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Morphological and phytochemical variability of *Satureja hortensis* L. accessions: An effective opportunity for industrial production

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A R T I C L E I N F O

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A B S T R A C T

Summer savory (*Satureja hortensis* L.) as an endemic species identified in Iran and other countries is widely used in traditional medicine. Several isolated molecules of this species are used to elaborate antifungals and can also be used in the pharmaceutical industry. This investigation was performed to evaluate the levels of variabilities of some agro-morphological characteristics and essential oil constituents of *S. hortensis* accessions originated from Iran, Bulgaria, Germany, Czech, Georgia, Syria, Hungary, Poland, Italy, Greece, and Uzbekistan. The different properties of accessions such as the highest plant fresh, dry weight, plant height, leaf length, internode length, and main branch number were found in the Bulgaria. The maximum amount of essential oil content was obtained in Uzbekistan accessions (0.75 %). The Bulgaria accession had the highest thymol and ɣ-terpinene contents, while the Karaj accession was the best in carvacrol and delta-3-carene contents. The highest correlation coefficient was observed between the plant's internode number and internode length ($r = 0.99$) and the plant height had a positive correlation with traits influencing plant yield. The accessions were classified into five main categories according to morphological properties and most of the accessions originated from each geographical site placed in the same class. The findings of this research can be used for sketching efficient breeding programs for this species.

1. Introcuction

The use of various plant species as flavoring herbs and preserving the germplasm for the purpose of improving the nutritional properties and medicine compounds has been widely practiced among different nations since the ancient times. Natural essential oils of medicinal plants have recently gained scientific attention to meet the requirements of health and safety in food and medicine industries (Geetha and Chakravarthula, 2018). Thus, the use of homogeneous cultivars with distinguished and improved properties was the prerequisite for the industrial production (Herison et al., 2018). Existence of genetic diversity among plant accessions originated from different areas can be a reliable opportunity for the selection of desirable traits for the production of new cultivars (García-Díaz et al., 2020). Genetic diversity occurs for the adaptation of plants to environmental conditions (Mohebodini et al., 2011), and the purpose of plant breeding is the recognition of favorable accessions among various accessions (Herison et al., 2018).

Satureja hortensis L. is a medicinal plant from the Lamiaceae family having antioxidant, antispasmodic, antimicrobial, and antidiarrheal effects, which plays an important role in the pharmaceutical industry. The antimicrobial and antioxidant properties of medicine herbals have recently gained increasing attention in pharmaceutical and food sciences, for instance, *S. hortensis* is a rich source of those properties (Feyzioglu and Tornuk, 2016). The raw material of this species was applied for the preservation of food (Semerdjieva et al., 2020) and production of plant-derived drugs (Mozafari et al., 2018). The main oil of *S. hortensis* with a lot of carvacrol acts as antimicrobial agents (Mazarei and Rafati, 2019) and it is used for animal production and veterinary medicine (Mozafari et al., 2018). The *S. hortensis* methanol extract contains rosmarinic acid as an ester of caffeic acid and is mostly responsible for the antioxidative, therapeutic properties and the anti-inflammatory activity (Nunes et al., 2017). Previous studies have reported the expectorant and disinfectant activity (Moghtader, 2012) and the antispasmodic effects of thymol (Parsaei et al., 2016). The monoterpenes such as ɣ-terpinene and *p*-cymene have antimicrobial, anti-inflammatory and antioxidant attributes (de Oliveira et al., 2015). Additionally, the anticancer effect is believed to be because of *S. hortensis* essential oil and its components (Ramezani et al., 2016).

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Morphological and phytochemical characters of medicinal plants are influenced by three important factors: genetic background, environmental conditions and genotype × environment interaction (Mohebodini et al., 2006). The *S. hortensis* is an adaptable species to environmental condition. The genetic diversity of *S. hortensis* along with diversity in morphological traits and medicinal compound in this species is observed in local accessions (Feyzioglu and Tornuk, 2016). Previously, morphological and phytochemical diversities were reported in *S. hortensis* (Hadian et al., 2010). The investigation of morphological diversity represents useful information about relationships among species (Mohebodini et al., 2018) and can be used in plant breeding for indicating new cultivar with promised efficiency (Khadivi-Khub et al., 2012). Hadian et al. (2011) studied eight Iranian populations of *Satureja khuzistanica* based on the morphological properties of leaf, flower, and essential oil content. They identified Abdanan and Kaver as the most useful accessions. Phenotypic diversity among Iranian landraces of *S. hortensis* was reported previously by Hadian et al. (2010). There has been no comprehensive study done on the global potential of diversity among *S. hortensis* accessions; thus, the present study is conducted to investigate the morphological and phytochemical variability in Asian and European accessions. This research attempts to identify the accessions with the best properties and use them as initial materials in breeding programs.

2. Materials and methods

2.1. Plant material

Seeds from 20 accessions of *S. hortensis* were collected from different Asian and European accessions. Iranian accessions were collected from a local field, and accessions from other countries were gathered from the Institute of Plant Genetics and Crop Research in Germany (Table 1). The collected accessions were planted with the same conditions in a research field located in Ardabil city (the longitude, latitude, and altitude of Ardabil city are 48°30′13″, 38°24′94″, and 1333, respectively) for one year, so that the germplasm variation was determined independently. The size of the plot was 100 cm × 120 cm. the distance of the plants within and between the rows was 15 cm and 25 cm respectively. The test started in April 2019 and ended in October (for 7 months).

The soil properties of field were mentioned in Table 2. The soil of the field was drained and fertilized by manure as well as regularly irrigated to maintain the moisture of the soil. Average temperature, rainfall and humidity of the field are displayed in Table 3. During the growing season, weeds were eliminated manually. Additionally, no pest or diseases were observed during the experiment. Some morphological and phytochemical properties of accessions were investigated in the flowering step. The traits measured in this study were about different parts of plants, especially principal properties influencing bioactive characters of plants. The measured traits are listed in Table 4.

Table 1
Geographic coordinates of *S. hortensis* accessions.

Accession	Latitude (N)	Longitude (E)	Altitude (m)
Bulgaria	42°69′75"	23°32′41″	558
Germany	52°51′66″	13°39′99″	35
Czech	50°08′78″	14°42′41″	245
Georgia	41°72′50″	44°79′08″	420
Syria	36°20′27″	37°15′86″	380
Hungary	47°50′20″	19°08′33″	100
Karaj	35°82′87″	50°99′82″	1360
Poland	52°25′00″	21°10′23″	94
Rasht	37°27′94″	49°58′58″	5
Italy	41°90′00″	12°48′33″	14
Greece	37°98′33″	23°73′33″	110
Uzbekistan	24°86′66″	67°05′04″	14
Zanjan	36°67′36″	48°47′86″	1639
Kashmar	35°23′63″	58°48′19″	1072
Kermanshah	34°31′41″	47°06′49″	1389
Tabriz	38°08′00″	46°29′19″	1395
Ardabil	38°24′94″	48°30′13″	1333
Mazandaran	36°83′94″	54°43′61″	175
Kerman	30°29′38″	57°08′41″	1764
Isfahan	32°65′97″	51°67′13″	1566

Table 2
The soil properties of field in the experiment.

Factor	Unit	Amount	Method
EC	ds/m	2.38	Electrical Conductivity
pH	_	6.85	Electrometric
Sand	%	43.	Pipette
Slit	%	43.1	Pipette
Clay	%	13.7	Pipette
Texture	_	Loam	Pipette

Table 3
Average temperature, rainfall and humidity of the field.

Months	Temperature (°C)	Rainfall (ml)	Humidity (%)
April	9.2	39	45
May	12.7	36.6	47
June	15.9	16.4	49
July	17.9	8.5	51
August	18.1	6.6	52
September	15.2	9.7	52
October	11.3	27.5	53

2.2. Essential oil extraction and GC–MS analysis

The shoots of accession were dried in the shade. The 25 g of dried parts (leaves and flowers) of different accessions were exposed to hydrodistillation to extract the essential oil by Clevenger apparatus for 3 h according to Khadivi-Khub et al. (2014) method. Essential oil content was measured by weight-volume method and then the oils were kept in the dark condition at 4 °C, and then 1 μL of them were injected into a Thermoquest- Finnigan GC–MS to determine the type of the constituents. The EL-type ionization system equipped the GC detector. The analyzer was Single Quadrupole and the detector was the Triple-Axis Detector. Helium was used as a carrier gas. The type of capillary column was HP-5M5 (30 m×0.25 mm; film thickness 0.25 μm). The compositions were identified based on the comparison of mass spectra and their internal reference (NIST05A, and Wiley7N libraries) and certified by contrasting their retention indices with reliable compounds. The retention indices of essential oils compounds were calculated by a series of *n*-alkanes (C8-C26) standard. Linear indices of compounds were calculated by Babushok et al. (2011) formula:

$$Ix = 100n + 100\ (tx - tn)\ /\ (tn + 1 - tn)$$

That tx is the retention time of essential oil that is being analyzed, and tn and $tn + 1$ show the retention times of alkanes eluted before and after the essential oil.

2.3. Statistical design

The *S. hortensis* seeds planted in the field in a randomized complete block design (RCBD) with three replications. The residuals were tested for normality by the Kolmogorov–Smirnov normality test using the SPSS 21 software. The means were compared using Duncan's multiple range tests at a 5% level of significance. The cluster analysis was performed on morphological properties and the discriminant analysis was conducted to determine the cut line in the cluster diagram. Factor analysis was performed by the SPSS 21 software based on the Varimax rotation. The numbers above 0.5 were considered significant. The sampling adequacy of data to be used for Factor Analysis was determined by the *Kaiser-Meyer-Olkin's* (KMO) test. The correlation coefficient for important

Table 4
Descriptive statistics for morphological traits of *S. hortensis* accessions.

