers were published about the effect of drought stress on the secondary metabolites of the *Lamiaceae* species [Gershenzon et al. 1978, Simon et al. 1992, Baher et al. 2002, Zámboriné et al. 2005, Radácsi et al. 2010] but only a few about the genus *Satureja*: Gershenzon et al. [1978] described that *Satureja duglasii* produced lower biomass, shorter stems and smaller leaf area but deeper antocyanic coloration and more glandular trichomes on the leaves as the result of lower soil moisture. However, the monoterpenoid yield per leaf dry weight did not change significantly. Baher et al. [2002] reported that the height, stem fresh and dry weight of *Satureja hortensis* was reduced under low water supply while the EO concentration was increased. Differences were not detectable in the EO components.

Although in the Central European area precipitation seems to be the primary yield limitation factor in most of our cultivated crops, till now it is not clear what is the real effect of drought on the production and secondary metabolites of the different species. Selmar and Kleinwächter [2013] concluded that the level of secondary metabolites is frequently enhanced by the drought stress but the stress induced is counteracted by the loss of biomass. The aim of this study was to get a deeper insight into the effects of water deficit on summer savory. Our goal was to support growers with appropriate information on the consequences of water supply concerning quantity and quality of the drug.

MATERIAL AND METHODS

Plant material and culture establishment. *Satureja hortensis* L. 'Budakalászi' cultivar was used as plant material. Seeds were provided by the gene bank of the Department of the Medicinal and Aromatic Plants (Corvinus University of Budapest). Plants were grown in a climatic chamber (type Conviron E-15) in pots (1.6 L). The medium above a gravel drainage (140 g, diameter: 5–8 mm) was a combination of Rekyva Remix D soil mixture, black peat and perlite in a ratio of 7:2:1. Three seedlings were planted in each pot in a two-leaved stage. The stress treatment was initiated 1 week after planting and continued 55 days until harvesting. The climatic program of the chamber was the following: 14 h day/10 h night cycle, (photosynthetically active radiation = 370 μmol photons$\cdot$m$^{-2}\cdot$s^{-1}; fluorescent lamp (4200 K) and incandescent lamp (2700 K)) temperature program: 25°C day / 17°C night, relative humidity 65%. Plants were fertilized weekly with Wuxal Super complex fertilizer (Aglukon Spezialdünger GmbH & Co. KG; Düsseldorf, Germany); 100 ml 0.4% solvent was added weekly to each pot.

Treatments. Three levels of water supply were applied: for modelling a slight drought stress effect (S1) we used a 50% saturation of soil water holding capacity (SWC), while to induce a severe stress effect (S2), the saturation level of SWC was 30%. The control (K) plants were grown in soil with a 70% saturation level of SWC. SWC was determined using the modified gravimetric method of Reynolds [1970] based on the water holding capacity of the soil. During the experiment, both SWC and the water supplement were checked 3 times per week.

Water potential. The water potential (ψ) of the plants was determined in the leaves of the second and third nodes under the top ofthe shoots. The measurements were carried out in 9 replications (9 plants) per treatment in full flowering phase, 2 d after watering, between noon and 2 p.m. in a pressure chamber (Model 610, PMS Instrument Company, Albany, USA). For increasing the pressure in the chamber CO2 was used [Scholander et al. 1965].

Relative water content (RWC). The relative water content (RWC) was analysed in full flowering period from leaf samples from the third nodes under the top of the shoots (in 6 replications per treatment). Fully developed leaves were used. After determining fresh weight (FW), they were immersed in distilled water for 6 hours to estimate turgid weight (TW), and then the disks were dried at 60°C for 24 h to measure dry weight (DW).

The RWC was determined according to the following formula: RWC (%) = ((FW–DW) / (TW–DW))×100 [Weatherly 1950, Barrs 1968].

Chlorophyll content (SPAD). Chlorophyll content of the leaves indicated by the quantification of green colour intensity was measured by a SPAD 502Plus (Konica Minolta Inc., Japan) equipment. The readings were taken at the third internodes under the inflorescence one day before harvesting. Eight readings were made on each leaf and their mean was calculated. This measurement was repeated in 9 replications per each treatment.

