



Morphophysiological changes of wild *Stachys multicaulis* species under physical conditions during the cultivation process

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ABSTRACT

Depending on the physical environmental conditions, cultivation process can have significant effects on the wild plants' morphophysiological characteristics. *Stachys multicaulis* is an Iranian wild endemic medicinal plant species and its cultivation preformed under different Soil Textures (ST) and Soil Moisture Regimes (SMRs). Controlled pot culture conditions performed with light, moderate, heavy STs and a set of SMRs at 100% Field Capacity (FC), 70% FC and 30% FC. Plant cultivated in heavy STs had higher performance in all measured treats. Height of plant (HP), Calibrated Greenness (CG), Leaf Ratio (LR) and Angle (LA), aerial Moisture Content (MC) did not show a regular trend in comparison to the wild. Unlike the Density of Trichome (DT), Length of leave's Trichome (LT) showed a significant change under cultivation conditions ($p < 0.01$). Also, as a physiological response, Essential Oils Components (EOC), especially thymol and bicyclogermacrene decreased with decreasing soil MC for light ST and the lowest change were observed in heavy ST and 30%FC. Generally, cultivation reduced EOCs, but improved plant's morphological characteristics.

1. Introduction

The Iranian wild endemic *Stachys multicaulis* Benth. species is a medicinal and aromatic herb belonging to the Lamiaceae family and grows in different parts of Iran (Mozaffarian, 2007). A green bush with numerous stems which is wooden at the base, has a height of 20–40 cm and covered with long simple trichome. The plant is valuable in terms of food and medicine (Erdemoglu et al., 2006; Jamzad et al., 2009). Medicinally, *S. multicaulis* has many chemical and biological activities such as bicyclogermacren, spathulenol, germacrene etc (Rustaiyan et al., 2017). The plant has much considerable ecological importance in term of ecosystem services such as beauty, soil and water conserving as well. Considering the importance of the *S. multicaulis* from different aspects, its cultivation can have positive effects on its performance for different goals.

With globalization in the last century, introduction of wild plant species for commercial use has become more accessible (Shelef et al., 2016) but information using morphophysiological and yield traits is vital for developing cultivars (Joshi et al., 2018) and therefore, cultivation of wild plants is of paramount importance in order to produce higher

quantity and quality of plant products.

Cultivation is one of the steps in the process of plant domestication and can have notable effects on wild plant performance. Domestication is an evolutionary process through which domesticated plants and animals (Darwin, 1868; Harlan, 1992), consists of genetic and morphological changes within the plant (Fuller et al., 2010; Sakuma et al., 2011; Abbo et al., 2014; Milla et al., 2017). Remarkable phenotypic differences are between domesticated plants and their progenitors (Matesanz and Milla, 2018), are differ greatly in their phenotypes compared with wild ancestors (Turcotte et al., 2017) which contributed to human civilization (PérezJaramillo et al., 2016). This is generally considered to be the end-point of a continuum that starts with exploitation of wild plants, continues through cultivation of plants selected from the wild. Finally this process terminates in fixation, through human selection, of morphological and hence genetic differences distinguishing a cultivated from its wild progenitor (Pickersgill, 2007). This process involves selection, modification and adoption of wild plant species with useful characteristics for human use (Gepts, 2004; PérezJaramillo et al., 2016). Therefore, cultivation and its condition is very effective on plant performance along the domestication.

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However, cultivation as one of the most important stage of domestication process could have a positive effect on plant conservation strategy includes both the exploitation of wild populations, especially for medicinal plants (Nekratova and Shurupova, 2015), but environmental conditions have different effects on the performance of plants cultivated. For instance, climate factors represents a serious threat to the development of more environmentally resilient crops to safeguard the future of food production. Therefore, plant species which are able to cope with these changes are required (Beacham et al., 2018) and therefore, cultivation of wild plants can be one of the practical way to this. Wild plants cultivation is usually referred to as the fostering of wild plants for use by man (Puruganan and Fuller, 2009; Shelef et al., 2016) and that most of the these plants was adopted for cultivation based on their morphological and biochemical traits (Sharif et al., 2019). But, many of the changes in plant traits during cultivation were accompanied by progressive changes in the environment and management practices (Pérez-Jaramillo et al., 2016).

There are numerous well-documented examples of how environmental conditions of cultivation process can drive evolution in wild species (Turcotte et al., 2017). Yet, many different plant species were investigated under cultivation and domestication process in term of morphophysiological properties such as *Stenocereus stellatus* (Casas et al., 1999), *Triticum spp* (Matsuoka, 2011), *Phaseolus vulgaris* (Bitocchi et al., 2013), *Agave inaequidens* and *A. hookeri* (Figueredo et al., 2014), *Sorghum* (Winchell et al., 2017) or for other plant species (Sidina et al., 2009; Pérez-Jaramillo et al., 2016; Sun et al., 2015; Ulén and Aronsson, 2018; Rahman et al., 2018). However, there are many different reports about the morphophysiological plant properties response to change the environmental condition under cultivation. Therefore, a broad range of morphophysiological responses may be happen based on water-soil condition and plant type.

