

INVESTIGATING THE ALTITUDE IMPACT ON THE ECO-PHYTOCHEMICAL PARAMETERS OF *Ziziphora clinopodioides* AND *Sophora alopecuroides* IN THE DIFFERENT REGIONS OF NORTHERN IRAN

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ABSTRACT

Various environmental factors such as altitude significantly affect the pharmacological and chemical properties of the plant. Here, the effect of three different altitudes of 1800 m (Rineh region), 2300 m (Polur region) and 2800 m (Lar region) above sea level on growth traits, yield and compositions of essential oil of two medicinal plants (*Ziziphora clinopodioides* Lam and *Sophora alopecuroides* L.) during two successive years (2018 and 2019) was investigated. The results showed that increasing the altitude from 1800 to 2800 m above sea level increased the morphological traits such as height, side branch number, root length and root volume, however, decreased the dry and fresh weight of both *Ziziphora* and *Sophora* plants. In *Sophora* plant, increasing the altitude enhanced the yield of essential oil and the highest yield of essential oil was obtained in Lar region. However, in *Ziziphora*, elevating the altitude from 1800 to 2300 m decreased the yield of essential oil, but further increase to 2800 m significantly increased the yield of essential oil. In *Ziziphora*, the highest amount of sophoramine, sophoridane and sophocarpine compounds was obtained at 1800 m, while the highest rates of adenocarpine, vinylphenol and matridin was obtained at 2800 m. For *Sophora*, the highest amount of sophoramine and vinylphenol was obtained at 2300 m, while sophocarpine showed the highest rate at 2800 m. Therefore, altitude is one of the important parameters of natural ecosystems that effectively change the quantitative and qualitative parameters of medicinal plants.

Key words: altitude, medicinal plants, *Ziziphora clinopodioides*, *Sophora alopecuroides*, essential oil

INTRODUCTION

There is a wide variety of plant species in the Iranian plateau due to the different climates. Alborz altitudes is one of the most important floristic areas in the vast plateau of Iran, which due to its location between the Irano-Turanian and Euro-Siberian phytogeographical regions, has high biodiversity, especially in plants [Mozaffarian 2013]. Due to the high altitude, different topographical conditions, ecological

diversity, climate diversity and geographical location, important and diverse medicinal plants grow in the Alborz rangelands, which need to be maintained based on accurate knowledge of the interactions between the vegetation and various environmental factors and the awareness of the main components of this ecosystem. With the diversity of medicinal plants, this region can play an important role in the pharmaceutical, hygiene,

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cosmetics and food industry with a proper planning [Mozaffarian 2013]. Therefore, collecting and identifying medicinal plants in this region can be one of the appropriate ways to protect the gene reserves of medicinal plants.

In addition to genetic processes, environmental factors play a major role in regulating growth and increasing the quality and quantity of secondary metabolites in medicinal plants [Omidbeigi 2005]. Various factors affect the growth and composition of secondary metabolites of medicinal plants, including the species, geographical area, altitude, soil and climate. Various reports have shown that environmental factors such as altitude, humidity, temperature and soil composition have affected the essential oil compositions of medicinal plants [Oztürk et al. 2009, Mahdavi et al. 2013, Rapposelli et al. 2015, Aboukhalid et al. 2017]. In natural areas and ecosystems, altitude is one of the most important environmental factors that has a substantial effect on the quantity and quality of secondary metabolites in medicinal plants. Changes in the quality and quantity of essential oils induced by altitude in the medicinal plants *Lavandula angustifolia*, *Ziziphora clinopodioides*, *Tanacetum polycephalum*, *Mentha piperita*, *Cymbopogon olivieri*, *Teucrium hyrcanicum* and *Thymus kotschyianus* have already been documented [Jamshidi et al. 2006, Mahdavi et al. 2013, Demasi et al. 2018].

Sophora (*Sophora alopecuroides* L.) is one of the most important medicinal plants of the *Faboideae* subfamily and the *Fabaceae* family, which is widely distributed in central, western, east and south-west Asia [Kianbakht and Hajiaghaee 2014]. *Sophora* has a long history as one of the medicinal herbs in the therapy of psoriasis, eczema, leucorrhea disorder and gastrointestinal diseases.