Fresh weight, dry mass and leaf ratio. The aerial parts of the plants were harvested in full flowering stage. The fresh weight of the plants was immediately measured by a digital scale. Plant material was dried at room temperature (22–24°C) in shadow. The dry mass was measured by analytical scale. After drying the leaves and infloresences were separated from the stems and their ratio in the total shoot mass was determined. Each of these measurements was carried out in 21 replications per treatment.

Based on the dried leaf mass and the detected essential oil concentration we calculated the production of essential oil per plant realized under the different water regimes.

Determination of essential oil (EO) concentration and composition. The EO concentration was measured from leaves and inflorescence (excluded the stems), in five replication per treatment with a Clevenger-type apparatus according to the VII. Hungarian Pharmacopoeia [Pharmacopoeia Hungarica 1986].

Volatile components of the aerial parts (Headspace – HS) were identified by a Solid Phase Microextraction (SPME) method. 2.5 g of fresh shoot was put into a 20 ml screwy vial which was closed hermetically. Vials were incubated in 19°C for 30 minutes. Sampling was carried out through the septum for 10 minutes. The fiber (Supelco, 100 µm polydimethyle-siloxane covered fiber) was hold in the inlet of GC for 33 seconds. The SPME analysis was carried out in 3 replications per treatment.

The composition of the EO and SPME volatiles were determined by GC-MS method. GC analysis was carried out using an Agilent Technologies 6890 N instrument equipped with HP-5 and HP-5MS capillary column (30 m × 0.25 mm, 0.25 µm film thickness), working with the following temperature program: initial temperature 60°C, heating at a rate of 3°C / min up to 240°C; the final temperature was maintained for 5 min; injector and detector temperatures: 250°C; carrier gas: helium (constant flow rate: 1 mL/min); split ratio: 30:1, injection volume 0.2 mL (10%, n-hexane). A mixture of aliphatic hydrocarbons (C9-C23) in n-hexane was injected to calculate the linear retention indices using the generalized equation of Van den Dool and Kratz [1963]. For the GC-MS analysis the above mentioned equipment was used with an Agilent Technologies MS 5975 detector. Ionization energy was 70 eV. The mass spectra were recorded in full scan mode, which revealed the total ion current (TIC) chromatograms. The linear retention indices (LRI) and mass spectra were compared with those of commercial (NIST, Wiley) and home-made library mass spectra built up from data obtained from standard (Sigma/Aldrich) pure compounds. The proportions of the individual compounds were expressed as total area percentages. The GC-MS analysis was carried out in 3 replications/treatment.

Statistical analysis. The results were analysed with an IBM SPSS 22.0 statistical program. One-way ANOVA was applied, and for the pairwise comparisons of the variances, the Scheffe test was used with a confidence level of 5%.

RESULT AND DISCUSSION

Physiological parameters. The RWC values of the plants decreased significantly as a result of the lower water supply (tab. 1). The highest RWC values (an average of 93.17%) were measured in the control plants, in a soil saturated to 70% of water capacity (SWC). In the 50% (S1) treatment we measured 89.83% water content while under the driest circumstances only 73.54% was observed. This shows that in consequence of the increasing lack of water in the soil, the RWC of the savory leaves may decrease by almost 20%. Formerly similar results were detected in sweet basil [Radácsi et al. 2010, Barbiei et al. 2012] and the current data are comparable to results from dragonhead and maize, as well [Bai et al. 2006, Rahbarian et al. 2010].

Table 1. Effect of different water supply on the main physiological parameters (A), production (B) and essential oil production (C) of savory

Parameter		Treatment		
		K (mean ±S.D.)	S1 (mean ±S.D.)	S2 (mean ±S.D.)
A	RWC (%)	93.17 a ±6.19	89.83 ab ±5.16	73.54 b ±10.10
	water potential (MPa)	-0.52 a ±0.07	-1.58 b ±0.18	-2.51 c ±0.11
	chlorophyll content (SPAD Unit)	45.12 c ±3.03	57.37 b ±1.73	65.47 a ±1.62
B	fresh weight (g)	58.29 a ±6.19	46.79 b ±5.26	26.70 c ±3.28
	dry weight (g)	13.19 a ±1.83	11.42 b ±1.61	7.20 c ±0.99
	proportion of leaves in the shoot mass (%)	56.02 a ±4.48	55.16 a ±5.99	58.68 a ±6.60
C	essential oil concentration (ml·100 g^{-1}DW)	4.922 b ±0.223	5.300 a ±0.096	4.782 b ±0.092
	essential oil production (ml·plant^{-1})	0.365 a	0.340 a	0.202 a