Over the last decades, the effects of cultivation on phenotypic plasticity remain scarcely explored (Matesanz and Milla, 2018) and there are many gaps of knowledge about morphological and physiological changes for specific and endemic plants species under cultivation process {e.g. response to different soil texture (ST)}. Also, plant species have various response during cultivating process because the spatial heterogeneity and plants adaptive mechanisms in face of different treatments (Noori et al., 2014).

Table 1
Soil's physicochemical properties for pot culturing.

ST	Clay (%)	Silt (%)	Sand (%)	Texture	Bulk density (g/cm ³)
Light	5.00	25.00	70.00	Sandy loam	1.52
Medium	15.00	42.00	43.00	Loam	1.43
Heavy	40.00	30.00	30.00	Clay loam	1.35
N (Meq/L)	P (Meq/L)	K (Meq/L)	pH	OM (%)	EC(ds/m)
4.40 ± 0.10	16.80 ± 3.25	82.40 ± 11.13	7.87 ± 0.40	1.60 ± 0.08	0.93 ± 0.12

ST = Soil texture.

Table 2
Analysis of variance for plant's morphophysiological changes under cultivation conditions.

SV	df	Morphological treats							Physiological treats				
		Plant height	Plant biomass	calibrated greenness	leaf ratio	leaf angle	aerial moisture content	Trichome density	thymol	Bicycle germacrene	b-caryophyllene	a-pinene	d-cadinene
ST	2	0.001**	0.032*	0.034*	0.023*	0.044*	0.058 ^{ns}	0.064 ^{ns}	0.001**	0.031*	0.041*	0.023*	0.088 ^{ns}
SMR	2	0.001**	0.001**	0.001**	0.032*	0.021*	0.015*	0.074 ^{ns}	0.001**	0.035*	0.032*	0.031*	0.067 ^{ns}
ST×SMR	4	0.001**	0.021*	0.017*	0.045*	0.062 ^{ns}	0.057 ^{ns}	0.087 ^{ns}	0.012*	0.046*	0.051 ^{ns}	0.041*	0.075 ^{ns}

* = Significant different at level of 5%, ** = Significant different at the level of 1%, ns = Not significant, df = Degrees of Freedom, SV = Source of variation, ST = Soil Texture, SMR = Soil moisture regime.

Therefore, the hypothesis is that the morphophysiological characteristics of native plants will not change under culture conditions. Considering all the above mentioned, this study was designed to investigate the effects of physical conditions included different Soil Textures (ST) and Soil Moisture Regimes during the cultivation process on morphophysiological properties of *Stachys multicaulis* Benth., an Iranian wild endemic medicinal plant species.

2. Material and methods

2.1. Ecological factors of the plant habitat

Natural habitat of the *S. multicaulis* is located at the border of steppe and semi-steppe climatic zones, Iran central rangelands (Yazdanshenas et al., 2016). The average altitude of the plant habitat is 2350 m above sea level; annual temperature about 11°C and annual precipitation about 250 mm, with mild climatic conditions and cold winters.

2.2. Plant's morpho-physiological characteristics in habitat

Morphophysiological characteristics of the *S. multicaulis* were studied in the wild. For this purpose, systematic random sampling performed and then, four plant stands was selected. Plant's morphophysiological properties were measured in filed and laboratory as follows: Height of Plant (HP), Leaf Angle (LA), Leaf length/width Ratio (LR), Distance Between Nodes (DBN), the relative Calibrated Greenness (CG) and leaf color (RGB), Length and Density of leaf's Trichome (LT and DT) (using Zeiss microscope Model: 47 60 05–9901). The physiological properties of Essential Oils Components (EOC) were also studied for samples.

2.3. Plant material and culturing conditions

In order to study the effects of cultivation (and its condition) on morphophysiological properties of the plant areal parts, cylindrical plastic pots were used in specific height and diameter (21*15 cm). Soil samples were taken from the original habitat of the species and transferred to the home garden for pot culturing. Three different STs were prepared on the basis of changes in soil components -i.e., percentage of sand, silt and clay- (Prakash et al., 2010).

Therefore, different STs including light (5, 25, 70 percent for clay, silt and sand, respectively), medium (15, 42, 43 percent for clay, silt and sand, respectively) and heavy (40, 30, 30 percent for clay, silt and sand, respectively) were prepared for pot culturing. Some other main soil nutrient elements including N (4.4 Meq/L), P (16.8 Meq/L), K (82.4 Meq/L) and OM (1.6 %) were analyzed for soil samples in pots as well (Table 1).