As a traditional medicinal herb, *Ziziphora* (*Ziziphora clinopodioides* Lam, family *Lamiaceae*) is grown in different regions including Kazakhstan, Kyrgyzstan, Mongolia, China and Turkey [Liu 1985]. In traditional Iranian medicine, *Ziziphora* has been used as a food disinfectant, antiemetic, anti-inflammatory, sedative and carminative [Maya 2011]. It is also widely used in the treatment of various diseases such as cough, cold, antiseptic and wound healing medicine [Ji et al. 2012].

Considering the importance of *Ziziphora* and *Sophora* and the effects that different altitudes may have

on the eco-phytochemical parameters of these two important medicinal plants growing in northern Iran, in the present study the effects of three different altitudes (1800, 2300 and 2800 m above sea level) on the quantity and quality of *Ziziphora* and *Sophora* essential oils collected from northern Iranian rangelands during 2018 and 2019 has been investigated.

MATERIAL AND METHODS

Study areas

The study areas were located between northern Iran (southern part of the Caspian Sea) and the Alborz Mountains range (the northern part). Medicinal plants were collected from three regions of Rineh, Polur and Lar, which had altitudes of 1800, 2300 and 2800 m above sea level, respectively (Tab. 1). Rineh is located in Amol County, Mazandaran province, Iran, which is the capital of Lahijan District. Polur is a village on Haraz River, which is located in Larijan District of Amol County. Lar Plain is located in the north and northeast of Larijan District of Amol County and the foothills of Damavand peak. Amol County is located in the northernmost province of Iran, Mazandaran and south of the Caspian Sea. The coordinates and geographic parameters, average temperatures and soil properties of the study areas in the 2018 and 2019 growing seasons are given in Table 1.

Data collection and statistical experiment

After determining the distribution areas of medicinal plants based on the resources of Iranian flora library such as Flora of the Champion and Flora Iranica, and also according to climatic diversity in Amol County, three regions of Rineh, Polur and Lar were selected. The present study was designed as a randomized complete block with three replications. Two medicinal plants, *Ziziphora* (*Ziziphora clinopodioides*) and *Sophora* (*Sophora alopecuroides*) from three regions of Rineh, Polur and Lar Plain, with three altitudes of 1800, 2300 and 2800 m above sea level, respectively were the treatments of this study in the two growing seasons of 2018 and 2019. After preliminary surveys and identification of study areas, randomized plots were used to evaluate the reproductive stage of the species. Therefore, in each area, 10 plots were randomly placed and the morphological characteristics of

Table 1. Description of the average temperature, geographical coordinate and soil properties (0–30) of the studied areas during 2018 and 2019

Description	Rineh region		Polur region		Lar region	
Altitude above sea level	1800 m		2300 m		2800 m	
Geographical Coordinate	35°52'53" N 52°10'407" E		35°50'31" N 52°02'55" E		35°58'24" N 51°58'49" E	
Harvest season	2018	2019	2018	2019	2018	2019
Air temperature (min – max, °C)	–10/30	–9/28	–13/27	–13/28	–15/25	–14/26
Average annual rainfall (mm)	510	495	483	477	405	425
<i>Ziziphora clinopodioides</i> Lam						
Soil properties						
Organic matter (%)	1.07	1.12	1.41	1.35	2.33	2.41
EC (dS m ⁻¹)	0.57	0.61	0.53	0.52	0.88	0.91
pH	7.69	7.49	7.79	7.71	7.36	7.42
N (%)	0.05	0.06	0.06	0.05	0.11	0.13
Phosphorus (mg kg ⁻¹)	17.5	17.3	9.6	9.7	23.6	23.8
Potassium (mg kg ⁻¹)	239	247	60	64	294	287
Soil texture	silt loam		silt		silt loam	
<i>Sophora alopecuroides</i>						
Soil properties						
Organic matter (%)	1.01	1.04	1.50	1.53	3.37	3.41
EC (dS m ⁻¹)	1.04	1.06	0.82	0.84	0.85	0.88
pH	7.61	7.72	7.53	7.57	7.22	7.18
N (%)	0.04	0.06	0.07	0.06	0.16	0.17
Phosphorus (mg kg ⁻¹)	6.20	6.27	23.40	23.45	14.40	14.52
Potassium (mg kg ⁻¹)	375	3.82	385	391	452	436
Soil texture	silt		silt loam		clay loam	

EC: electrical conductivity; N: nitrogen

plants were recorded in each plot. In each area, plants were collected at the time of flowering with three replications.