NO.	Character	Abbreviation	Unit	Mean	Min	Max	SD	CV(%)
1	Plant height	PHL	cm	36.61	23.67	82.24	12.73	2.61
2	Leaf width	LEW	cm	0.47	0.08	1.65	0.32	32.96
3	Internode length	ITL	cm	2.98	1.04	6.50	9.41	17.43
4	Main branch number	MBN	cm	14.99	6.59	31.70	6.17	20.65
5	Branch number	BNU	–	4.70	1.00	19.32	4.09	40.25
6	Leaf fresh weight	LFW	g	0.78	0.28	2.15	0.32	34.87
7	Inflorescence length	INL	cm	1.32	0.55	2.28	0.48	21.29
8	Sepal diameter	SED	cm	0.46	0.20	1.59	0.24	42.93
9	Plant fresh weight	PFW	g	8.06	1.91	28.08	6.55	53.58
10	Plant dry weight	PDW	g	0.97	0.18	3.25	0.74	65.2
11	Leaf dry weight	LDW	mg	0.13	0.05	0.43	0.06	42.13
12	Peduncle length	PEL	cm	0.68	0.20	2.02	0.43	42.11
13	Day to flowering	DFL	day	72.41	37.52	131.19	20.98	11.53
14	Bract length	BRL	cm	0.87	0.10	3.34	0.63	43.007
15	Bract width	BRW	cm	0.33	0.03	1.06	0.23	55.87
16	Petal diameter	PED	cm	0.67	0.10	2.39	0.51	39.2
17	Stem length	STL	cm	21.8	8.64	55.12	9.01	28.46
18	Stem diameter	STD	cm	0.3	0.09	1.19	0.22	29.81
19	Stamen number	STN	–	4.6	2.76	6.70	0.88	13.4
20	Petal length	PLE	cm	0.83	0.38	2.12	0.36	20.86
21	Essential oil content	EO	%	0.28	0.03	0.83	0.2	39.12
22	Leaf length	LEL	cm	4.63	3.00	8.48	1.14	11.94
23	Shoot color	SHC	Code	3.74	1.00	7.50	1.56	4.85
24	Branch density	BRD	Code	3.74	0.84	6.24	1.57	4.55
25	Leaf density	LED	Code	3.75	0.97	8.04	1.7	8.04
26	Growth habit	GRH	Code	4.8	1.00	7.38	1.61	3.42
27	Leaf upper surface color	LUC	Code	4.01	0.85	6.54	1.58	4.79
28	Leaf lower surface color	LLC	Code	3.56	1.44	6.00	1.21	5.1
29	Seed color	SCO	Code	3.53	0.00	6.30	1.75	1.26
30	Seed length	SEL	cm	4.09	1.30	7.08	1.52	2.18
31	Seed width	SEW	cm	2.89	1.00	5.33	1.14	4.37
32	Flower length	FLL	cm	2.31	1.20	3.53	0.61	1.93
33	Flower width	FLW	cm	1.44	0.58	2.60	0.46	4.91
34	Flower fresh weight	FFW	mg	22.18	14.84	38.33	5.3	10.73
35	Flower dry weight	FDW	mg	2.23	0.90	4.43	0.73	21.96
36	Leaf area	LAR	Cm^2	24.1	9.53	48.32	10.16	27.21
37	Internode number	INU	–	3.45	1.15	8.00	1.36	17.39
38	Flower number	FLN	–	50.66	13.39	150.68	33.54	44.713
39	Petal color	PEC	Code	3.06	0.89	6.83	1.56	33.16
40	Sepal color	SEC	Code	2.35	0.95	6.48	1.47	22.91
41	Bract color	BRC	Code	1.95	0.72	6.00	1.16	26.64
43	Seed shape	SSH	Code	4.08	1.00	6.96	1.81	3.28
44	Bract density	BDE	Code	3.92	0.95	7.00	1.6	1.14
45	Day to germination	DGE	day	4.39	2.57	6.48	0.77	11.15
46	Day to 50 % flowering	DTF	day	82.15	49.04	115.56	18.43	1.4
47	Day to seed formation	DTS	Day	103.32	63.84	139.36	18.76	0.45
48	Day to seed ripening	DSR	day	142.51	76.08	228.36	28.64	11.47

properties was estimated based on the Pearson method. The correlation coefficients were considered to investigate the direct and indirect effects of different properties on the essential oil.

3. Result and discussion

3.1. Morphological and growth characteristics

The results of this study revealed that the most of morphological and phytochemical traits showed different significant values. The highest and lowest coefficients of variation (CV) were observed for the plant dry weight (65.2 %) and the day to seed formation (0.45 %) respectively (Table 4). Khadivi-Khub et al. (2014) reported that the coefficient of variation ranged between 11.56 % (for sepal length) and 120.1 (for stem weight). The results of multi-observation ANOVA showed that in several measured traits, the CV values were less than 6 that indicated the number of samples was sufficient for obtaining accurate results (Table 5). In some other cases, the CV values were higher than 6 that demonstrated in future studies the number of samples must be increased to get more accurate results. However, in this study, the significance level of Accessions was high and this indicates more differences among accessions. Variation of plant height, plant dry weight, and leaf and flower yield traits of accessions are presented in Fig. 1. The accessions from Bulgaria and Uzbekistan yielded the highest plant height (82.24 and 68.4 cm, respectively) and plant dry weight (3.25 and 2.66 g per plant respectively). The highest leaf and flower dry yield obtained from Uzbekistan's (25.15 g) accession. As expected, Bulgaria and Uzbekistan accessions had higher plant dry germplasm yield due to plant height (Byeon and Back, 2014).

The results of the mean comparison of morphological traits are explained in Table 6. As the results showed, the highest diversity belonged to the flower number (14.6–115.06). Previously, Hadian et al. (2010) showed that among 30 Iranian *S. hortensis* accessions, Tabriz accession had the maximum plant height (46.1 cm), while in the present study, the plant height of Bulgaria and Uzbekistan and some other accessions were more than Tabriz accession. The plant fresh weight was ranged from 2.78 g to 23.15 g. Bulgaria accessions had the highest fresh weight (23.15 g). While, lowest fresh weight (2.78) belonging to Zanjan accession following by Rasht accessions with value of 3.46 g. Leaf fresh weight was varied between 0.35 g and 1.26 g. variability of leaf fresh weight was lower than plant fresh weight. It is due to higher variability of woody parts of plant. Shabankare et al. (2015) reported that among the studied populations of *Teucrium polium* L., a member of *lamiaceae*, the fresh weight of plants varied between 45.5 g (in Sepidan) and 66.6 g

Table 5
Analysis of variance for measured traits, estimations of experimental and sampling variances and coefficient of variation (CV) for accession mean.

SOV	DF	PHL	LEW	ITL	MBN	BNU	LFW	INL	SED	PFW	PDW	LDW	PEL	DFL	BRL
Block	2	791.0**	1.961**	9.69**	151.0**	208.86**	0.21**	9.04**	3.24**	202.71**	0.973**	0.035**	1.523**	52493.0**	1.387**
Accession	19	2926.4**	1.469**	19.81**	500.5**	246.72**	1.09**	2.53**	0.33**	555.14**	5.381**	0.036**	2.436**	1839.7**	5.751**
Error	38	5.6^{ns}	0.144**	1.64**	57.6**	21.48**	0.44**	0.48**	0.23**	111.90**	2.406**	0.019**	0.495**	417.2**	0.838**
Error Sampling	300	26.2	0.005	0.18	5.0	0.82	0.01	0.04	0.01	2.07	0.030	0.000	0.011	107.4	0.022
σ_e^2†		−6.8807	0.046	0.49	17.5	6.89	0.14	0.15	0.08	36.61	0.792	0.006	0.161	103.3	0.272
σ_{eS}^2‡		26.2	0.005	0.18	5.0	0.82	0.01	0.04	0.01	2.07	0.030	0.000	0.011	107.4	0.022
$V(\bar{x})$§		0.6	0.016	0.18	6.4	2.39	0.05	0.05	0.03	12.43	0.267	0.002	0.055	46.4	0.093
$\bar{x}$¶		36.612	0.473	2.98	14.9	4.70	0.79	1.32	0.47	8.07	0.978	0.140	0.690	72.4	0.872
$CV(\bar{x})$®		2.1	26.7	14.3	16.9	32.9	28.2	17.4	34.4	43.7	52.9	32.5	34.0	9.4	35.0

SOV	DF	BRW	PED	STL	STD	STN	PLE	EO	LEL	SHC	BRD	LED	LES	LUC	LLC
Block	2	0.694**	3.519**	1511.1**	0.331**	6.061**	3.055**	0.171**	38.48**	23.63**	20.42**	58.63**	29.37**	29.64**	40.08**
Accession	19	0.585**	3.651**	892.6**	0.856**	9.418**	1.878**	0.625**	16.62**	42.74**	43.45**	47.02**	45.13**	43.49**	22.78**
Error	38	0.206**	0.416**	231.1**	0.045**	2.296**	0.178**	0.071**	1.84**	0.20^{ns}	0.18^{ns}	0.55**	0.16^{ns}	0.22^{ns}	0.20^{ns}
Error Sampling	300	0.003	0.009	9.2	0.002	0.357	0.012	0.002	0.43	0.30	0.29	0.31	0.43	0.35	0.24
σ_e^2†		0.068	0.136	74.0	0.014	0.646	0.055	0.023	0.47	−0.03	−0.04	0.08	−0.09	−0.04	−0.01
σ_{eS}^2‡		0.003	0.009	9.2	0.002	0.357	0.012	0.002	0.43	0.30	0.29	0.31	0.43	0.35	0.24
$V(\bar{x})$§		0.023	0.046	25.7	0.005	0.255	0.020	0.008	0.20	0.02	0.02	0.06	0.02	0.02	0.02
$\bar{x}$¶		0.338	0.672	21.8	0.301	4.605	0.839	0.290	4.63	3.74	3.74	3.75	4.80	4.02	3.57
$CV(\bar{x})$®		44.8	32.0	23.2	23.5	11.0	16.8	30.5	9.8	4.0	3.7	6.6	2.8	3.9	4.2

SOV	DF	SCO	SEL	SEW	FLL	FLW	FFW	FDW	LAR	INU	FLN
Block	2	49.05**	6.62**	12.95**	2.747**	7.037**	642.7**	1.42**	3939.0**	37.14**	9855.2**
Accession	19	52.10**	42.50**	22.99**	6.676**	3.253**	388.7**	7.03**	994.2**	26.30**	13777.4**
Error	38	0.01^{ns}	0.05^{ns}	0.10^{ns}	0.009^{ns}	0.031^{ns}	34.0**	1.47**	258.1**	2.20**	3078.8**
Error Sampling	300	0.28	0.31	0.15	0.100	0.034	8.6	0.10	13.2	0.24	60.9
σ_e^2†		−0.09	−0.09	−0.02	−0.030	−0.001	8.5	0.46	81.6	0.65	1005.9
σ_{eS}^2‡		0.28	0.31	0.15	0.100	0.034	8.6	0.10	13.2	0.24	60.9
$V(\bar{x})$§		0.00	0.01	0.01	0.001	0.003	3.8	0.16	28.7	0.24	342.1
$\bar{x}$¶		3.53	4.10	2.90	2.314	1.446	22.2	2.24	24.1	3.45	50.7
$CV(\bar{x})$®		1.1	1.8	3.6	1.4	4.1	8.8	18.1	22.2	14.3	36.5

SOV	DF	PEC	SEC	BRC	SSH	BDE	DGE	DTF	DTS	DSR
Block	2	1.13**	3.87**	12.89**	11.15**	48.639**	1.76**	3248.7**	5117.3**	36387.5**
Accession	19	33.16**	36.55**	20.60**	59.76**	42.647**	8.11**	5974.2**	6021.0**	8259.6**
Error	38	6.23**	1.79**	1.65**	0.11^{ns}	0.012 ^{ns}	1.46**	8.0^{ns}	1.3^{ns}	1600.8**
Error Sampling	300	0.21	0.14	0.09	0.36	0.302	0.35	116.1	183.6	391.7
σ_e^2†		2.01	0.55	0.52	−0.08	−0.096	0.37	−36.0	−60.7	403.0
σ_{eS}^2‡		0.21	0.14	0.09	0.36	0.302	0.35	116.1	183.6	391.7
$V(\bar{x})$§		0.69	0.20	0.18	0.01	0.001	0.16	0.9	0.1	177.9
$\bar{x}$¶		3.1	2.4	2.0	4.1	3.922	4.39	82.2	103.3	142.5
$CV(\bar{x})$®		27.1	19.0	22.0	2.7	0.9	9.2	1.1	0.4	9.4

Grand mean of accession.
®Coefficient of variation for accession mean.
†Error variance.
‡Sampling Error variance.
§ Variance of accession mean.