At first, a germination test was conducted on *S. multicaulis* seeds which has been collected from the plant's natural habitat last year and due to the problem in its germination, plant's scion of plant was used for propagation in pots. For this purpose, at the beginning of the growing season, plant species stands were identified and plant's scion were collected in same shape and size, transferred to the home garden and

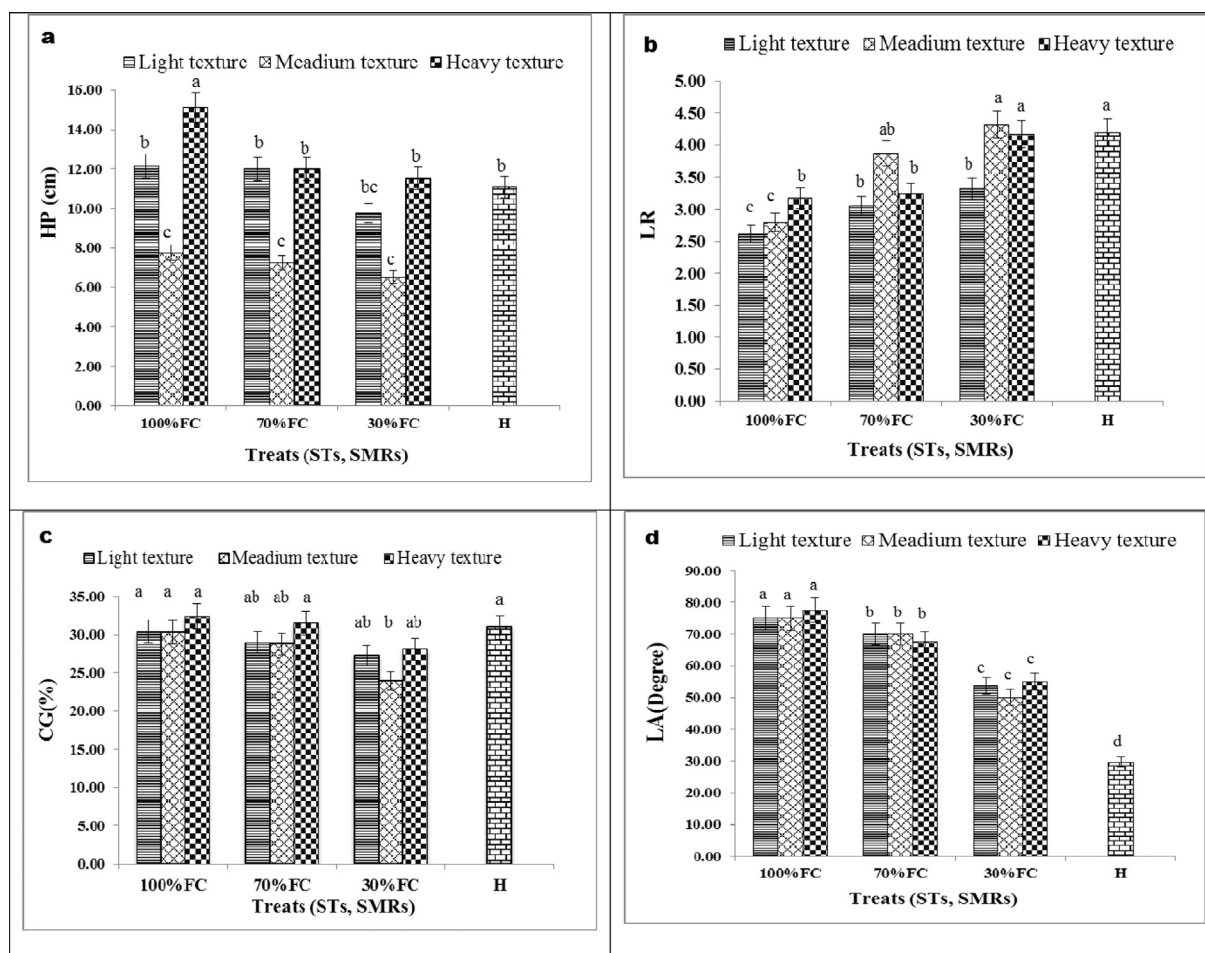


Fig. 1. HP (a), LR (b), CG (c), LA (d) changes for *S. multicaulis* under cultivation condition in relation to the different STs and SMRs. (H= Habitat conditions).

cultivated in pots. Cultivating populations of the plant performed in relation to three different STs. Then, a randomized complete block with factorial treatment structure were used based on different levels of STs and SMRs. The experiment was conducted at the botanical garden of the faculty of natural resources, University of Tehran, Karaj, Iran, at the spring of 2017.

2.4. Measuring plants' morpho-physiological characteristics

The experiment was conducted in a randomized complete block with factorial treatment structure with 4 replications and irrigation treatments were used for cultivated plants including 100 % Field Capacity (100% FC), 70% Field Capacity (70%FC) and 30% Field Capacity (30%FC) for all three different STs. Then, At the end of the experimental (a period of 90 days), plant's morphophysiological properties including HP, LA, LR, DBN, CG, LT and DT of the leave's and Moisture Content (MC) were measured.

HP, LR and DBN were measured using a simple method (Promkhambut et al., 2010). The plants CG was measured using RGB based on image analysis and crating correlation to SPAD results (Yadav et al., 2010). For LT and DT measurement, leaves of plant were cut and observed with a stereomicroscope -in lab-using Zeiss microscope Model: 47 60 05-9901- (Karray-Bouraoui et al., 2009).