Measurements

After sampling, plant height, root length and fresh weight of shoot and root were determined. The dry weight of shoots and roots were also measured after drying the plant samples in the laboratory setting. The essential oil was extracted using the hydrodistillation method and Clevenger apparatus. 50 g of the dried aerial parts of the collected plants were mixed with 800 ml of distilled water in a round-bottomed flask. To extract the essential oil, the mixture was subjected to hydrodistillation using a Clevenger for 4 hours. Hydrodistillation was repeated three times for each

sample. The resulting oil was dried over anhydrous sodium sulphate and stored in the refrigerator.

The GC-MS analysis was carried out employing a GC-7890A/MS-5975C equipped with an HP-5MS column (30 m in length × 250 µm in diameter × 0.25 µm in the thickness of film). The oven temperature was programmed at 45°C for 2 min. then 100°C at 10°C/min. and ultimately raised to 200°C and kept isothermally for 10 min. The carrier gas was helium at 1 mL/min. and the sample injection was 2 µL. The ionization of the sample components was carried out at 70 eV. Essential oil compounds were identified by comparison of their retention indices and mass spectra with NIST and Wiley libraries, and other published references [Wu et al. 2005, Senejoux et al. 2010, Lee et al. 2013]. The percentage of the identified compounds

was determined based on GC peak areas without any correction factors.

Statistical analysis

Data analysis was performed by SPSS 20.0 software and the mean comparison was determined based on Duncan's multiple range test ($P < 0.05$).

RESULTS

Agronomic traits

The results showed that the increase in altitude significantly enhanced the height plant in both *Ziziphora* and *Sophora* plants in both harvest seasons. In *Ziziphora* plant, the highest plant height was recorded in Lar region in two harvest seasons. In *Sophora* plant, the highest plant height was observed in Lar (67.1 cm) and Polur (95 cm) regions in 2018 and 2019 harvest seasons, respectively (Tab. 2). With increasing altitude, fresh and dry weight of *Ziziphora* showed a significant decline in both harvest seasons and the lowest fresh and dry weight of *Ziziphora* was recorded in Polur region. The fresh and dry weight of *Sophora* plant decreased with elevating altitude and the lowest amount of these traits was observed in Polur region during 2018. However, during 2019, the lowest dry and wet weight of *Sophora* was obtained in Rineh region, which the raise in altitude enhanced the fresh and dry weight of *Sophora* plant. The highest fresh and dry weight of *Sophora* was recorded in the Polur re-

gion during the 2019 harvest season (Tab. 2). In both *Ziziphora* and *Sophora* plants, the number of lateral branches increased significantly with increasing altitude during 2018 and 2019 years. The highest number of lateral branches in *Ziziphora* was recorded in the Lar region, with an increase of 22 and 8.9% during 2018 and 30.6 and 16.4% during 2019 compared to the Rineh and Polur regions, respectively. However, in *Sophora*, the highest number of lateral branches was recorded in the Polur region, with an increase of 2.6- and 2.1-fold during 2018 and 2.9- and 2.5-fold during 2019, respectively compared to the Rineh and Lar regions (Tab. 2).

In both harvest seasons, there was no significant difference between the root length of *Ziziphora* in Rineh and Polur regions. However, with increasing altitude to 2800 m in Lar region, the root length showed a significant increase compared to Rineh and Polur regions. In *Sophora* plant, no significant difference in root length was observed between the three regions of Rineh, Polur and Lar during 2018 year; however, in 2019, the increase in altitude enhanced the root length and the highest root length was obtained in the Polur region (Tab. 2). The results also showed an increasing trend in root volume of *Ziziphora* with increasing altitude in both harvest seasons. In *Sophora*, the highest root volume was observed in plants collected from the Polur region during 2018 and 2019, while there was no significant difference between the Rineh and Lar regions (Tab. 2).