Water saturation in the soil: K = 70%, S1 = 50%, S2 = 30% of SWC. The different letters represent significant differences in the means in rows

The applied drought stress treatment presented itself also in the significantly reduced water potential of the plants (tab. 1). Low water potential of leaves appears when the transpiration rate of the leaves is higher than the water absorption rate of the roots [Jarvis 1976]. Low soil water content is one of the most common reasons of the roots' reduced water uptake. In our experiment, the lowest leaf water potential was measured under severe drought stress conditions (S2) while the increasing water saturation level in the soil influenced it positively. The highest value (-0.52 MPa) was detected in the control (K) plants, while an almost 5 times higher negative water potential could be measured when the water saturation level was only 30% of SWC. The results measured under the moderate stress parameters (S1) were between the values of K and S2. Thus, the applied water regime S2 seems to be a severe water stress condition for savory. Leaf water potential may indicate growth potential of the plants as found by Boyer [1968] in sunflower.

A reverse reaction to water potential was observed concerning the chlorophyll content of the leaves (tab. 1). The highest SPAD value (65.4 SPAD unit) was detected in the plants of S2 treatment while a 30% lower chlorophyll content was measured under the control circumstances (SWC = 70%). Former findings in connection with drought stress and chlorophyll content are contradictious. Rahimi et al. [2010] detected similar result to our ones in *Plantago ovata* and *Plantago psyllium* plants while intensive decrease of SPAD value was reported in soy and cotton plants [Inamullah and Akihiro 2005]. As the result of drought the photosynthetic activity of plants might decrease. However, the complexity of the question is illustrated well in the case of German chamomile: the chlorophyll a and b content was hardly modified by the drought while parameters of chlorophyll fluorescence (quantum efficiency of PSII and photochemical quenching coefficient) were significantly decreased [Bączek-Kwinta et al. 2011]. The background of these changes may be the altered ratio of lipoproteins and pigment-proteins or the enhanced activity of chlorophyllase enzyme, as well [Iyengar and Reddy 1996, Parida et al. 2007].

Fresh and dry mass of the plants. Although both in the scientific literature [Sváb and Hornok 1992, Momtaz and Abdollahi 2008, Hoppe 2012] and in the cultivation practice *Satureja hortensis* is described as a species preferring sunny and arid conditions, in our experiment the higher water regime resulted in higher production. Under lower soil water saturation levels both fresh and dry mass of the plants decreased significantly (tab. 1). Fresh weight of the control plants (58.29 g·plant^{-1}) was double compared to the plants of severe water deficit treatment (26.70 g·plant^{-1}). The biomass production of the plants in the S1 treatment was statistically lower than in the control but significantly higher than in S2.

The same tendency was observed in the case of dry weight (tab. 1). The three treatments were statistically different from each other with the highest value in control and the lowest one in S2.

No significant difference concerning the leaf ratios compared to the total shoot mass was measured among the treatments (tab. 1). The average values were between 55 and 58%.

Essential oil concentration and composition. The highest EO concentration was measured under moderate drought stress (S1) conditions (5.300 ml·100 g^{-1} DW) while the K and S2 plants were characterised by significantly lower accumulation levels (K: 4.922; S2: 4.783 ml·100 g^{-1} DW) (tab. 1). Different data were published by Baher et al. [2008] who detected the highest EO content (2.3% ±0.01) under the strongest water deficit (33% of field capacity).

According to the results the relative increase of the accumulation of essential oil under the moderate stress effect (S1) cannot compensate the reduction of the dry mass. Therefore, the highest essential oil production, calculated for an individual plant, could be achieved in the control treatment (tab. 1).