Also in order to investigate the plant's physiological characteristics changes, water-distilled EOCs from the aerial parts of wild *S. multicaulis* in habitat and also, for plants cultivated under pot culturing were measured using gas chromatography– mass spectrometry (GC-MS)

method (Safaei-Ghomi et al., 2007). EOC including percentage of a-pinene, thymol, methyl eugenol, b-caryophyllene, spathulenol, loger-macrene, cedr-8(15)-en-9a-ol, d-cadinene and bicyclogermacrene were measured for each sample.

End of the experiment and measurements, Kolmogorov-Smirnov test was used for testing the normality of data. ANOVA test, other analysis and then, the post hoc test were performed using the Duncan method ($p \leq 0.05$) in SPSS software.

Table 3

Plant's Morphological changes under cultivation process.

Factor (s)	ST	SMR			NHP
		FC	70%FC	30%FC	
DBN (cm)	L	1.9 ± 0.4 ^{ABa}	1.6 ± 0.3 ^{Bb}	0.9 ± 0.2 ^{Cb}	2.0 ± 0.5 ^A
	M	1.43 ± 0.2 ^{Ab}	1.3 ± 0.2 ^{Ab}	0.9 ± 0.3 ^{Bb}	-
	H	1.8 ± 0.5 ^{Aa}	1.8 ± 0.3 ^{Aa}	1.5 ± 0.3 ^{Ba}	-
TD (Per unit)	L	5 ± 0 ^{Aa}	5 ± 1 ^{Aa}	5 ± 1 ^{Aa}	5.0 ± 2.0 ^A
	M	4 ± 0 ^{Aa}	4 ± 0 ^{Aa}	5 ± 0 ^{Aa}	-
	H	4 ± 0 ^{Aa}	5 ± 0 ^{Aa}	5 ± 1 ^{Aa}	-
TL (mm)	L	2.3 ± 0.4 ^{Ba}	2.3 ± 0.3 ^{Ba}	2.3 ± 0.2 ^{Ba}	4.3 ± 0.7 ^A
	M	1.8 ± 0.2 ^{Bb}	1.5 ± 0.2 ^{Cc}	2.3 ± 0.3 ^{Aa}	-
	H	1.8 ± 0.5 ^{Cb}	2.0 ± 0.3 ^{Bb}	2.3 ± 0.3 ^{Aa}	-

The uppercase letters represent the comparison for the row and the lowercase letters show the comparison for each column. The same letters do not show a significant difference at the 5% level. NHP = Native habitat of the plant, ST = Soil texture, L = Light, M = Medium, H=Heavy, DBN = Distance between nodes, TD = Trichome density (Per unit), TL = Trichome length (mm).

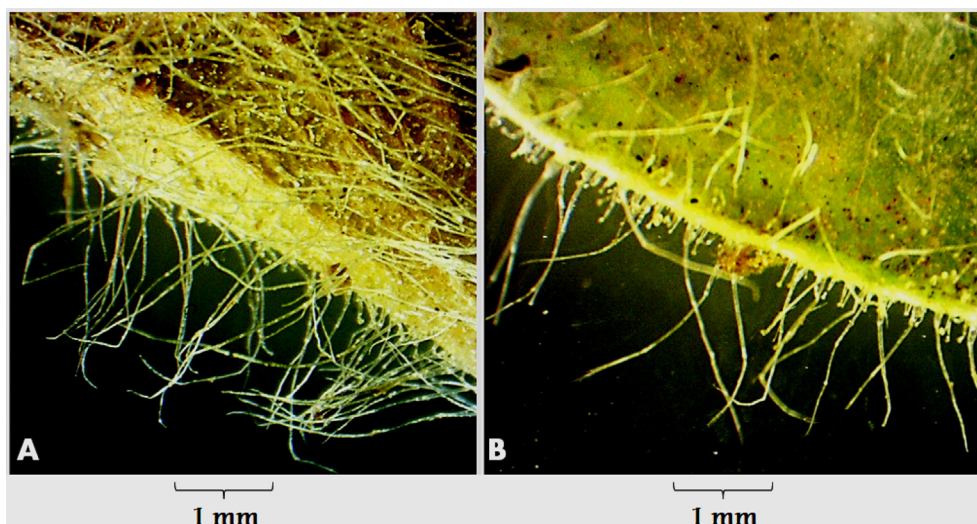


Fig. 2. Change of plant's trichome properties under cultivation process (B) in relation to the natural habitat conditions (A).