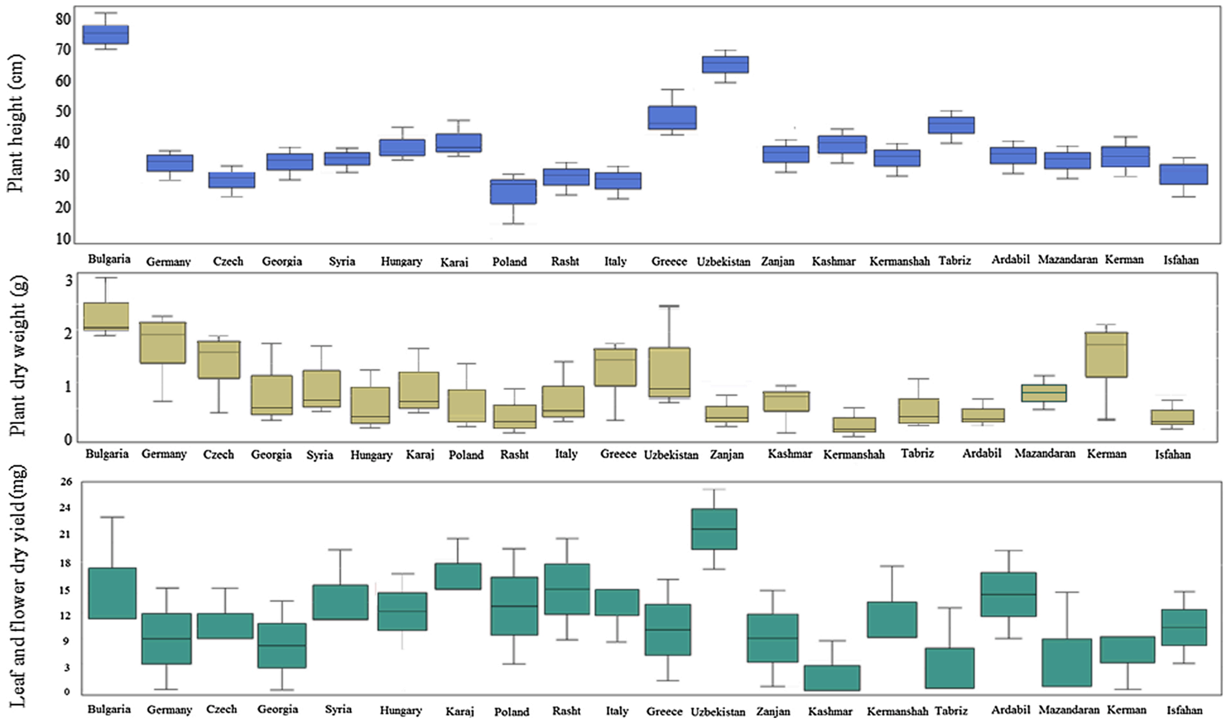

Fig. 1. Variability of plant height, plant dry weight and leaf and flower dry yield per plant *S. hortensis* accessions.

(in Zibashahr). The dry yield of the leaf and flower have important role in essential oil efficiency while stems do not have essential oil. In this study the range of dry yield of leaf and flower was higher than previous studies (0.5 mg–25.2 mg). Pank et al. (2004) reported 34 populations of *S. hortensis* had a high variability in term of leaf and flower dry yield and lower and higher yield were 0.9 mg and 17.52 mg respectively. This variability related to cultivation of *S. hortensis* accessions from different geographical origins.

The leaf length varied between 3.91 cm (in Kermanshah accession) to 7.77 cm (in Bulgaria accession). The leaf width ranged between 0.19 and 1.35 cm (in Georgia and Ardabil accessions, respectively). Leaf and plant dimension variability of some studied accessions of *S. hortensis* is shown in Fig. 2. Hadian et al. (2010) reported that the leaf length varied between 5.05 cm in Tabriz to 1.47 cm in Ahvaz accessions, and leaf width varied between 0.71 and 0.28 cm in Tabriz and Urmieh accessions, respectively. In the present study, the maximum internode length (6.13 cm) was observed in Bulgaria and the minimum amount obtained was in the Poland accession (1.78 cm). The main branch number and branch number were the highest in Bulgaria (29.26 and 15.56, respectively), while Rasht and Italy showed the lowest main branch number and branch number (10.19 and 1.04, respectively). The Inflorescence length varied between 0.72 cm (in Syria accession) to 1.95 cm (in Uzbekistan accession). The peduncle length varied between 0.25 cm (in Greece) and 1.69 cm (in kashmar).

The Hungary accession showed the earliest 50 % flowering (52.21 days after seed germination), and Kashmar showed the longest (108.46 day after seed germination). Hadian et al. (2008) showed earliest flowering was belong to accession number 28 (43 days), and accession number 3 had last flowering (65 days). Pank et al. (2004) reported the precocity of *S. hortensis* accessions varied between 29 days and 51 days. The stem length and diameter were diverse between 12.04–41.3 cm and 0.15−0.98 cm, respectively. The petal length varied between 0.25 cm in the Greece accession and 1.69 cm in the Kashmar accession. Maximum rang of seed length was observed in Zanjan, also the highest Leaf area, and internode numbers were achieved by the Bulgaria accession 50 % of the samples showed intermediate branch density. The leaf upper and lower surface color varied from light-green to dark-green and reddish green. Most of the samples showed spreading growth habit (73 %) (Table 6).

The correlation coefficients of morphological traits are shown in Table 7. The highest correlation coefficient was observed between internode number and internode length ($r = 0.99$). There were positive relationships between plant heights and important morphological traits such as plant fresh ($r = 0.71$), and dry weight ($r = 0.6$). Previously, similar results were reported by Hadian et al. (2014), which suggested a positive correlation plant height and fresh and dry weight. These achievements can be used in breeding programs for cultivar production. The essential oil content had a positive correlation with the stem length ($r = 0.56$) as Yavari et al. (2010) reported that stem length and plant height had a significant correlation with the essential oil content.

In this research Uzbekistan and Bulgaria accessions had high stem length, stem diameter and also essential oil content. Previously it was reported that plant height and stem length showed positive correlation to essential oil yield (Karimi et al., 2014; Mirzaie-Nodoushan et al., 2001). It may be due to more received sunlight and increased photosynthesis in plant (Mashmoul et al., 2013; Singh and Mittal, 2003). The leaf length and flower length had a negative correlation with the essential oil content. In line with these results, (Rahimmalek et al., 2018) reported that the essential oil percentage showed a negative correlation with shoot number and leaf length. It was found that leaf length was in significant positive correlation with leaf area ($r = 0.79$). Mashmoul et al. (2013) suggested that the leaves trap sunlight and use it for photosynthesis. It can be resulted that with increasing values of leaf area, it provides the place for production of secondary metabolites after primary metabolites. Besides, leaf area had positively correlated with plant fresh and dry weight. These correlations display that two linked genetic factors are controlling both characters. This results were in agreement with Khadivi-Khub et al. (2015).

The cluster analysis based on morphological traits allocated the *S. hortensis* accessions into five distinct groups (Fig. 3). Also discriminant analysis confirmed the cut line in the cluster diagram (Table 8). Most of the samples originated from each geographical site placed in the same class. The Syria, Bulgaria, Greece, Hungary, Germany, Italy, Poland and Rasht accessions were in the first cluster. The genetic diversity or

Table 6
Mean comparison of morphological and phytochemical traits in *S. hortensis* accessions.