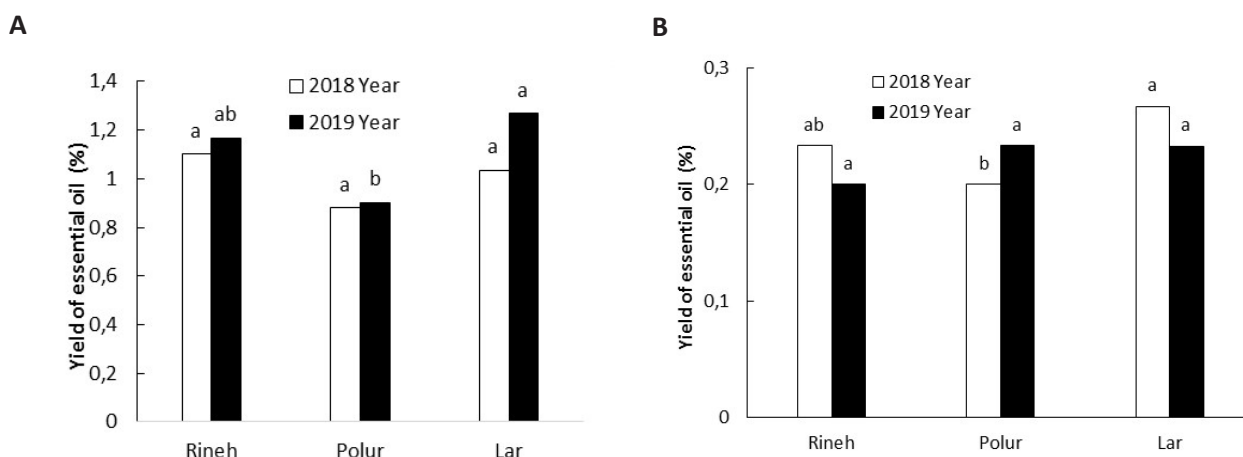


Fig 1. The essential oil yield of *Ziziphora* (A) and *Sophora* (B) in three regions of Rineh, Polur and Lar regions during 2018 and 2019. Values followed by same letter are not significantly different at Duncan's multiple rang test ($P \leq 0.05$)

Table 2. Analysis of variance and mean comparison of morphological parameters of *Ziziphora* and *Sophora* collected from three regions of Rineh, Polur and Lar regions during 2018 and 2019 years

Sources of variation	df	Analysis of variance						
		Height (cm)	plant fresh weight (g)	plant dry weight (g)	side branch number	root length (cm)	root volume	
<i>Ziziphora clinopodioides</i> Lam								
2018	block	2	0.4	157	76	0.11	0.5	4.1
	treatment	2	113**	5769**	4503**	10**	5.5**	77**
	error	4	2.2	321	208	0.5	0.4	0.4
	CV (%)		2.5	13	13	3.6	1.5	0.8
2019	block	2	0.8	175	63	0.3	0.5	4.1
	treatment	2	137**	5974*	4571**	19**	5.5*	126.8*
	error	4	2	348	215	0.3	0.11	10.5
	CV (%)		5.7	13.3	12.6	3	2	4
<i>Sophora alopecuroides</i>								
2018	block	2	4.95	15029	7909	3.1	1.3	6.8
	treatment	2	126**	32081**	14560*	501**	4.3 ^{ns}	40.4**
	error	4	1.9	1343	1334	4.5	1.6	1.3
	CV (%)		2.3	6.5	8.5	8.8	4.6	2.2
2019	block	2	13.8	4571	2804	0.33	0.11	0.8
	treatment	2	1120**	8713*	8376**	966**	4.11*	33.4*
	error	4	11.9	899	132	11.7	0.5	3.5
	CV (%)		4.7	8	4.3	12.1	2.7	2
Comparison of means								
Treatments		height (cm)	plant fresh weight (g)	plant dry weight (g)	side branch number	root length (cm)	root volume	
<i>Ziziphora clinopodioides</i> Lam								
2018	Rineh region (1800 m)		20.27 b	181.0 a	151.5 a	16.67 c	15.33 b	73.5 b
	Polur region (2300 m)		22.43 ab	93.7 b	72.3 c	18.67 b	16.33 b	80.5 a
	Lar region (2800 m)		31.80 a	130.4 ab	107.3 b	20.33 a	18.00 a	83.3 a
2019	Rineh region (1800 m)		20.09 b	187.0 a	156.3 a	16.33 c	17.33 b	75.7 b
	Polur region (2300 m)		21.40 b	98.0 b	78.3 c	18.33 b	18.33 b	82.3 ab
	Lar region (2800 m)		32.37 a	136.7 ab	114.4 b	21.33 a	20.00 a	88.7 a
<i>Sophora alopecuroides</i>								
2018	Rineh region (1800 m)		50.87 b	680 a	508 a	14.67 b	23.33 a	113.3 b
	Polur region (2300 m)		65.87 a	485 b	374 b	38.67 a	24.00 a	120.0 a
	Lar region (2800 m)		67.10 a	522 ab	408 b	18.33 b	24.66 a	114.0 b
2019	Rineh region (1800 m)		57.67 c	346 b	224 b	16.67 b	23.33 b	116.0 b
	Polur region (2300 m)		95.00 a	437 a	328 a	49.00 a	25.67 a	122.3 a
	Lar region (2800 m)		67.67 b	341 b	264 ab	19.33 b	24.33 ab	117.3 b