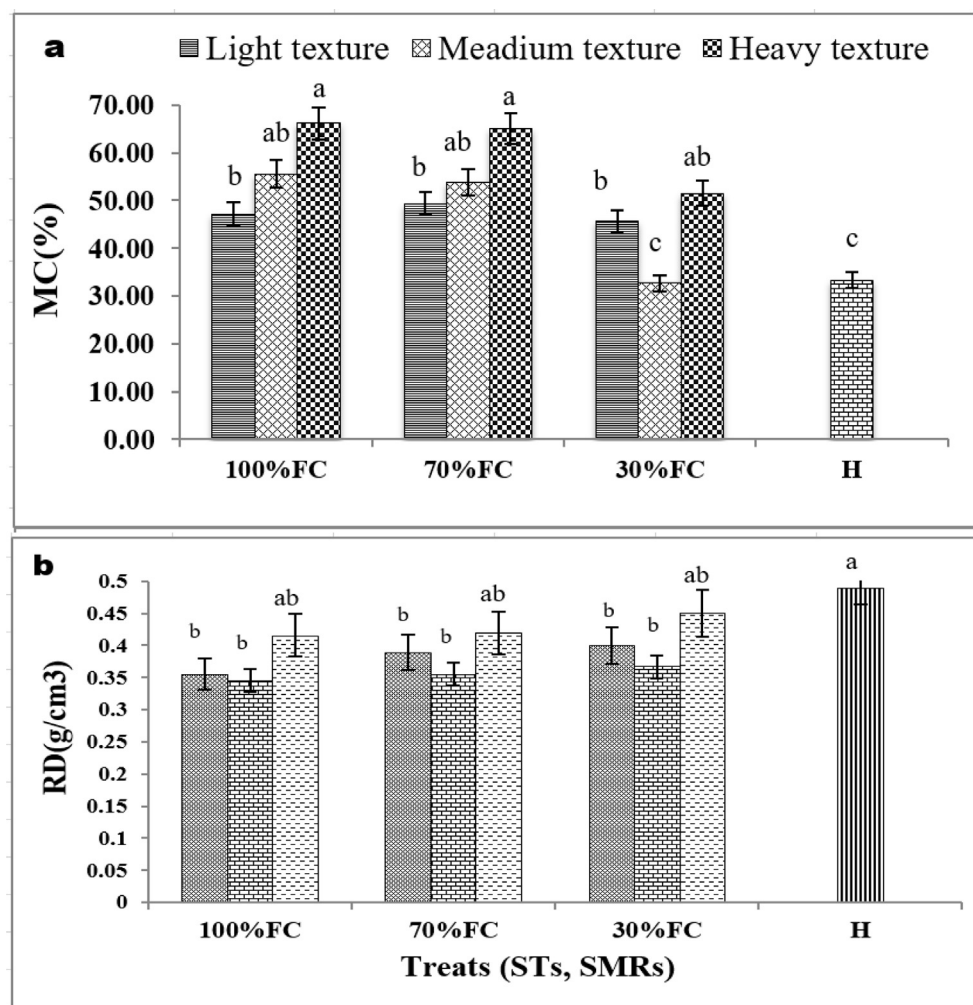


Fig. 3. RD and MC changes under cultivation process in different STs and SMRs.

3. Results

The analysis of the all trait measurements for *S. multicaulis* species showed that different environmental factors in term of soil and water

conditions affected domesticated plant traits significantly. According to the results, HP, LA, LR, DBN, LT and DT were significantly different in various STs ($P < 0.001$). Also, significant difference was observed among the all measurements of the LR under domestication in different ST

Table 4
Changes in plant's EOCs of areal parts under cultivation process.