Region	LEL	LEW	ITL	MBN	BNU	LFW (g)	INL	SED	PFW	LDW
Bulgaria	7.77 ^{a}	0.75 ^{bc}	6.13 ^{a}	29.26 ^{a}	15.56 ^{a}	0.74 $^{a-e}$	1.88 ^{ab}	0.55 ^{ab}	23.15 ^{a}	0.12 ^{abc}
Germany	4.72 ^{cd}	0.4 ^{cd}	2.87 $^{d-g}$	15.28 ^{bc}	4.94 $^{c-f}$	0.87 $^{a-e}$	1.5 ^{abc}	0.48 ^{ab}	16.78 ^{ab}	0.16 ^{abc}
Czech	4.74 ^{cd}	0.33 ^{d}	2.07 ^{fg}	14.12 ^{bc}	8.7 ^{bc}	0.64 $^{b-e}$	1.04 ^{cd}	0.38 ^{b}	5.65 ^{c}	0.08 ^{c}
Georgia	5.66 ^{bc}	0.19 ^{d}	2.11 ^{fg}	18.21 ^{b}	7.23 ^{bcd}	0.72 $^{b-e}$	1.24 $^{a-d}$	0.24 ^{b}	9.39 ^{bc}	0.1 ^{c}
Syria	4.29 ^{cd}	0.35 ^{d}	2.82 ^{dg}	15.95 ^{bc}	5.99 ^{cde}	0.8 $^{a-e}$	0.72 ^{d}	0.55 ^{ab}	4.86 ^{d}	0.15 ^{abc}
Hungary	4.1 ^{d}	0.35 ^{d}	3.36 $^{c-f}$	29.01 ^{a}	11.15 ^{b}	0.54 ^{cde}	1.82 ^{ab}	0.38 ^{ab}	5.96 ^{d}	0.09 ^{c}
Karaj	4.04 ^{d}	0.42 ^{cd}	2.91 $^{d-g}$	16.46 ^{bc}	5.79 ^{cde}	0.37 ^{de}	1.46 $^{a-d}$	0.48 ^{ab}	7.87 ^{cd}	0.06 ^{bcd}
Poland	4.19 ^{cd}	0.31 ^{d}	1.78 ^{fg}	12.42 ^{bc}	2.87 ^{def}	0.69 $^{b-e}$	0.97 ^{cd}	0.38 ^{ab}	4.27 ^{d}	0.64 ^{c}
Rasht	3.95 ^{d}	0.28 ^{d}	1.94 ^{fg}	10.19 ^{c}	2.3 ^{ef}	0.56 ^{cde}	1.93^{a}	0.27 ^{b}	3.46 ^{d}	0.1 ^{c}
Italy	4.53 ^{cd}	0.27 ^{d}	1.9 ^{fg}	11.54 ^{c}	1.04 ^{f}	0.73 $^{a-e}$	0.97 ^{cd}	0.31 ^{b}	5.42 ^{d}	0.12 ^{bc}
Greece	6.3 ^{b}	0.34 ^{d}	4.1 ^{bc}	15.62 ^{bc}	5.66 ^{cde}	0.35 ^{de}	1.46 $^{a-d}$	0.45 ^{ab}	5.94 ^{d}	0.07 ^{c}
Uzbekistan	4.54 ^{cd}	0.53 ^{cd}	4.42 ^{b}	10.75 ^{c}	2.16 ^{ef}	0.78 $^{a-e}$	1.95 $^{-a}$	0.46 ^{ab}	16.97 ^{ab}	0.12 ^{bc}
Zanjan	4.37 ^{cd}	0.21 ^{d}	2.21 ^{fg}	12.65 ^{bc}	1.07 ^{f}	0.66 $^{b-e}$	0.97 ^{cd}	0.87 ^{a}	2.78 ^{d}	0.14 ^{abc}
Kashmar	4.12 ^{d}	0.49 ^{cd}	3.89 ^{bcd}	11.1 ^{c}	3.74 ^{def}	0.84 $^{a-e}$	1.32 $^{a-d}$	0.55 ^{ab}	5.76 ^{d}	0.15 ^{abc}
Kermanshah	3.91 ^{d}	0.39 ^{cd}	2.91 $^{d-g}$	13.32 ^{b}c	1.74 ^{ed}	0.89 $^{a-d}$	1.27 $^{a-d}$	0.48 ^{ab}	4.9 ^{d}	0.15 ^{abc}
Tabriz	3.94 ^{d}	1.04 ^{ab}	3.08 $^{c-f}$	12.75 ^{bc}	3.94 ^{def}	0.91 ^{abc}	1.65 ^{abc}	0.59 ^{ab}	5.59 ^{d}	0.17 ^{abc}
Ardabil	4.92 ^{cd}	1.35 ^{a}	3.36 $^{b-e}$	11.02 ^{c}	2.48 ^{ef}	1.25 ^{a}	0.97 ^{cd}	0.49 ^{ab}	3.56 ^{d}	0.23 ^{a}
Mazandaran	4.41 ^{cd}	0.56 ^{cd}	2.59 ^{efg}	13.29 ^{b}c	1.07 ^{f}	0.9 ^{abc}	1.17 ^{bcd}	0.41 ^{ab}	6.9 ^{c}	0.16 ^{abc}
Kerman	4.38 ^{cd}	0.5 ^{cd}	2.87 $^{d-g}$	12.52 ^{bc}	3.19 ^{def}	1.26 ^{a}	1.04 ^{cd}	0.45 ^{ab}	14.96 ^{bc}	0.22 ^{ab}
Isfahan	3.66 ^{d}	0.3 ^{d}	2.25 ^{efg}	14.32 ^{bc}	3.33 ^{def}	1.14 ^{ab}	1.01 ^{cd}	0.51 ^{ab}	3.59 ^{d}	0.13 ^{abc}
Region	SEL	PEL	DFL	BRL	BRW	PED	STL	PLE	STD	STN
Bulgaria	3.89 ^{f}	0.43 ^{de}	87.78 ^{a}	1.03 ^{bcd}	0.42 ^{bc}	0.32 ^{fg}	27.94 ^{bc}	0.83 $^{c-f}$	0.18 ^{def}	4.4 ^{c}
Germany	2.66 ^{hi}	0.86 ^{bcd}	64.69 ^{a}	0.59 ^{cd}	0.2 ^{c}	0.4 ^{efg}	32.11 ^{bcd}	0.56 ^{f}	0.28 ^{c}-f	3.13 ^{d}
Czech	3.77 ^{f}	0.29 ^{de}	66.38 ^{a}	0.73 ^{cd}	0.29 ^{bc}	0.42 ^{efg}	18.33 ^{bcd}	1.06 ^{cd}	0.37 ^{cd}	4.67 ^{b}
Georgia	4.58 ^{e}	0.51 ^{de}	79.12 ^{a}	0.51 ^{cd}	0.24 ^{bc}	0.39 ^{efg}	24.88 ^{bcd}	0.59 ^{ef}	0.18 ^{def}	4.68 ^{bc}
Syria	3.73 ^{f}	0.7 ^{cde}	84.77 ^{a}	0.74 ^{cd}	0.32 ^{bc}	0.35 ^{efg}	26.06 ^{bc}	0.81 $^{c-f}$	0.4 ^{c}	4.05 ^{cd}
Hungary	1.38 ^{j}	0.36 $^{d-e}$	65.81 ^{a}	0.48 ^{cd}	0.11 ^{c}	0.15 ^{g}	27.8 ^{bc}	0.6 ^{ef}	0.78 ^{a}	4.41 ^{c}
Karaj	5.65 ^{cd}	0.51 ^{de}	64.15 ^{a}	0.34 ^{d}	0.41 ^{bc}	0.76 ^{cf}	25.99 ^{b}	0.71 ^{def}	0.28 $^{c-f}$	5.02 ^{bc}
Poland	2.45 ^{i}	0.46 ^{de}	66.58 ^{a}	1.69 ^{b}	0.33 ^{bc}	0.63 $^{c-g}$	17.33 ^{bcd}	0.56 ^{f}	0.13 ^{ef}	4.07 ^{cd}
Rasht	2.98 ^{g}	0.5 ^{de}	66.3 ^{a}	0.58 ^{cd}	0.31 ^{bc}	0.5 ^{efg}	19.05 ^{cd}	0.63 ^{def}	0.13 ^{ef}	3.75 ^{cd}
Italy	3.22 ^{g}	0.26 ^{e}	103.53 ^{a}	1.18 ^{bc}	0.11 ^{c}	0.23 ^{fg}	12.04 ^{d}	0.62 ^{def}	0.1 ^{f}	3.77 ^{cd}
Greece	6.38 ^{ab}	0.25 ^{e}	72.36 ^{a}	0.88 ^{cd}	0.19 ^{c}	1.1 ^{bcd}	14.16 ^{bcd}	1.18 ^{bc}	0.3 ^{cde}	4.7 ^{bc}
Uzbekistan	2.66 $^{-hi}$	0.75 ^{cde}	79.94 ^{a}	0.35 ^{d}	0.41 ^{bc}	1.91 ^{a}	41.3 $^{-a}$	1.49 ^{ab}	0.98 ^{a}	4.71 ^{bc}
Zanjan	6.4 ^{ab}	0.85 $^{b-e}$	64.72 ^{a}	1.18 ^{bc}	0.59 ^{ab}	1.16 ^{bc}	21.1 $^{b-e}$	1.68 ^{a}	0.22 $^{c-f}$	4.71 ^{bc}
Kashmar	4.48 ^{e}	1.69 ^{a}	67.61 ^{a}	0.51 ^{cd}	0.15 ^{a}	0.47 ^{efg}	21.84 $^{b-e}$	1.03 ^{cde}	0.23 $^{c-f}$	5.01 ^{bc}
Kermanshah	5.33 ^{d}	0.58 ^{cde}	70.06 ^{a}	0.95 ^{cd}	0.26 ^{bc}	0.81 ^{cf}	18.97 $^{b-e}$	1.01 ^{cde}	0.16 ^{ef}	5.94 ^{ab}
Tabriz	6.74 ^{a}	0.73 ^{cde}	72.38 ^{a}	0.88 ^{cd}	0.26 ^{bc}	0.93 $^{b-e}$	22.59 $^{b-e}$	0.79 $^{c-f}$	0.27 $^{c-f}$	4.07 ^{cd}
Ardabil	2.66 ^{h}	0.62 ^{cde}	67.57 ^{a}	0.54 ^{cd}	0.82 ^{a}	0.53 $^{d-g}$	17.74 ^{cde}	0.75 $^{c-f}$	0.24 $^{c-f}$	6.27 ^{a}
Mazandaran	3.2 ^{g}	1.15 ^{bc}	59.36 ^{a}	2.83 ^{a}	0.59 ^{ab}	1.45 ^{ab}	20.78 $^{b-e}$	0.47 ^{f}	0.15 ^{ef}	5.03 ^{bc}
Kerman	3.84 ^{f}	0.5 ^{de}	72.84 ^{a}	0.65 ^{bc}	0.22 ^{bc}	0.58 $^{c-g}$	19.5 $^{b-e}$	0.71 ^{def}	0.32 ^{cde}	4.38 ^{c}
Isfahan	5.97 ^{bc}	1.36 ^{ab}	78.17 ^{a}	0.72 ^{cd}	0.47 ^{abc}	0.22 ^{fg}	14.34 ^{cde}	0.57 ^{f}	0.2 ^{def}	5.05 ^{bc}