CV: coefficient variation; df: degrees of freedom; ns, * and **: non-significant and significant in 5% and 1% probability level, respectively. Values within the same column and the same year followed by same letter are not significantly different at Duncan's multiple rang test ($P \leq 0.05$)

Table 3. Analysis of variance of medicinal parameters of *Ziziphora* and *Sophora* plants collected from three regions of Rineh, Polur and Lar regions during 2018 and 2019 years

S.O.V.	df	Analysis of variance								
		essential oil yield	sophoramine	sophoridane	sophocarpine	neophytadiene	adenocarpine	vinylphenol	matridin	
<i>Ziziphora clinopodioides</i> Lam										
2018	block	2	0.05	0.003	0.008	0.001	0.025	0.044	0.002	0.005
	treatment	2	0.14 ^{ns}	0.001**	0.59**	0.27**	0.25**	1.5**	0.007*	0.02**
	error	4	0.02	0.0001	0.001	0.0001	0.005	0.056	0.001	0.001
	CV (%)		15	1.1	1	5	6.3	11.8	20	6.2
2019	block	2	0.043	0.0001	0.004	0.001	0.02	0.17	0.001	0.005
	treatment	2	0.123*	0.001**	0.48**	0.31**	0.234**	2.34*	0.02*	0.02**
	error	4	0.02	0.0001	0.0002	0.0001	0.005	0.22	0.0001	0.001
	CV (%)		12.5	2	1.8	5	6	21	18	5.7
<i>Sophora alopecuroides</i>										
2018	block	2	0.00003	0.22	6.82	0.14	0.007	0.004	0.0007	0.011
	treatment	2	0.03**	77245**	1741**	151**	0.51**	25.5**	0.14**	15**
	error	4	0.00013	0.005	0.05	0.007	0.00006	0.006	0.0001	0.009
	CV (%)		4	0.36	1.3	2.5	3.5	1.1	5.5	2.6
2019	block	2	0.004	0.09	0.345	0.48	0.08	0.021	0.005	0.03
	treatment	2	0.001 ^{ns}	668**	63**	118**	0.111 ^{ns}	18.5**	0.09**	1.12**
	error	4	0.006	0.1	0.01	0.11	0.03	0.004	0.0001	0.006
	CV (%)		24.2	1.35	0.5	1.8	7.1	2	4.5	8

ns, * and **: non-significant and significant in 5% and 1% probability level, respectively

Essential oil yield

The results of analysis of variance showed that the yield of essential oil in *Ziziphora* during 2019 and in *Sophora* during 2018 were statistically significant in 5 and 1% probability level, respectively on altitude treatment (Tab. 2). The results showed that in 2018, there was no significant difference between the essential oil yield of *Ziziphora* collected from the three regions of Rineh, Polur and Lar, however, in 2019, the highest and lowest essential oil yields were obtained in Lar (1.27%) and Polur (0.9%) regions, respectively (Fig. 1A). In *Sophora*, the highest and lowest essential oil yields were observed from Lar (0.27%) and Polur (0.2%) regions in 2018, while during 2019 season, there was no significant difference between the three regions (Fig. 1B).