Table 2. The effects of water supply on the essential oil composition (GC area percentages) of savory

Component	RT	LRI		Treatment	
			K (mean ±SD)	S1 (mean ±SD)	S2 (mean ±SD)
α-Thujene	5.31	928	0.88 ±0.18	0.63 ±0.26	0.50 ±0.14
α-Pinene	5.56	938	0.90 ±0.19	0.59 ±0.24	0.60 ±0.17
ß-Pinene	6.64	981	0.50 ±0.07	0.32 ±0.09	0.42 ±0.06
ß-Myrcene	6.99	995	1.22 ±0.12	1.06 ±0.15	0.98 ±0.08
α-Phellandrene	7.43	1008	0.22 ±0.03	0.17 ±0.05	0.15 ±0.01
α-Terpinene	7.79	1018	3.20 ±0.40	2.65 ±0.71	2.42 ±0.38
p-Cymene	8.09	1026	2.45 ±0.83	2.67 ±1.34	3.50 ±1.36
Limonene	8.19	1029	0.34 ±0.02	0.30 ±0.02	0.31 ±0.02
γ-Terpinene	**9.2**	**1056**	**32.30 ±1.23**	**29.67 ±2.58**	**30.06 ±2.14**
trans-Sabinene hydrate	9.73	1070	nd	nd	0.03 ±0.07
Terpinen-4-ol	13.96	1175	nd	nd	0.02 ±0.04
Thymol	18.81	1290	nd	nd	0.02 ±0.05
Carvacrol	**19.2**	**1300**	**56.66 ±1.45**	**60.65 ±2.92**	**59.82 ±2.24**
Carvacrol acetate	22.04	1377	0.07 ±0.08	0.10 ±0.07	0.03 ±0.07
β-Caryophyllene	23.68	1420	0.90 ±0.11	0.81 ±0.34	0.76 ±0.22
ß-Bisabolene	27.23	1508	0.32 ±0.04	0.39 ±0.17	0.38 ±0.12
Total			99.93	100.00	100.00

RT = retention time, LRI = linear retention index relative to C9-C23 n-alkanes on a HP-5MS capillary column, nd = not detected. Water saturation in the soil: K = 70%, S1 = 50%, S2 = 30% of SWC

16 compounds were identified in the distilled EO (tab. 2). In each sample carvacrol and γ-terpinen were the main components of the oil. The water supply did not modify their ratio significantly. Proportion of carvacrol was detected between 56.7% (K) and

60.6% (S1) (total GC peak area) while γ-terpinene changed between 29.7% (S1) and 32.30 (K) total area %. Additionally, the number of identified components in the EO increased in the samples of the severe water stress treatment (S2): trans-sabinene hydrate, terpinen-4-ol and thymol could be identified only in these oils. Similar tendencies were found by Baher et al. [2002], Svoboda and Greenway [2003].

Table 3. The effects of water supply on the HS-SPME composition (GC area percentage) of savory

Component	RT	LRI	Treatment		
			K (mean ±SD)	S1 (mean ±SD)	S2 (mean ±SD)
α-Thujene	5.31	928	1.27 ±0.43	1.17 ±0.44	0.96 ±0.44
α-Pinene	5.56	938	1.56 ±0.24	2.26 ±0.67	1.82 ±1.52
Camphene	5.95	952	nd	0.04 ±0.06	0.02 ±0.03
Sabinene	6.52	976	0.05 ±0.09	0.11 ±0.12	0.04 ±0.07
ß-Pinene	6.64	981	0.87 ±0.17	1.54 ±0.44	1.05 ±0.74
ß-Myrcene	6.99	995	0.66 ±0.65	1.30 ±0.85	0.99 ±0.72
2-Octanone	7.04	997	nd	nd	0.09 ±0.15
α-Phellandrene	7.43	1008	0.22 ±0.20	0.31 ±0.16	0.24 ±0.12
α-Terpinene	7.79	1018	4.29 ±1.06	5.04 ±1.79	5.06 ±1.20
p-Cymene	**8.09**	**1026**	**22.20 ±5.83**	**13.22 ±6.96**	**12.69 ±10.10**
Limonene	8.19	1029	0.58 ±0.16	0.59 ±0.22	0.47 ±0.19
(E)-Ocimene (*trans*-β-Ocimene)	8.85	1046	nd	0.05 ±0.06	0.04 ±0.06
γ-Terpinene	**9.2**	**1056**	**50.13 ±5.75**	**60.14 ±10.39**	**67.56 ±8.37**
trans-Sabinen hydrate	9.73	1070	nd	0.07 ±0.06	0.04 ±0.06
α-Terpinolene	10.29	1085	0.14 ±0.14	0.02 ±0.03	0.02 ±0.03
dehidro-p-Cymene	10.38	1087	nd	0.06 ±0.11	nd
Z-Ocimenone	15.98	1223	nd	0.02 ±0.04	0.08 ±0.08
Carvacrol metyl ether	16.61	1238	nd	0.05 ±0.05	nd
Isobornyl acetate	18.41	1281	nd	0.55 ±0.11	0.63 ±0.71
Carvacrol	**19.2**	**1300**	**12.24 ±2.11**	**9.32 ±5.70**	**5.26 ±5.02**
carvacrol acetate	22.04	1377	nd	0.11 ±0.13	0.09 ±0.15
β-Cariophyllene	23.68	1420	4.89 ±1.73	3.09 ±1.07	1.29 ±1.16
ß-Bisabolene	27.23	1508	0.41 ±0.49	0.22 ±0.14	0.08 ±0.08
Total			99.50	99.30	98.50