Region	SEW	FLL	FLW	FFW	FDW	LAR	INU	FLN	DGE	DTF
Bulgaria	2.55 ^{fg}	2.14 ^{d}	1.01 ^{e}	18.2 $^{e-h}$	2.26 ^{cd}	36.12 ^{a}	6.99 ^{a}	115.06 ^{a}	5.08 ^{bc}	86.37 ^{fg}
Germany	2.2 ^{g}	1.28 ^{f}	1.1 ^{de}	21.14 $^{d-h}$	2.25 ^{cd}	26.4 $^{a-d}$	3.32 ^{cde}	26.39 ^{ef}	4.02 ^{dg}	70.3 ^{jk}
Czech	2.89 ^{def}	1.6 ^{e}	1.69 ^{bc}	17.08 ^{fgh}	1.69 ^{de}	26.47 $^{a-d}$	2.39 ^{de}	47.01 $^{b-f}$	3.99 ^{dg}	62.2 ^{kl}
Georgia	3.52 ^{d}	2.14 ^{c}	1.27 ^{cd}	19.04 $^{d-h}$	1.96 ^{cde}	35.23 ^{ab}	2.38 ^{de}	21.44 ^{ef}	4.81 $^{b-e}$	81.35 ^{gh}
Syria	2.18 ^{g}	2.77 ^{c}	0.67 ^{e}	18.64 $^{e-h}$	1.57 ^{de}	21.49 $^{a-d}$	3.22 ^{cde}	40.17 ^{def}	5.22 ^{b}	53.22 ^{lm}
Hungary	1.1 ^{h}	1.6 ^{e}	1.27 ^{cd}	21.48 $^{d-h}$	2.22 ^{cd}	20.04 $^{a-d}$	3.87 ^{bcd}	27.2 ^{ef}	3.86 ^{efg}	52.21 ^{m}
Karaj	3.85 ^{bc}	1.49 ^{ef}	1.35 ^{cd}	22.34 $^{c-h}$	2.17 ^{cd}	19.09 $^{a-d}$	3.31 ^{cde}	48.65 $^{b-f}$	3.25 ^{g}	76.32 ^{hij}
Poland	1.12 ^{h}	2.78 ^{c}	1.05 ^{de}	22.55 $^{c-h}$	2.47 ^{cd}	21.4 $^{a-d}$	2.02 ^{e}	15.67 ^{f}	4.24 $^{c-f}$	62.26 ^{kl}
Rasht	2.75 ^{efg}	3.31 ^{a}	1.35 ^{cd}	25.29 ^{bcd}	2.79 ^{bc}	18.66 ^{bcd}	2.2 ^{e}	14.6 ^{f}	4.08 $^{d-g}$	105.45 ^{abc}
Italy	3.3 ^{cde}	2.77 ^{c}	2.03 ^{ab}	22.9 $^{c-g}$	2.23 ^{cd}	34.44 ^{ab}	2.25 ^{e}	66.14 $^{b-d}$	6.32 ^{a}	80.34 ^{ghi}
Greece	2.73 ^{efg}	2.99 ^{bc}	1.69 ^{bc}	23.4 $^{c-f}$	2.14 ^{cde}	35.29 ^{ab}	4.78 ^{bc}	14.64 ^{f}	4.41 $^{b-f}$	93.41 ^{def}
Uzbekistan	2.2 ^{g}	1.49 ^{ef}	1.68 ^{bc}	19.8 $^{d-h}$	2.71 ^{bc}	30.89 ^{abc}	5.15 ^{b}	48.64 $^{b-f}$	4.86 ^{bcd}	102.4 ^{bcd}
Zanjan	4.4 ^{ab}	2.14 ^{d}	1.64 ^{bc}	16.84 ^{gh}	1.21 ^{e}	23.1 $^{a-d}$	2.61 ^{de}	88.26 ^{de}	3.79 ^{fg}	82.35 ^{gh}
Kashmar	2.31 ^{fg}	2.12 ^{d}	1.1 ^{de}	16.3 ^{h}	1.58 ^{de}	19.83 $^{a-d}$	4.57 ^{bc}	63.72 $^{b-d}$	4.14 $^{c-f}$	108.46 ^{a}
Kermanshah	3.52 ^{cd}	2.83 ^{bc}	2.19 ^{a}	19.35 $^{d-h}$	1.54 ^{de}	11.62 ^{d}	3.38 ^{cde}	53.81 $^{b-f}$	4.27 $^{b-f}$	96.41 ^{cde}
Tabriz	4.73 ^{a}	2.99 ^{c}	1.94 ^{ab}	23.79 ^{cde}	2.11 ^{cde}	17.39 ^{cd}	3.57 ^{cde}	48.63 $^{b-f}$	4.43 $^{b-f}$	60.26 ^{lm}
Ardabil	4.4 ^{ab}	3.1 ^{a}	2.2 ^{a}	22.5 $^{c-h}$	2.07 ^{cde}	27.83 $^{a-d}$	3.93 ^{bcd}	77.23 $^{d-d}$	4.1 $^{c-f}$	98.42 $^{b-e}$
Mazandaran	1.43 ^{h}	2.35 ^{d}	1.1 ^{de}	28.45 ^{bc}	2.4 ^{cd}	22.88 $^{a-d}$	3.01 ^{de}	92.99 ^{de}	3.64 ^{fg}	92.39 ^{ef}
Kerman	2.53 ^{fg}	2.14 ^{d}	1.18 ^{d}	30.03 ^{ab}	3.83 ^{a}	22.58 $^{a-d}$	3.36 ^{cde}	43.91 $^{c-f}$	4.42 $^{b-f}$	107.46 ^{ab}
Isfahan	4.73 ^{a}	2.12 ^{d}	1.27 ^{cd}	34.51 ^{a}	3.43 ^{ab}	11.12 ^{d}	2.62 ^{de}	58.98 ^{de}	4.8 $^{b-e}$	71.3 ^{ijk}

Character	Abbreviation	Code and frequency (%)			
		1	3	5	7
Shoot color	SHC	Light-green (12)	Green (44)	Dark-green (25)	Reddish green (19)
Branch density	BRD	Low (23)	Intermediate (50)	High (23)	Very high (4)
Leaf density	LED	Low (17)	Intermediate (35)	High (40)	Very high (8)
growth habit	GRH	Drooping (2)	Spreading (73)	Spreading to upright (20)	Upright (5)
Leaf upper surface color	LUC	Light-green (17)	Green (51)	Dark-green (23)	Reddish green (9)
Leaf lower surface color	LLC	Light-green (37)	Green (41)	Dark-green (20)	Reddish green (2)
Seed color	SEO	Light-brown (9)	Brown (38)	Dark-brown (34)	Black (19)
Petal color	PEC	White (23)	Purple (49)	Dark-Purple (12)	Pink (16)

(*continued on next page*)

Table 6 (*continued*)

Character	Abbreviation	Code and frequency (%)			
		1	3	5	7
Sepal color	SEC	Light-green (22)	Green (65)	Dark-green (13)	–
Bract color	BRC	Light-green (38)	Green (43)	Dark-green (19)	–
Seed shape	SSH	Medium-elliptic (24)	Elliptic (31)	Circular (45)	–
Bract density	BDE	Low (13)	Intermediate (60)	High (23)	Very high (4)

Means within a column followed by the same letter are not significantly different at ($p < 0.05$).

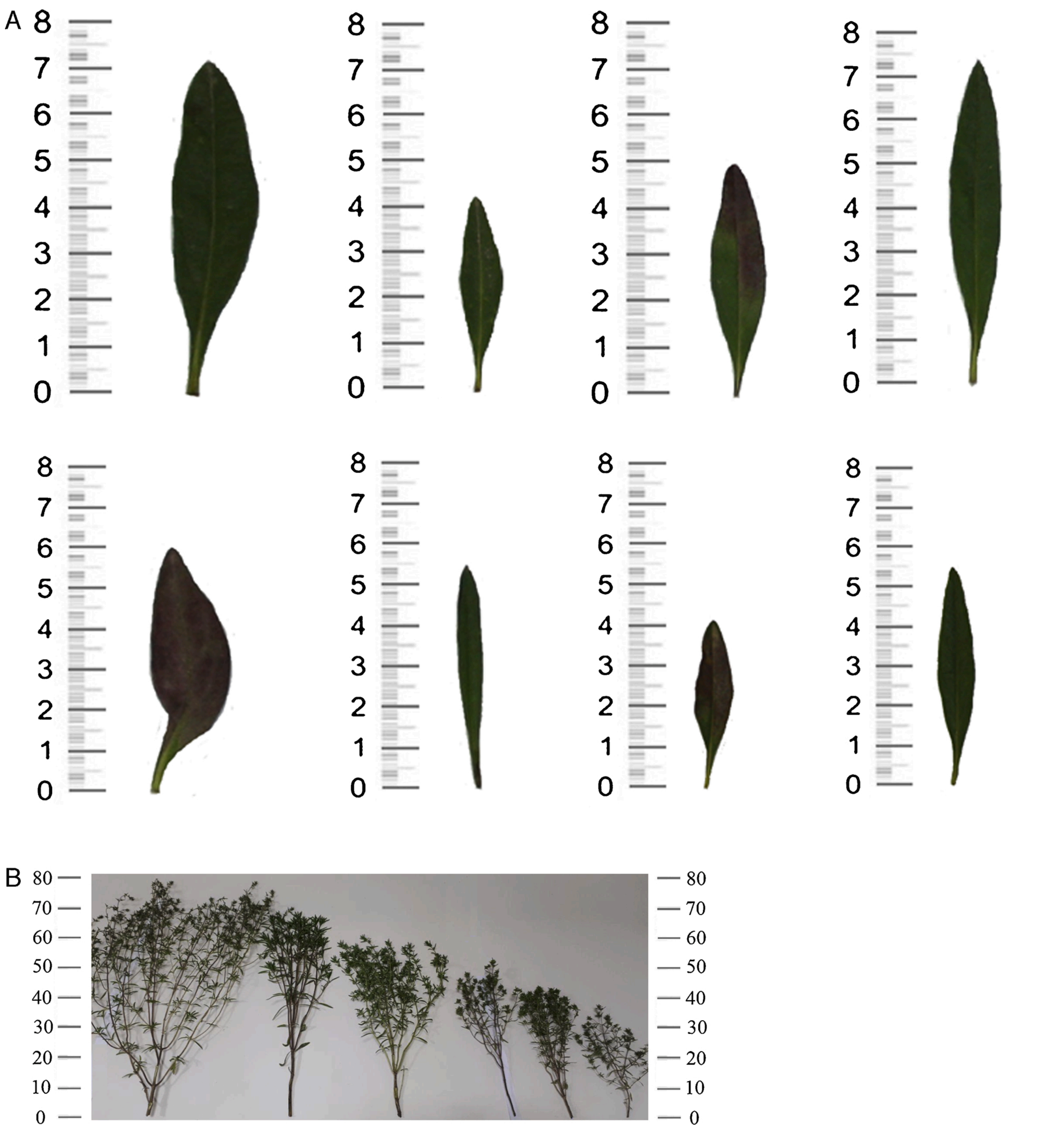

Fig. 2. Leaf and plant dimension (cm) variability of some studied accessions of *S. hortensis*.

phenotypic plasticity can cause morphological diversity in species (Geng et al., 2016). Hadian et al. (2011) showed morphological variability and clustering of the *Satureja khuzistanica* accessions were mostly in agreement with the geographical position while Khadivi-Khub et al. (2014) reported that morphological cluster analysis of *Satureja bachtiarica* accessions showed that the samples originated from each local

Table 7
Correlation coefficients among morphological and phytochemical traits of *S. hortensis* accessions.