Factor (s)	ST	SMR			NHP
		FC	70%FC	30%FC	
a-pinene (%)	L	0.6 ± 0.04 ^{Bb}	0.7 ± 0.03 ^{Bab}	0.9 ± 0.1 ^{ABa}	1.1 ± 0.3 ^A
	M	0.6 ± 0.08 ^{Ab}	0.6 ± 0.03 ^{Bb}	0.7 ± 0.02 ^{Ba}	-
	H	0.8 ± 0.1 ^{Ba}	0.8 ± 0.1 ^{2Ba}	0.9 ± 0.2 ^{Ba}	-
thymol (%)	L	1.4 ± 0.8 ^{Ca}	3.5 ± 1.0 ^{Ba}	5.0 ± 1.1 ^{Aa}	5.3 ± 0.2 ^A
	M	2.8 ± 0.8 ^{Ba}	3.2 ± 0.7 ^{ABa}	4.9 ± 0.8 ^{Aa}	-
	H	4.4 ± 0.7 ^{Ba}	4.8 ± 0.6 ^{Ba}	5.1 ± 1.1 ^{Aa}	-
methyl eugenol (%)	L	4.3 ± 0.3 ^{Ba}	4.7 ± 0.3 ^{Ba}	5.3 ± 0.2 ^{Aa}	5.4 ± 0.4 ^A
	M	4.1 ± 0.2 ^{Aa}	4.3 ± 0.2 ^{Aa}	4.6 ± 0.3 ^{Aa}	-
	H	4.5 ± 0.5 ^{Ba}	4.9 ± 0.3 ^{ABa}	5.2 ± 0.3 ^{Aa}	-
b-caryophyllene (%)	L	4.3 ± 0.2 ^{Bab}	4.8 ± 0.2 ^{ABb}	4.9 ± 0.4 ^{ABab}	5.5 ± 0.7 ^A
	M	3.9 ± 0.3 ^{Ab}	4.5 ± 0.3 ^{Ab}	4.5 ± 0.5 ^{Ab}	-
	H	4.8 ± 0.4 ^{Aa}	5.2 ± 0.2 ^{Aa}	5.4 ± 0.4 ^{Aa}	-
spathulenol (%)	L	16.1 ± 2.3 ^{Ba}	18.3 ± 5.1 ^{Aa}	18.3 ± 4.6 ^{Aa}	20.7 ± 5.6 ^A
	M	16.6 ± 3.2 ^{Aa}	17.5 ± 3.4 ^{Ab}	17.6 ± 5.2 ^{Ab}	-
	H	18.8 ± 4.4 ^{Aa}	20.4 ± 4.3 ^{Aa}	20.4 ± 5.1 ^{Aa}	-
logermacrene (%)	L	3.3 ± 0.5 ^{Ba}	3.4 ± 0.3 ^{Ba}	3.9 ± 0.5 ^{Aa}	4.3 ± 0.5 ^A
	M	3.1 ± 0.2 ^{Aa}	3.2 ± 0.3 ^{Aa}	3.4 ± 0.4 ^{Aa}	-
	H	3.2 ± 0.3 ^{Ba}	3.8 ± 0.5 ^{ABa}	4.2 ± 0.4 ^{Aa}	-
cedr-8(15)-en-9a-ol (%)	L	1.5 ± 0.4 ^{Ba}	1.7 ± 0.2 ^{Bab}	1.8 ± 0.3 ^{Bb}	2.8 ± 0.9 ^A
	M	1.4 ± 0.3 ^{Aa}	1.5 ± 0.3 ^{Ab}	1.7 ± 0.2 ^{Ab}	-
	H	1.4 ± 0.4 ^{Ba}	2.0 ± 0.4 ^{ABa}	2.6 ± 0.4 ^{Aa}	-
d-cadinene (%)	L	1.4 ± 0.2 ^{Aa}	1.5 ± 0.3 ^{Aa}	1.5 ± 0.4 ^{Aa}	1.8 ± 0.5 ^A
	M	1.3 ± 0.3 ^{Aa}	1.4 ± 0.4 ^{Aa}	1.4 ± 0.4 ^{Aa}	-
	H	1.4 ± 0.3 ^{Aa}	1.5 ± 0.3 ^{Aa}	1.6 ± 0.5 ^{Aa}	-
bicyclogermacrene (%)	L	15.4 ± 2.4 ^{Ba}	17.8 ± 2.7 ^{Ba}	18.8 ± 3.4 ^{ABa}	23.4 ± 6.2 ^A
	M	16.1 ± 3.1 ^{Aa}	16.5 ± 4.6 ^{Aa}	17.2 ± 4.1 ^{Aa}	-
	H	18.8 ± 2.4 ^{Aa}	19.2 ± 2.8 ^{Aa}	22.6 ± 3.9 ^{Aa}	-

The uppercase letters represent the comparison for the row and the lowercase letters show the comparison for each column. The same letters do not show a significant difference at the 5% level. NHP = Native habitat of the plant, ST = Soil texture, L = Light, M = Medium, H=Heavy.

compared to wild (Table 2).

HP at the flowering time varied significantly under different STs and SMRs. The most HP (15 cm) was observed at 100%FC of SMR for heavy ST.

As a defense system in plants that preserve MC against sunlight, LR was different under cultivation process. LR had the most value under SMR at 30%FC in loamy soil and was similar to wild (Fig. 1: b).

Generally, CG, as a factor for biomass production, had no significant difference for heavy soil compared with control sample (habitat condition). Light and moderate texture, had more negative effect on plant CG (Fig. 1: c).

Leaf angle (LA) also, is a physiological and morphological attribute that changes with sunlight condition. This attribute had a regular trend for different levels of SMRs in comparison to the wild condition. Fig. 1d shows the change of the plant LA under cultivation conditions in different STs. In more moisture severity of the stress at 30%FC, LA had a tendency to the wild (Fig. 1: d).

Moreover, other measured plant factors including DBN (cm), number of trichome per unit (NT), LT (mm) were noticeable under cultivation process (Table 3). LT and DT under cultivation process were significantly different from those find in native habitats. Fig. 2 shows the change of the DT and LT under cultivation compared to the wild.

Both ST and SMR had significant effect on aerial parts MC of the plant cultivated. However, MC increased along with the increasing the SMR in plant's aerial parts and the most value was observed at 100%FC for heavy ST (Fig. 3: a).

A critical feature in determining plants potential to uptake water and nutrients, Root Density (RD), showed considerable results. Plant's RD increased along with decreasing soil moisture (SMR). The most RD was observed at lowest SMR for heavy ST (Fig. 3: b).

The results of the relation between RD and ST (e.g. clay content) in different levels of SMRs indicated that heavy clay soil (s) has the most positive effect on RD. On the other hand, plant cultivated in clay soil, may uptake and store more nutrition and mineral in itself roots (Fig. 3 b). However, this factor may be affected by other environmental factors in

relation to the origin plant habitat.