RT = retention time, LRI = linear retention index relative to C9-C23 n-alkanes on a HP-5MS capillary column, nd = not detected. Water saturation in the soil: K = 70%, S1 = 50%, S2 = 30% of SWC

The HS-SPME method resulted in a higher number of compounds identified from the aerial parts of *S. hortensis* (tab. 3). The main detected components were the γ-terpinene, p-cymene and carvacrol. It could be established that carvacrol was present in a smaller ratio while the total area percentages of γ-terpinen and p-cymene were much higher than in the spectrum of the distilled EO. This spectrum was affected by the drought treatment much more characteristically than it was experienced in the distilled oil. As the result of decreasing SWC the ratio of γ-terpinene in S2 treatment increased by 17%, and parallelly, the ratio of p-cymene and carvacrol decreased considerably. Thus, original flavour compounds of the plant seem to be more sensitive to water supply conditions then those gained by distillation method after harvesting.

CONCLUSION

1. Under the circumstances of the trial 70% saturation level of SWC seems to assure the highest biomass production of savory compared to lower water regimes. The treatments did not modify the ratio of different plant organs in the harvested material.

2. The accumulation level of the essential oil is hardly affected by the drought treatment. However, the essential oil yield of the plant may be significantly reduced by the lower water supply as it is stronger affected by the biomass production.

3. Headspace volatiles as original flavour compounds of the plant seem to be more sensitive to water supply conditions then those gained by distillation method after harvesting.

4. The shortage of water influences the majority of the measured parameters of *Satureja hortensis.* Thus, under arid conditions in the cultivation practice irrigation might enhance fresh mass and EO yield without significantly influencing its quality.

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REFERENCES

Bączek-Kwinta, R., Kozieł, A., Seidler-Łożykowska, K. (2011). Are the fluorescence parameters of German chamomile leaves the first indicators of anthodia yield in drought conditions? Photosynthetica, 49(1), 87–97.

Baher, Z.F., Mirza, M., Ghorbanli, M, Rezaii, M.B. (2002). The influence of water stress on plant height, herbal and essential oil yield and composition in *Satureja hortensis* L. Flav. Fragr. J., 17, 275–277.

Bai, L., Sui, F., Ge, T., Sun, Z., Lu, Y., Zhou, G. (2006). Effect of soil drought stress on leaf water status membrane permeability and enzymatic antioxidant system of maize. Pedosphere, 16, 326–332.

Barbieri, G., Vallone, S., Orsini, F., Paradiso, R., De Pascale, S., Negre-Zakharov, F., Maggio, A. (2012). Stomatal density and metabolic determinants mediate salt stress adaptation and water use efficiency in basil (*Ocimum basilicum* L.). J. Plant Physiol., 169, 1734–1746.

Barrs, H.D. (1968). Determination of water deficits in plant tissues. In: Water deficits and plant growth. Vol. 1, Kozlowski, T.T. (ed.). Academic Press, New York, 235–368.

Boyer, J.S. (1968). Relationship of water potential to growth of Leaves. Plant Physiol., 43, 1056–1062.

Exarchou, V., Nenadis, N., Tsimidou, M., Gerothanassis, I.P., Troganis, A., Boskou, D. (2002). Antioxidant activities and phenolic composition of extracts from Greek oregano, Greek sage and summer savory. J. Agric. Food Chem., 50(19), 5294–5299.