	PHL	LEW	ITL	MBN	BNU	LFW	INL	SED	PFW	PDW	LDW	PEL	DFL	BRL	BRW	PED	STL
PHL	1																
LEW	0.337	1															
ITL	0.900	0.437	1														
MBN	0.445	−0.042	0.497	1													
BNU	0.490	0.031	0.545	0.895	1												
LFW	−0.083	0.493	−0.033	−0.294	−0.310	1											
INL	0.619	0.123	0.537	0.369	0.366	−0.374	1										
SED	0.256	0.209	0.266	−0.027	−0.083	0.146	−0.163	1									
PFW	0.716	0.122	0.632	0.410	0.514	0.084	0.443	−0.035	1								
PDW	0.602	0.077	0.574	0.431	0.586	−0.049	0.359	−0.046	0.914	1							
LDW	−0.087	0.589	−0.018	−0.350	−0.392	0.860	−0.366	0.246	0.007	−0.085	1						
PEL	−0.080	0.077	0.020	−0.300	−0.339	0.451	−0.147	0.381	−0.133	−0.244	0.300	1					
DFL	0.206	−0.104	0.111	0.064	0.076	0.082	−0.132	−0.192	0.170	0.125	−0.055	−0.237	1				
BRL	−0.138	−0.025	−0.193	−0.100	−0.266	0.061	−0.289	0.022	−0.155	−0.030	0.190	0.106	−0.145	1			
BRW	0.105	0.497	0.056	−0.179	−0.211	0.341	−0.218	0.379	−0.108	−0.172	0.355	0.215	−0.284	0.266	1		
PED	0.340	0.127	0.183	−0.381	−0.438	−0.094	0.218	0.266	0.085	−0.015	0.018	0.126	−0.256	0.308	0.339	1	
STL	0.456	.052	0.366	0.222	0.201	−0.061	0.362	0.235	0.526	0.288	−0.062	0.140	−0.129	−0.277	0.021	0.397	1
STD	0.387	0.021	0.348	0.227	0.207	−0.131	0.408	0.028	0.297	0.138	−0.192	−0.101	−0.006	−0.396	−0.099	0.346	0.737
STN	0.023	0.372	0.159	−0.107	−0.144	0.267	−0.213	0.168	−0.272	−0.391	0.154	0.223	−0.244	0.003	0.531	0.226	−0.109
PLE	0.363	−0.057	0.293	−0.193	−0.124	−0.206	0.073	0.605	0.041	−0.007	−0.149	0.032	−0.044	−0.196	0.139	0.561	0.319
EO	0.157	−0.110	0.111	0.021	0.084	−0.251	0.086	0.024	0.118	−0.015	−0.397	−0.058	0.148	−0.389	0.056	0.196	0.564
LEL	0.633	0.155	0.653	0.534	0.640	−0.195	0.243	−0.033	0.601	0.695	−0.165	−0.354	0.256	0.021	0.053	−0.049	0.026
SHC	−0.164	0.232	−0.095	−0.168	−0.063	.473*	−0.351	−0.035	0.119	0.151	.592**	−0.049	0.262	−0.123	0.017	−0.447*	−0.227
BRD	0.199	0.136	0.258	0.301	0.200	0.091	0.046	−0.079	0.168	0.028	0.114	−0.098	0.127	−0.062	0.026	−0.113	0.272
LED	0.339	0.097	0.234	0.202	0.090	0.150	0.192	0.169	0.218	0.076	0.144	0.278	−0.194	0.096	0.338	0.145	0.257
GRH	0.235	−0.031	0.250	0.011	0.171	−0.025	0.123	0.294	0.089	0.117	−0.112	0.014	0.161	−0.420	−0.287	−0.020	−0.002
LUC	−0.145	−0.231	0.020	0.301	0.248	0.108	−0.368	0.050	0.231	0.247	0.153	0.140	0.139	−0.034	−0.148	−0.448*	0.145
LLC	0.167	−0.389	0.054	0.168	0.225	−.664**	0.305	0.130	0.116	0.184	−0.513*	−0.160	−0.197	−0.068	−0.113	0.083	0.211
SEO	0.327	−0.011	0.381	0.171	0.141	−0.206	0.270	0.019	0.279	0.220	−0.220	−0.092	0.233	−0.206	−0.015	0.160	0.324
SEL	0.057	−0.042	0.005	−0.167	−0.133	−0.095	−0.135	0.505*	−0.239	−0.168	−0.170	0.202	−0.010	−0.051	0.046	0.194	−0.220
SEW	0.009	−0.076	−0.096	−0.187	−0.146	−0.090	−0.062	0.336	−0.223	−0.163	−0.249	0.030	0.190	−0.234	0.005	0.070	−0.272
FLL	−0.192	0.260	−0.164	−0.345	−0.353	0.116	−0.196	−0.089	−0.541*	−0.447*	0.317	−0.139	0.184	0.255	0.113	−0.037	−0.687**
FLW	−0.058	0.342	−0.081	−0.357	−0.369	0.084	0.008	0.046	−0.285	−0.315	0.080	−0.272	0.102	−0.115	0.139	0.249	−0.217
FFW	−0.230	0.050	−0.263	−0.186	−0.320	0.414	−0.097	−0.225	−0.143	−0.102	0.251	0.160	−0.009	0.237	0.150	−0.015	−0.400
FDW	0.066	0.026	−0.027	−0.070	−0.103	0.391	0.154	−0.356	0.279	0.241	0.236	0.009	0.110	−0.030	−0.012	−0.031	−0.141
LAR	0.391	0.044	0.365	0.227	0.332	−0.238	0.119	−0.235	0.491*	0.565**	−0.172	−0.443	0.424	−0.006	−0.033	0.075	0.130
INU	.895**	0.444	0.999**	0.476*	0.523*	−0.021	0.534*	0.277	0.622**	0.564**	−0.006	0.035	0.104	−0.197	0.059	0.196	0.363
FLN	0.393	0.412	0.396	0.133	0.068	0.335	−0.118	0.513*	0.216	0.188	0.256	0.297	0.110	0.363	0.559*	0.143	0.000
PEC	.624**	0.250	.655**	0.401	0.378	−0.222	0.397	0.003	0.402	0.462*	−0.242	−0.047	0.090	0.195	0.000	0.362	0.258
SEC	0.222	−0.184	0.094	0.117	−0.014	0.130	−0.133	0.652**	−0.015	−0.076	0.005	0.345	0.036	0.068	0.412	0.106	0.099
BRC	0.269	−0.092	0.109	0.022	−0.124	0.176	−0.183	0.675**	0.030	−0.078	0.096	0.339	0.117	0.168	0.508*	0.285	0.272
SSH	−0.044	0.126	0.063	−0.008	−0.157	0.213	−0.266	0.282	−0.338	−0.312	0.156	0.539*	−0.159	0.437	0.432	0.044	−0.342
BDE	0.299	−0.022	0.209	0.116	0.085	0.062	0.022	0.375	0.112	−0.009	−0.102	0.292	0.407	−0.157	−0.027	0.027	0.269
DGE	0.185	−0.085	0.094	0.013	0.032	0.177	−0.156	−0.199	0.162	0.129	0.061	−0.176	.971**	−0.056	−0.284	−0.251	−0.168
DTF	0.217	0.163	0.271	−0.402	−0.373	0.230	0.193	−0.046	0.162	0.066	0.233	0.245	−0.062	−0.031	0.173	0.374	−0.135
DTS	−0.344	−0.243	−0.210	−0.340	−0.428	0.035	−0.146	−0.344	−0.460*	−0.499*	−0.052	0.265	0.178	−0.032	−0.158	−0.087	−0.414
DSR	0.190	−0.088	0.100	0.028	0.044	0.165	−0.150	−0.194	0.163	0.129	0.042	−0.189	.979**	−0.075	−0.287	−0.252	−0.159

	STD	STN	PLE	EO	LEL	SHC	BRD	LED	GRH	LUC	LLC	SEO	SEL	SEW	FLL	FLW
STD	1															
STN	−0.024	1														
PLE	0.374	0.243	1													
EO	0.672**	0.055	0.256	1												
LEL	−0.078	−0.030	0.106	−0.209	1											
SHC	−0.344	−0.207	−0.180	−0.440	0.216	1										

(*continued on next page*)

Table 7 (*continued*)

	STD	STN	PLE	EO	LEL	SHC	BRD	LED	GRH	LUC	LLC	SEO	SEL	SEW	FLL	FLW
BRD	0.210	0.045	−0.257	0.322	0.083	−0.002	1									
LED	0.197	0.020	−0.178	0.155	−0.085	−0.149	0.373	1								
GRH	0.004	−0.006	0.444	−0.089	0.198	−0.098	−0.216	−0.466*	1							
LUC	−0.106	−0.221	−0.206	−0.115	0.227	0.454*	−0.037	−0.041	−0.131	1						
LLC	0.201	−0.352	0.296	0.243	0.048	−0.147	−0.221	0.283	−0.275	0.072	1					
SEO	0.219	0.035	0.381	0.090	0.528*	0.137	0.089	−0.416	0.204	0.167	−0.039	1				
SEL	−0.333	0.236	0.371	−0.163	0.013	−0.255	−0.293	−0.113	0.557*	−0.281	−0.109	−0.083	1			
SEW	−0.284	0.129	0.317	−0.083	0.008	−0.146	−0.303	−0.230	0.548*	−0.355	−0.139	0.053	0.9**	1		
FLL	−0.508*	0.124	−0.114	−0.496*	−0.020	0.200	−0.033	−0.243	0.178	−0.329	−0.394	−0.146	0.177	0.168	1	
FLW	−0.020	0.437	0.352	−0.027	−0.108	0.037	−0.129	−0.466*	0.126	−0.56**	−0.269	0.261	0.251	0.427	0.306	1
FFW	−0.183	−0.010	−0.516*	−0.210	−0.292	−0.054	0.015	0.407	−0.269	−0.213	−0.358	−0.491*	0.065	0.137	0.178	−0.076
FDW	0.082	−0.189	−0.424	−0.097	−0.097	0.109	0.035	0.519*	−0.256	−0.095	−0.134	−0.398	−0.197	−0.081	−0.053	−0.206
LAR	0.094	−0.194	0.142	−0.020	0.794**	0.341	−0.079	−0.297	−0.012	0.310	0.117	0.66**	−0.208	−0.099	−0.081	0.037
INU	0.354	0.169	0.309	0.108	0.640**	−0.092	0.245	0.227	0.256	0.013	0.048	0.386	0.010	−0.091	−0.160	−0.066
FLN	−0.184	0.378	0.206	−0.076	0.275	0.002	−0.155	0.119	−0.064	0.103	−0.071	0.097	0.134	0.051	−0.061	0.114
PEC	0.320	−0.006	−0.014	0.201	0.470*	−0.406	0.299	0.311	−0.052	−0.168	0.005	0.153	0.102	−0.009	−0.153	−0.160
SEC	0.041	0.104	0.414	0.050	0.042	−0.026	0.057	0.429	0.041	0.018	0.204	0.088	0.317	0.312	−0.173	−0.102
BRC	0.177	0.083	0.453*	0.234	−0.018	−0.077	0.120	0.433	−0.050	0.026	0.168	0.107	0.189	0.169	−0.188	−0.099
SSH	−0.395	0.501*	−0.040	−0.355	0.051	0.026	0.017	0.332	−0.302	0.018	−0.083	−0.030	0.295	0.141	0.182	0.006
BDE	0.048	0.052	0.396	0.021	0.222	0.131	−0.035	−0.165	0.287	0.078	−0.034	.555*	0.364	0.433	−0.181	0.231
DGE	−0.047	−0.285	−0.058	0.022	0.266	0.359	0.152	−0.203	0.172	0.127	−0.260	0.244	−0.068	0.116	0.269	0.073
DTF	−0.127	0.366	0.263	−0.259	0.139	0.090	−0.338	−0.060	0.140	−0.069	−0.136	0.229	0.041	0.018	0.195	0.221
DTS	−0.241	0.189	−0.269	−0.008	−0.290	−0.111	0.256	0.007	−0.004	−0.121	−0.352	−0.037	0.094	0.114	0.432	−0.003
DSR	−0.028	−0.275	−0.045	0.040	0.267	0.343	0.139	−0.214	0.181	0.131	−0.255	0.253	−0.061	0.129	0.253	0.086

	FFW	FDW	LAR	INU	FLN	PEC	SEC	BRC	SSH	BDE	DGE	DTF	DTS	DSR
FFW	1													
FDW	0.830**	1												
LAR	−0.339	−0.096	1											
INU	−0.258	−0.025	0.359	1										
FLN	−0.076	−0.164	0.097	0.398	1									
PEC	0.144	0.152	0.330	.649**	0.147	1								
SEC	0.073	0.001	−0.155	0.098	0.410	−0.042	1							
BRC	0.019	−0.044	−0.093	0.112	0.496*	0.026	0.929**	1						
SSH	0.251	−0.040	−0.162	0.069	0.443	0.152	0.486*	0.370	1					
BDE	−0.385	−0.393	0.242	0.211	0.339	0.032	0.485*	0.457*	0.278	1				
DGE	0.009	0.127	0.417	0.090	0.088	0.059	0.061	0.133	−0.111	0.413	1			
DTF	0.096	0.229	0.144	0.290	0.219	−0.075	−0.094	−0.111	0.142	−0.090	−0.041	1		
DTS	0.398	0.202	−0.276	−0.203	−0.352	−0.033	−0.110	−0.169	0.277	−0.162	0.195	0.285	1	
DSR	0.001	0.120	0.423	0.096	0.095	0.060	0.062	0.134	−0.122	0.421	.999**	−0.044	0.184	1

* , **: significant at 0.01 and 0.05 probability levels respectively.