The physiological characteristics of the plant under cultivation process were also significantly different from the main habitat. EOCs of *S. multicaulis* is listed in Table 4, in which the percentages of components are given. The most changes have occurred in different SMRs for evaluated properties. Chemical factors included a-pinene, thymol, and bicyclogermacrene had the most changes under different SMRs. Also, some other properties such as spathulenol, b-caryophyllene and cedr-8(15)-en-9a-ol have received the most impact from STs ($p < 0.05$).

Changes in plant's thymol and bicyclogermacrene under different STs is presented in Fig. 4 under all SMRs. EOCs for STs with light or heavy texture was higher. This results showed a highest correlation coefficient to SMRs. The figure below shows the change in trends only for Thymol and bicyclogermacrene, which have had the most changes among the all EOCs measured.

4. Discussion

Cultivation and subsequently domestication as a crop improvement process (Bellucci et al., 2014) involves obtaining desirable plants with distinct phenotypes by sophisticated and conscious human choice-making (Abbo et al., 2014). Modification of wild for cultivation species leads to unprecedented population growth and providing the potential basis for surplus production (Fuller et al., 2010) is a classic approach to plant improvement (Dumont and Vernier, 2000). Understanding these impacts is crucial for the proper development and implementation of sustainable agricultural practices (Turcotte et al., 2017). Therefore, this is necessary to find out the morphophysiological changes of the valuable wild plants under cultivation process.

The results described in this study indicate that there is important morphophysiological divergence between wild and cultivated *S. multicaulis* which is depend on cultivation conditions, STs and SMR especially. Although some plant species didn't showed morphophysiological changes (Qayyum et al., 2018) but, this research showed different results under cultivation conditions. Casas et al. (2007) and Slugina et al.

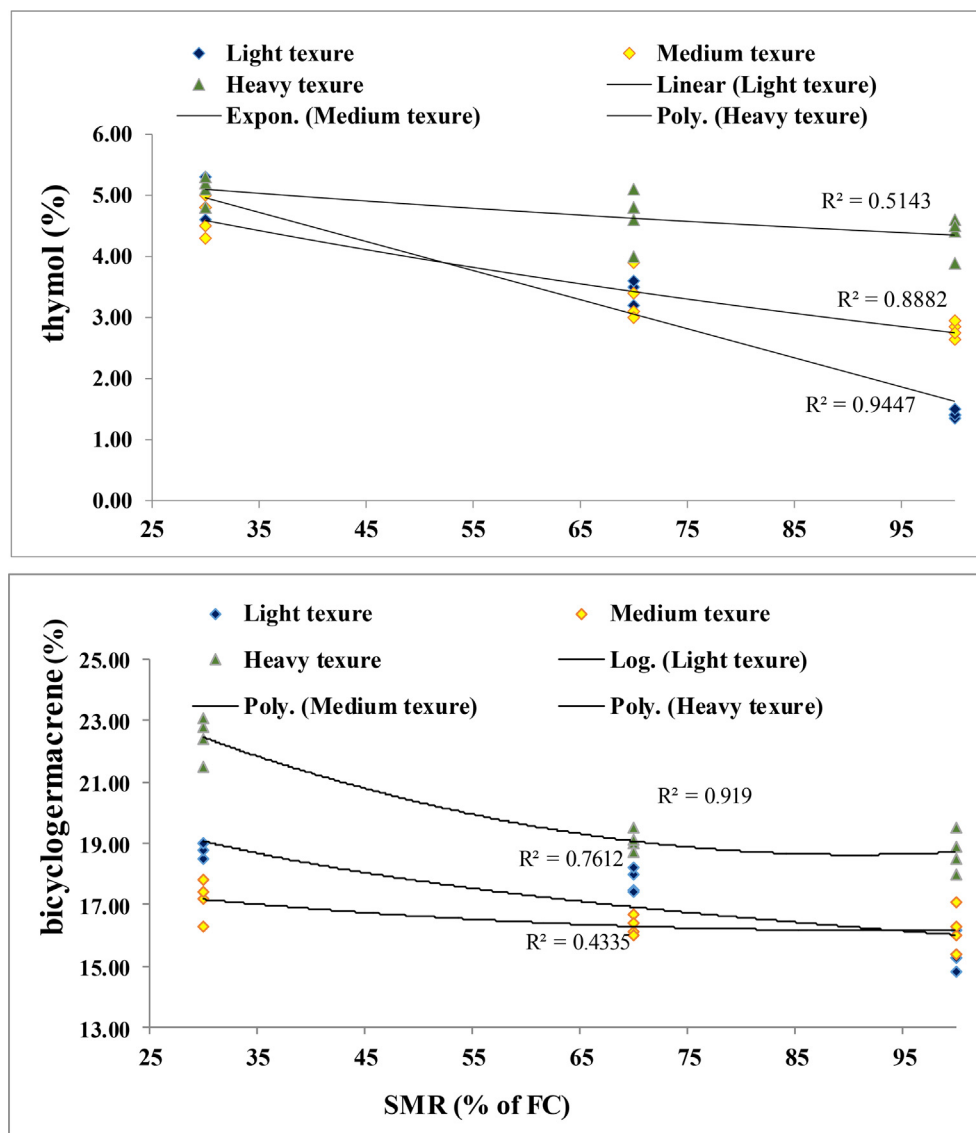


Fig. 4. Changes of plant's thymol and bicyclogermacrene under different levels of STs and SMRs.