Medicinal qualitative parameters

The results of analysis of variance showed that all qualitative parameters of *Ziziphora* and *Sophora*

plants including sophoramine, sophocarpine, sophoridane, neophytadiene, vinylphenol, adenocarpine and matridin were statistically significant under region treatment (Tab. 3).

The results revealed that sophoramine in *Ziziphora* decreased with increasing altitude and in both harvest seasons, the lowest amount of sophoramine was obtained in Lar region. However, in *Sophora*, the highest amount of sophoramine was observed in the Polur region in both harvest seasons region (Tab. 4). In 2018, the highest amount of sophoridane was obtained from *Ziziphora* plants collected from Lar and Rineh regions, while in 2019, the highest amount of sophoridane was obtained from Rineh region and no significant difference was observed between Polur and Lar regions. In both 2018 and 2019 years, the highest and lowest sophoridane levels were obtained in *Sophora* harvested from the Rineh and Polur regions, respectively (Tab. 4). In both harvest seasons, a decreasing trend was observed in the sophocarpine content of

Table 4. Mean comparison of medicinal parameters of *Ziziphora* and *Sophora* plants collected from three regions of Rineh, Polur and Lar regions during 2018 and 2019 years

Treatments	Analysis of variance							
	sophoramine	sophoridane	sophocarpine	neophytadiene	adenocarpine	vinylphenol	matridin	
<i>Ziziphora clinopodioides</i> Lam								
2018	Rineh region (1800 m)	0.180 a	1.76 a	0.66 a	1.37 a	2.14 a	0.137 ab	0.526 ab
	Polur region (2300 m)	0.170 a	1.05 b	0.26 b	0.80 b	1.25 b	0.070 b	0.426 b
	Lar region (2800 m)	0.140 b	1.87 a	0.07 c	1.14 a	2.64 a	0.166 a	0.590 a
2019	Rineh region (1800 m)	0.186 a	1.81 a	0.71 a	1.42 a	2.19 ab	0.183 a	0.573 ab
	Polur region (2300 m)	0.180 a	1.10 b	0.30 b	0.87 b	1.29 b	0.080 b	0.473 b
	Lar region (2800 m)	0.150 b	1.13 b	0.08 c	1.18 a	3.06 a	0.233 a	0.636 a
<i>Sophora alopecuroides</i>								
2018	Rineh region (1800 m)	12.33 c	23.52 a	11.42 c	1.75 b	5.66 a	0.070 b	5.293 b
	Polur region (2300 m)	33.20 a	13.37 c	16.90 b	1.95 a	0.36 c	0.430 a	2.683 c
	Lar region (2800 m)	14.34 b	18.21 b	25.51 a	1.15 c	0.91 b	0.040 b	7.130 a
2019	Rineh region (1800 m)	14.09 c	24.37 a	13.43 c	2.12 a	6.32 a	0.146 b	1.590 a
	Polur region (2300 m)	40.42 a	15.18 c	18.88 b	2.43 a	2.05 b	0.473 a	0.433 b
	Lar region (2800 m)	15.08 b	19.36 b	25.95 a	2.83 a	2.00 b	0.230 b	0.666 b

Values within the same column and the same year followed by the same letter are not significantly different at Duncan's multiple rang test ($P \leq 0.05$)

Ziziphora with increasing altitude, while in *Sophora*, with elevating altitude, an increasing trend in sophocarpine content was recorded (Tab. 4).

The highest neophytadiene content was recorded in *Ziziphora* plants collected from Rineh and Lar regions during 2018 and 2019 seasons. In 2018, the neophytadiene content in *Sophora* harvested from the Polure region was 11.4 and 69.6% higher than in the Rineh and Lar regions, respectively, while in 2019, no significant difference was observed between the three regions (Tab. 4). In *Ziziphora* plant, the highest adenocarpine content was obtained in Rineh and Lar regions during 2018 and 2019, while in *Sophora* plant,

the highest amount of adenocarpine was related to plants collected from Rineh region (Tab. 4). During the 2018 and 2019 harvest seasons, the highest content of vinylphenol was obtained in *Ziziphora* plants collected from Rineh and Lar regions. However, in *Sophora*, the highest vinylphenol content was recorded in the Polur region in both harvest seasons (Tab. 4). The highest content of matridin in *Ziziphora* was related to plants harvested from Lar region in both seasons. In 2018, the matridin content of *Sophora* plants collected from Lar region was 34.7 and 165.7% higher than the Rineh and Polur regions, respectively, while in 2019, the matridin content of *Sophora* plants harvested

from the Rineh region was 267 and 138.7% higher than the Polur and Lar regions, respectively (Tab. 4).