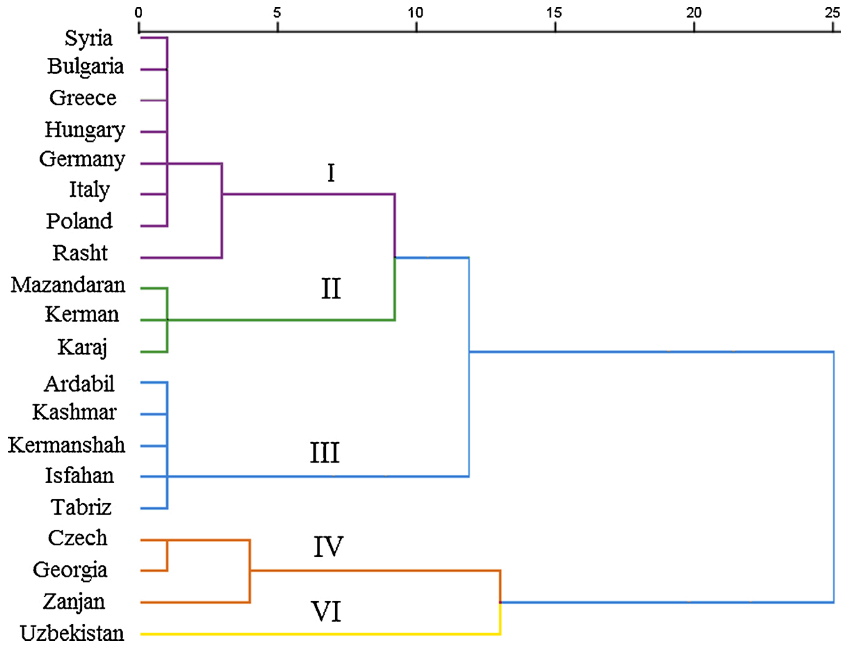

Fig. 3. Cluster analysis of *S. hortensis* samples for morphological traits.

were not placed in the same cluster completely and they showed the high intraregional morphological variability. The second cluster contained Mazandaran, Kerman and Karaj accessions. The Kashmar, Ardabil, Kermanshah, Isfahan and Tabriz accessions were placed in the third cluster. Three accessions were placed in the cluster 4, which belonged to Czech, Georgia and Zanjan. The fifth main group included Uzbekistan accession.

Factor analysis was performed to provide a reduced dimension model declaring diversity among traits. This analysis used as a data reduction method to investigate the multiple data categories of morphological and phytochemical traits and it has proven to be a valuable tool to understand relationships among traits and accessions. Factor analysis allows to evaluate multicollinear data and define the characteristics appropriate for classification (Du, 2019). The results of the factor analysis showed 13 factors with more than one eigenvalues that allocated 92.35 % of the variance (Table 9). The first three factors explained 33.21 % of the total variances. For each factor, a number of traits have highest loading factors and participate in total variation. The first factor included the size factors of the plant as plant height, internode length, branch number, plant fresh weight, plant dry weight, leaf length, internode number and petal color which had the highest factor loadings. Investigation of these traits showed that Bulgaria and Uzbekistan were highest in these traits. Khadivi-Khub et al. (2015) also reported first factor included the size factors of the plant and the first three factors explained 41.97 % of the total observed variability. In present study the sepal diameter, leaf density, Sepal color and Bract color had the maximum amount in the second factor. In the third-factor day to flowering, days to germination and day to seed ripening showed the highest variance. These results were in agreement with the research of Hadian et al. (2011) about genetic diversity among of *S. khuzistanica* accessions. The results of the KMO test illustrated that the factor analysis was appropriate for this research (KMO adequacy: 0.73).

Table 8
Discriminant analysis for determine the cut line in the cluster diagram.

			Predicted group membership					
			1	2	3	4	5	Total
Original	Count	1	5	1	0	2	0	8
		2	0	1	1	1	0	3
		3	0	1	2	2	0	5
		4	1	1	0	1	0	3
		5	0	0	0	0	1	1
	%	1	62.5	12.5	.0	25.0	0	100.0
		2	0	33.3	33.3	33.3	0	100.0
		3	0	20.0	40.0	40.0	0	100.0
		4	33.3	33.3	0	33.3	0	100.0
		5	0	0	0	0	100.0	100.0
Cross validated	Count	1	4	1	0	3	0	8
		2	0	0	2	1	0	3
		3	0	1	2	2	0	5
		4	2	1	0	0	0	3
		5	0	1	0	0	0	1
	%	1	50.0	12.5	0	37.5	0	100.0
		2	0	0	66.7	33.3	0	100.0
		3	0	20.0	40.0	40.0	0	100.0
		4	66.7	33.3	0	0	0	100.0
		5	0	100.0	0	0	0	100.0
Total percentage of validity of discriminant analysis								100 %

4. Essential oil compound analysis

The components of essential oils in different accessions were varied, and the superlative content of oil was observed in Uzbekistan (0.75 %) accession (Fig. 4), while the Georgia accession essential oil content was minimal (0.1 %). Following the Uzbekistan accession, Karaj, Syria and Czech accessions showed the highest mean oil contents (0.63, 0.56, and 0.47 %, respectively). Farmanpour-Kalalagh et al. (2020) suggested that different parts of *S. hortensis* have essential oil but the leaf has higher essential oil content and carvacrol than other parts. The oil content of *S. hortensis* from Turkey accessions was diverse and the highest amount was 4.75 % (Baser et al., 2004). The carvacrol percentage in the *S.hortensis* of 34 regions was studied and the highest content was 83 % (Hadian et al., 2014). Azaz et al. (2005) reported that the essential oil percentage in two *Satureja* cultivars was varied, and thymol, *p*-cymene, ɣ-terpinene, and carvacrol were the main compounds. The investigation of previous research showed that carvacrol, thymol, and *p*-cymene formed a large part of the *S. hortensis* essential oil. The thymol and carvacrol biosynthesis is regulated by several epistatic loci (Azizi et al., 2016). As previously reported, the *S. hortensis* essential oil and monoterpenes, including carvacrol,l are genetically governed; thus, the

Table 9
The results of Factor analysis for morphological and phytochemical traits.