(2018) disclosed that significant differences may occur in morpho-physiology between wild and cultivated populations of the studied species. But Quilot et al. (2004) reported that no effect of level of cultivation was observed on these characteristics for plants under cultivation process.

Generally, water shortage is by far the most important environmental stress (Cattivelli et al., 2008) and improving the efficient use of irrigation is becoming a key issue (Mubeen et al., 2016). Therefore, this study indicated that physical condition can be effect on the performance of the wild plant cultivated during the cultivation process. HP depend highly on ST and SMR. Also, based on the results (Fig. 1: a), it seems that *S. multicaulis* has high performance in light or heavy (not medium) ST under SMRs. This has been confirmed in previous studies for other plants (Thapa et al., 2019). Plants respond to environmental conditions by altering their phenotypes (Matesanz and Milla, 2018). Kanmegne et al. (2018) also reported an initial difference in characteristics of *Xylopia parviflora* under cultivation process. Similar to this, Figueredo et al. (2014) reported that cultivated populations of *Agave inaequiden* had taller plants with longer stems, longer and wider leaves than the wild populations.

The plant CG (Calibrated greenness based on RGB) of the cultivated *S. multicaulis* which is related to photosyntess, shows no visible and

significant difference with wild (Fig. 1c). Similarly, Ranjbar and Mousavi (2015) reported that different SMRs had a slightly negative effect on this factor in *Nitraria schoberi*. However, Denison (2015) reported that photosynthetic efficiency and stress tolerance improved under cultivation process.

LA and LR as physiological and morphological characteristics that reflect the sunlight had a similar and regular trend for the plant under different levels of SMRs compared to the wild. Fig. 1: b, d show the changes of the LA and LR under cultivation conditions. Under more drought stress condition (lower levels of SMRs), leaves had a tendency to the shoot (55° for 30%FC in all three STs) and also LR increased to 5 units which was similar to wild. Tajamoliyan et al. (2013) reported that increasing water deficit stress led to decreasing in water potential, specific leaf area in *Fortuynia bungei* ($P < 0.01$), and the species is adapted to dry conditions by modification of the leaves morphology.

MC change of the plant's aerial parts under cultivation in relation to the different STs was noticeable (Fig 3: a). The results indicate that *S. multicaulis* increased it's MC at all levels of SMRs in different STs. In this regard, Chakhchar et al. (2016) mentioned that water deficiency significantly decreased the leaf water potential and stomatal conductance for the plants.

According to Table 3, the highest value of the plant factors was

happened in heavy ST under different levels of SMRs. For example; the DBN (cm) decreased under plant cultivation process from wild and the LT and NT per unit decreased under cultivation process for all three STs and SMRs compared to the wild populations. Similar to this, the change of trichomes attributes is reported in previous study of Karray-Bouraoi et al. (2009) against environmental change for cultivated plants. Many of these changes in plant morphophysiological traits will lead to better (or not in some rare case) performance for different purposes under cultivation process. However cultivation and subsequently domestication is not a statistic process and happens over the time.

The physiological characteristics of EOCs included α -pinene, thymol, methyl eugenol, β -caryophyllene, spathulenol, logermacrene, cedr-8(15)-en-9a-ol, d-cadinene and bicyclogermacrene showed different values under different physical conditions under cultivation process. EOC such as thymol and bicyclogermacrene in light ST and 100%FC decreased and the lowest changes were observed in heavy ST at 30%FC of SMR. Components of thymol and bicyclogermacrene had the 70% and 18% change compared to wild populations. There are many different reports of the change EOCs under cultivation process. Similar to these findings, Azizi et al. (2009) reported a significant change in EOCs of *Bunium persicum* under cultivation process. Also quantitative differences were reported between EOCs obtained from wild and cultivated Thymus species in which carvacrol, borneol and γ -terpinene had the most change in values of 71.6%, 20.1% and 8.9%, respectively (El Bouzidi et al., 2013). Therefore, despite the overall improvement in some traits not exposed to consistent selection have probably deteriorated during cultivation (Denison, 2015).

5. Conclusion

Morphophysiological changes of the *S. multicaulis* under cultivation process closely depend on STs and SMRs. Vegetative factors including: HP, CG, LA, MC, NT, LT, LR, and DBN was differed under cultivation condition compared to the wild. Also, this study showed that cultivation reduced plant's EOC, but improved plant's morphological characteristics.

Declarations

Author contribution statement

Ali Tavili, Mohammad Jafari: Conceived and designed the experiments.

Hossein Bashari: Performed the experiments.

Habib Yazdanshenas: Wrote the paper.

Hossein Arzani: Contributed reagents, materials, analysis tools or data.

Hossein Azarnivand: Analyzed and interpreted the data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

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