Geshenzon, J., Lincoln, D.E., Langenheim, J.H. (1978). The effect on moisture on monoterpenoid yiels and composition in *Satureja duglasii*. Biochem. Syst. Ecol., 6, 33–43.

Hadian, J., Tabatabaei, S.M.F., Naghavi, M.R., Jamzad, Z., Ramak-Masoumi, T. (2007). Genetic diversity of Iranian accessions of *Satureja hortensis* L. based on horticultural traits and RAPD markers. Sci. Hortic., 115, 196–202.

Hoppe, B. (2012). Handbuch des Arznei- und Gewürzpflanzenanbaus, Band 4., Saluplanta e.V./GFS e.V., Bernburg, Germany, 265–276. (In German)

Inamullah, Akihiro, I. (2005). Adaptive responses of soybean and cotton to water stress II. Changes in CO_2 assimilation rate, chlorophyll fluorescence and photochemical reflectance index in relation to leaf temperature. Plant Prod. Sci., 8, 131–138.

Iyengar E.R.R., Reddy, M.P. (1996). Photosynthesis in high salt-tolerant plants. In: Hand book of photosynthesis, Pessarakli, M. (ed.). Marshal Dekar, Baton Rouge, 56–65.

Jarvis, P.G. (1976). The interpretation of the variations in leaf water potential and stomatal conductance found in canopies in the field. Phil. Trans. R. Soc. Lond. B., 273, 593–610.

Madsen, H.L., Andersen, L., Christiansen, L., Brockhoff, P., Bertelsen, G. (1996). Antioxidative activity of summer savory (*Satureja hortensis* L.) and rosemary (*Rosmarinus officinalis* L.) in minced, cooked pork meat. Z. Lebensm. Unters. For., 203, 333–338.

Momtaz, S., Abdollahi, M. (2008). A systematic review of the biological activities of *Satureja L.* species. PhOL, 2, 34–54.

Novak, J., Bahoo, L., Mitteregger, U., Franz, C. (2006). Composition of individual essential oil glands of savory (*Satureja hortensis* L., Lamiaceae) from Syria. Flav. Fragr. J., 21, 731–734.

Pank, F., Pfefferkorn, A., Krüger, H. (2004). Evaluation of a summer savory (*Satureja hortensis* L.) collection with regard to morphology, precocity, yield components and essential oil and carvacrol content. Z. Arznei. Gewurzpfla. 9(2), 72–79. (In German)

Parida, A.K., Dagaonkar, V.S., Phalak, M.S., Umalkar, G.V., Aurangabadkar, L.P. (2007). Alterations in photosynthetic pigments, protein and osmotic components in cotton genotypes subjected to short-term drought stress followed by recovery. Plant Biotechnol. Rep., 1, 37–48.

Pharmacopoeia Hungarica (1986). Medicina Könyvkiadó, Budapest, Hungary, 1, 395–398.

Radácsi, P., Inotai, K., Sárosi, Sz., Czövek, P., Bernáth, J., Németh, É. (2010). Effect of water supply on the physiological characteristic and production of basil (*Ocimum basilicum* L.). Eur. J. Hortic. Sci., 75 (5), 193–197.

Rahbarian, P., Afsharmanesh, G., Shirzadi, M.H. (2010). Effects of drought stress and manure on relative water content and cell membrane stability in dragonhead (*Dracocephalum moldavica)*. Plant Ecophysiol., 2, 13–19.

Rahimi, A., Hosseini, S.M., Pooryoosef, M, Fateh, I. (2010). Variation of leaf water potential, relative water content and SPAD under gradual drought stress and stress recovery in two medicinal species of *Plantago ovata* and *P. psyllium*. Plant Ecophysiol., 2, 53–60.

Reynolds, S.G. (1970). The gravimetric method of soil moisture determination. Part I. A study of equipment, and methodological problems. J. Hydrol., 11, 258–273.

Scholander, P.F, Hammel, H.T., Bradstreet E.A., Hemmingsen, E.A. (1965). Sap pressure in vascular plants. Science, 148, 339–346.