DISCUSSION

In natural ecosystems, environmental factors significantly affect the growth and production of secondary medicinal metabolites of medicinal plants. Altitude as one of the effective ecological factors can change the eco-physiological characteristics of plants, especially medicinal plants [Hong et al. 2009]. Although increasing altitude enhanced height and root length of both medicinal plants, plant biomass production (fresh and dry weight) decreased with increasing altitude. Similar results of the effect of altitude on the growth of *Achillea aucheri* have been previously reported by Sardrodi et al. [2015]. It has been reported that with increasing altitude, the growth period of the plant decreases and the plant enters the flowering phase quickly, which can be accompanied by a decline in growth indices [Ghani et al. 2012]. In addition, increased UV radiation at high altitudes can significantly affect phytohormones and plant growth [Zuk-Golaszewska et al. 2003]. Therefore, the enhance in altitude by affecting the humidity, UV ray, temperature and other environmental factors required for plant growth [Sardrodi et al. 2015], may create unfavorable growth conditions for the plant, which reduces the plant growth and biomass production.

The amount of water, type and amount of nutrients and sunlight that the plant may receive at different altitudes varies significantly, which affects the growth and composition of medicinal metabolites of medicinal plants [Khalil et al. 2020]. The results of the current study showed that the highest essential oil yield in both *Ziziphora* and *Sophora* plants was observed at the highest altitude studied in this study (2800 m above sea level), which shows that increasing the altitude induces the accumulation of medicinal compounds. Similar results of enhancing the essential oil yield of *Tanacetum polycephalum* and *Achillea aucheri* with increasing altitude have been reported by Mahdavi et al. [2013] and Sardrodi et al. [2015], respectively. Mahdavi et al. [2013] indicated that the increase in the essential oil yield of medicinal plants at high altitudes could be due to changes in the light period, X-rays, humidity and temperature at high altitudes. However, Jamshidi et al. [2006] and Khalili et al. [2020] showed

that increasing the altitude reduced the essential oil yield of *Thymus kotschyanus* and *Satureja thymbra* plants, respectively, indicating that environmental factors may induce different responses on different plant species. The results also showed that increasing the altitude caused a change in the essential oil compounds of both *Ziziphora* and *Sophora*. The changes induced by altitude increase in the medicinal plants of *Satureja thymbra*, *Achillea aucheri* and *Nigella sativa* have also been previously documented by Sardrodi et al. [2015], Khalil et al. [2020] and Hosseini et al. [2018]. Katar et al. [2017] showed that elevating the altitude increased the essential oil yield as well as enhancing the medicinal compound of carvacrol in *Satureja hortensis* plant. It has been reported that quantitative and qualitative changes in the yield and composition of essential oils in medicinal plants can be affected by various genetic, agricultural and environmental factors such as collection season, amount of rainfall, humidity, temperature, plant species and even drying and extraction methods [Ricciardi et al. 2011, Djouahri et al. 2013]. Therefore, studies on medicinal compounds of medicinal plants in different geographical areas by increasing knowledge about the impact of environmental factors on medicinal compounds of plants can lead to the optimal use of medicinal plant resources.

CONCLUSION

The results of the present study revealed that although the growth and biomass of medicinal plants were higher at lower altitudes, however, increasing altitude enhanced the yield of essential oil and changed the composition of secondary medicinal metabolites of medicinal plants. Therefore, according to the intended use of medicinal plants, the altitude at which the plant grows should be considered. In addition, to augment the current results, more studies are needed on plants harvested from higher altitudes, as well as the impact of other environmental factors such as temperature, light exposure and humidity.

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