Seidler-Łożykowska, K., Mordalski, R., Kucharski, W., Golcz, A., Kozik, E., Wójcik, J. (2009). Economic and qualitative value of the raw material of chosen species of medicinal and aromatic plants from organic farming Part III. Yield and quality of herb and seed yield of summer savory (*Satureja hortensis* L.). Acta Sci. Pol. Hortorum Cultus, 8(4), 47–53.

Selmar, D., Kleinwächter, M. (2013). Stress enchances the synthesis of the secondary plant products: The impact of stress-related over-reduction on the accumulation of natural products. Plant Cell Physiol., 54(6), 817–826.

Simon, J.E., Reiss-Bubenheim, D., Joly, R.J., Charles, J.D. (1992). Water stress-inducated alterations in essential oil content and composition of sweet basil. J. Essent. Oil Res., 4, 71–75.

Sváb, J., Hornok, L. (1992). Summer savory (*Satureja hortensis* L.). In: Cultivation and processing of medicinal plants, Hornok, L. (ed.). Akadémiai Kiadó, Budapest, 218–220.

Svoboda, K.P., Greenaway, R.I. (2003). Investigation of volatile oil glands of *Satureja hortensis* L. (summer savory) and phytochemical comparison of different varieties. Int. J. Aromather., 13(4), 196–202.

Van Den Dool, H., Kratz, P. (1963). A generalization of the retention index system including linear temperature programmed gas-liquid partition chromatography. J. Chromatogr. A., 11, 463–471.

Wheatherley, P.E. (1950). Studies in the water relations of the cotton plant. 1. The field measurements of water deficits in the leaves. New Phytol., 49, 81–97. 38.

Zámboriné, N.É., Tanító, G., Novák, I., Rajhárt, P. (2005). Optimalisation of production of some medicinal species in consequence of the climatic change. Agro 21 Series, Hungarian Academy of Sciences, Budapest, 158–168. (In Hungarian)

WPŁYW ZAWARTOŚCI WODY W GLEBIE NA FIZJOLOGICZNE PARAMETRY, WYDAJNOŚĆ ORAZ SUBSTANCJE CZYNNE CZĄBRU OGRODOWEGO (*Satureja hortensis* L.)

Streszczenie. Badano wpływ dostarczanej wody na odmianę ‘Budakalászi’ *Satureja hortensis* L. (cząber ogrodowy). Trzy poziomy saturacji (70–50–30%) pojemności wodnej gleby (SWC) zastosowane w komorze klimatycznej spowodowały istotne zmiany parametrów fizjologicznych roślin cząbru. W porównaniu z kontrolą (70% SWC), najbardziej suche warunki (30% SWC) powodowały ponad 20% spadek względnej zawartości wody (RWC) w roślinach oraz prawie 5-krotnie mniejszy potencjał wodny. Wartości SPAD wskazywały na zawartość chlorofilu o 45% wyższą w najniższym reżimie nawadniania. Zmniejszenie SWC (30%) istotnie wpłynęło na plon cząbru: świeża masa zmniejszyła się o 54% natomiast sucha masa o 46%. Nie wykryto żadnych zmian w stosunku masaliści/całkowita masa kiełków. Najwyższe stężenie olejków lotnych (EO) w liściach (5,300 $\mathrm{ml \cdot 100\ g^{-1}}$) zmierzono w roślinach narażonych na umiarkowany stres suszy (50% SWC), natomiast rośliny kontrolne i rośliny wystawione na ostry stres wodny wykazywały niższą kumulację olejków lotnych (odpowiednio 4,922 i 4,782 $\mathrm{ml \cdot 100\ g^{-1}}$). Wytwarzanie EO obliczone na podstawie wartości świeżego plonu oraz stężenie EO były najniższe w przypadku roślin rosnących w doniczkach o najniższej zawartości wody w glebie. Głównymi składnikami olejku w każdym zabiegu był karwakrol (56,7–60,6% EO) oraz γ-terpinen (29,7–32,3% EO). Dostarczanie wody nie modyfikowało w sposób istotny składu ilościowego EO jednak wpływało w sposób zauważalny na olejki lotne uzyskane techniką HS. W przeciwieństwie do poprzedniej praktyki stwierdzono, że bez właściwej dostawy wody uprawa cząbru ogrodowego nie może być skuteczna.

Słowa kluczowe: pojemność wodna, stres suszy, olejek lotny, SPME, potencjał wodny, SPAD

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