	factor 1	2	3	4	5	6	7	8	9	10	11	12	13
PHL	0.906	0.247	0.115	0.196	−0.003	−0.014	0.050	0.066	0.151	−0.086	−0.043	0.025	−0.001
LEW	0.370	−0.038	−0.147	−0.070	0.691	−0.042	−0.085	−0.051	0.386	−0.083	0.273	0.005	−0.055
ITL	0.955	0.106	0.025	0.122	0.089	−0.125	0.024	0.034	−0.001	0.079	0.093	−0.043	−0.007
MBN	0.569	0.009	−0.029	0.003	−0.252	−0.024	−0.076	−0.650	−0.216	−0.079	0.043	−0.098	0.054
BNU	0.629	−0.111	−0.008	0.010	−0.247	−0.083	0.004	−0.583	−0.233	−0.213	0.036	−0.220	−0.036
LFW	−0.107	0.142	0.108	−0.038	0.885	0.298	−0.008	0.098	−0.132	0.003	0.155	−0.074	0.027
INL	0.627	−0.143	−0.256	0.175	−0.253	0.132	−0.022	0.060	0.330	0.057	−0.340	−0.157	0.168
SED	0.102	0.732	−0.209	0.050	0.239	−0.345	0.354	0.035	−0.025	−0.092	0.009	0.040	−0.135
PFW	0.711	−0.048	0.113	0.265	0.100	0.178	−0.084	0.052	−0.259	−0.404	−0.176	−0.028	0.130
PDW	0.688	−0.133	0.102	0.057	−0.021	0.157	−0.018	−0.007	−0.284	−0.520	−0.188	0.067	0.046
LDW	−0.084	0.136	0.002	−0.196	0.905	0.055	−0.215	0.164	−0.012	−0.030	−0.025	0.004	−0.128
PEL	−0.097	0.394	−0.286	0.050	0.354	0.091	0.186	0.233	−0.412	0.441	0.003	0.118	0.192
DFL	0.080	0.004	0.966	0.028	−0.012	0.036	0.075	−0.056	−0.014	0.014	−0.017	−0.054	0.043
BRL	−0.120	0.135	−0.055	−0.369	0.029	0.044	−0.215	0.021	−0.036	−0.051	0.051	0.846	−0.071
BRW	0.003	0.478	−0.217	−0.048	0.272	0.052	−0.201	0.112	0.213	−0.135	0.570	0.153	−0.041
PED	0.146	0.189	−0.211	0.353	−0.020	−0.052	0.049	0.554	0.376	−0.014	0.000	0.526	0.049
STL	0.296	0.161	−0.189	0.781	0.096	−0.187	−0.132	−0.021	−0.119	−0.104	−0.226	0.033	0.224
STD	0.253	0.036	−0.029	0.833	−0.077	−0.033	−0.166	0.009	0.137	−0.007	−0.096	−0.119	0.017
STN	0.029	0.074	−0.240	0.022	0.192	−0.104	0.107	0.133	0.167	0.268	0.825	−0.047	0.037
PLE	0.146	0.418	−0.010	0.289	−0.158	−0.501	0.299	0.460	0.212	−0.140	0.052	−0.081	−0.001
EO	−0.022	0.074	0.127	0.868	−0.247	−0.052	−0.082	−0.088	0.047	0.060	0.191	−0.062	−0.120
LEL	0.755	−0.054	0.262	−0.296	−0.149	−0.153	−0.036	−0.061	−0.096	−0.274	0.144	0.039	0.187
SHC	−0.092	0.031	0.316	−0.443	0.461	−0.068	−0.316	0.062	−0.154	−0.266	−0.141	−0.379	0.187
BRD	0.221	0.047	0.161	0.262	0.189	0.023	−0.361	−0.483	0.119	0.444	−0.022	0.014	−0.012
LED	0.258	0.536	−0.246	0.138	0.008	0.550	−0.318	−0.129	−0.034	0.191	−0.059	0.030	−0.203
GRE	0.227	−0.112	0.144	0.014	0.086	−0.322	0.774	0.118	−0.012	0.042	−0.166	−0.247	−0.123
LUC	0.001	0.021	0.134	−0.096	0.070	−0.175	−0.247	−0.080	−0.840	−0.138	−0.002	−0.120	0.107
LLC	0.081	0.331	−0.243	0.066	−0.683	−0.110	−0.264	0.075	−0.044	−0.267	−0.259	−0.127	−0.106
SEO	0.335	−0.032	0.252	0.102	−0.109	−0.441	−0.061	0.183	0.038	0.007	0.067	−0.069	0.676
SEL	−0.025	0.256	−0.065	−0.194	−0.088	−0.033	0.866	0.039	0.135	0.070	0.087	0.093	0.014
SEW	−0.112	0.193	0.133	−0.149	−0.138	0.083	0.839	0.020	0.281	−0.035	0.085	−0.096	0.165
FLL	−0.135	−0.126	0.263	−0.616	0.190	−0.140	0.035	0.131	0.436	0.323	0.013	0.085	−0.314
FLW	−0.177	−0.113	0.107	−0.022	0.152	−0.185	0.211	0.182	0.726	−0.114	0.313	−0.108	0.257
FFW	−0.176	−0.005	0.011	−0.152	0.166	0.886	0.062	0.010	0.078	0.149	0.052	0.161	−0.099
FDW	0.088	−0.051	0.105	0.013	0.126	0.928	−0.128	0.154	−0.003	−0.031	−0.123	−0.101	−0.118
LAR	0.435	−0.190	0.458	−0.087	−0.193	−0.204	−0.237	0.154	−0.049	−0.409	0.075	0.092	0.355
INU	0.948	0.109	0.021	0.125	0.099	−0.126	0.030	0.057	0.004	0.085	0.095	−0.047	−0.002
FLN	0.300	0.475	0.056	−0.128	0.268	−0.097	0.069	0.065	−0.119	−0.241	0.488	0.261	0.006
PEC	0.688	−0.047	0.039	0.189	−0.128	0.198	0.058	−0.171	0.106	0.131	0.048	0.509	0.051
SEC	0.017	0.930	0.056	−0.001	−0.082	0.079	0.143	−0.047	−0.055	0.019	0.065	−0.061	0.109
BRC	−0.005	0.928	0.151	0.200	0.019	−0.002	0.023	0.014	−0.028	−0.023	0.079	0.125	0.033
SSH	0.009	0.497	−0.165	−0.464	0.045	0.120	−0.011	−0.028	−0.071	0.383	0.399	0.237	0.261
BDE	0.107	0.446	0.318	0.062	0.062	−0.305	0.338	−0.092	−0.013	0.016	−0.037	−0.046	0.631
DGE	0.076	0.023	0.970	−0.056	0.085	0.019	0.022	−0.026	−0.015	0.051	−0.112	−0.017	0.065
DTF	0.259	−0.097	−0.055	−0.178	0.120	0.105	0.015	0.867	−0.008	0.130	0.212	−0.122	0.072
DTS	−0.234	−0.190	0.217	−0.134	−0.096	0.233	0.034	0.201	−0.013	0.832	0.098	−0.027	0.000
DSR	0.077	0.020	0.972	−0.039	0.071	0.015	0.035	−0.030	−0.015	0.039	−0.094	−0.028	0.068
Eigen value	6.979	4.396	4.235	3.860	3.757	3.294	3.267	2.688	2.629	2.569	2.179	1.904	1.648
Total variance (%)	14.849	9.353	9.010	8.213	7.993	7.008	6.951	5.719	5.593	5.466	4.637	4.052	3.506
Cumulative variance (%)	14.849	24.202	33.212	41.425	49.418	56.426	63.377	69.096	74.689	80.155	84.792	88.844	92.350

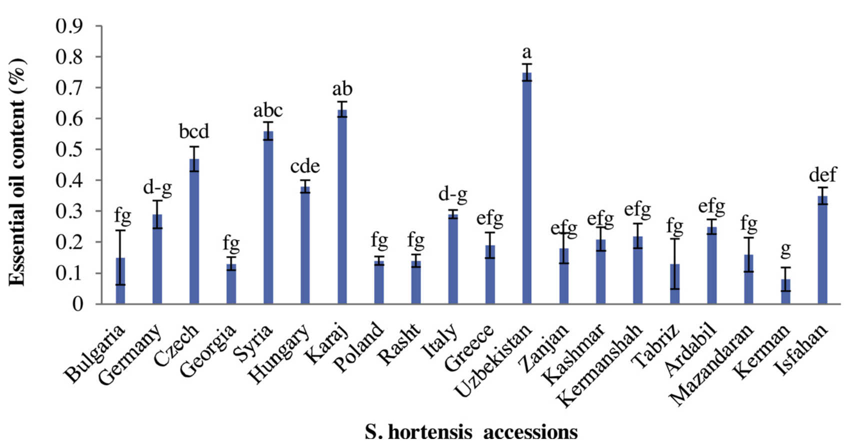

Fig. 4. Mean comparison of Essential oil content in *S. hortensis* accessions.

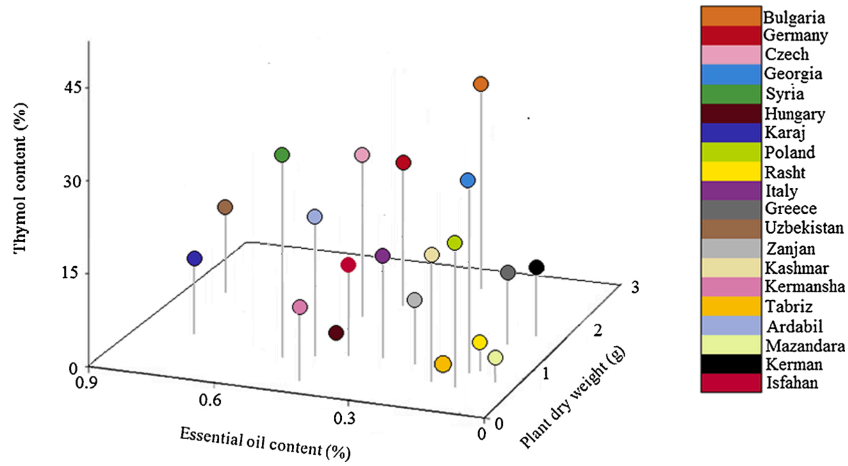

Fig. 5. Three plot for displaying the repartition of different *S. hortensis* accessions based on essential oil content, plant dry weight and thymol content.

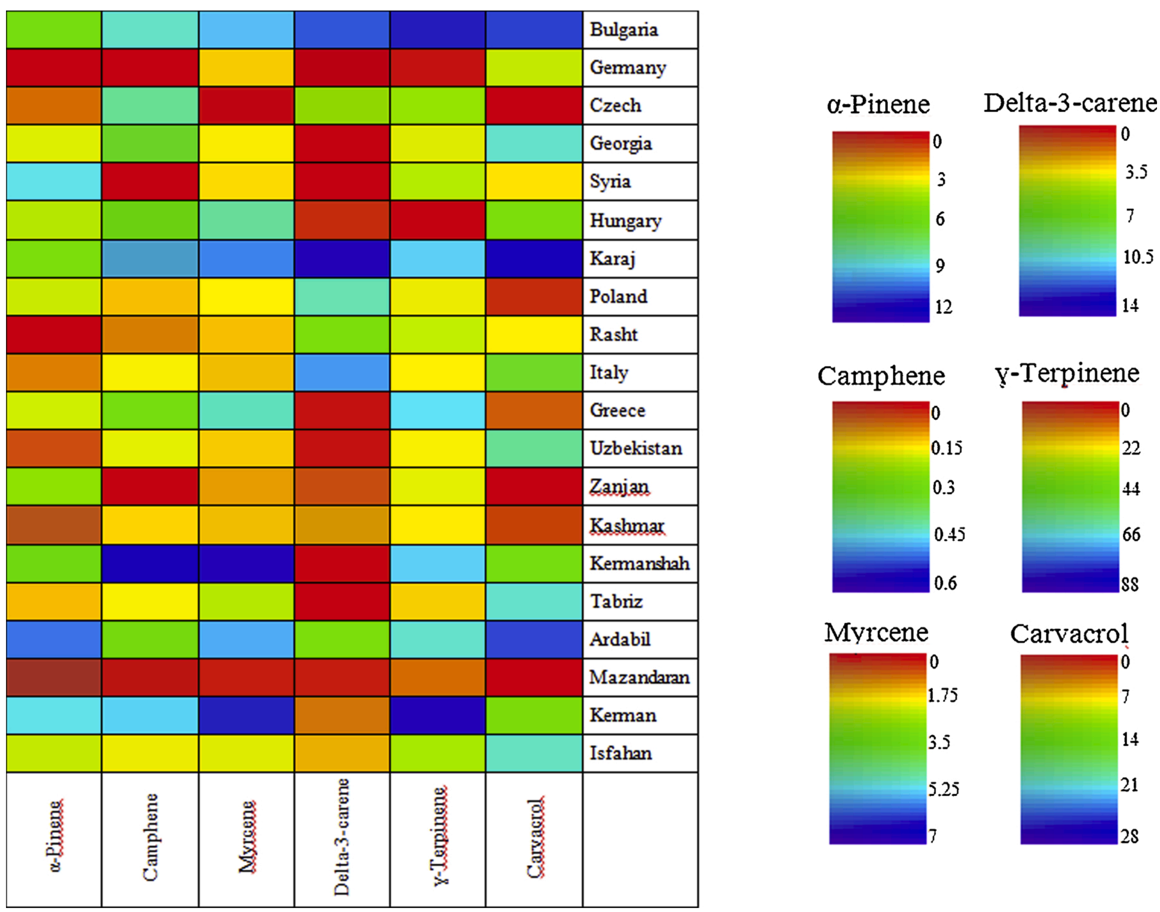

Fig. 6. Variation of chemical constituents of *S. hortensis* accessions. The legend denotes scaled values of the chemical constituents.

improvement of them by selection is necessary (Adiguzel et al., 2007; Bouyahya et al., 2019). It has been reported that genetic factors control the essential oil, thymol, and carvacrol contents (Adiguzel et al., 2007); thus, their selection for the enhancement of these traits would be possible. The Bulgaria accession showed an optimal efficiency (Fig. 5) according to the plant dry weight, essential oil content, and thymol percentage.

Growth and essential oil composition of plants can be affected by many factors, categorized into internal (genetic constitution and age or development stage) and external factors (soil properties, moisture, temperature, day length, light quality, nutrient levels, and wind patterns) (Li et al., 2020). Both categories have extremely variable effects on the plant growth, yield, quantity, and quality of the essential oil. Nooshkam et al. (2017) reported the higher temperature resulted in a better plant growth and performance in *S. khuzistanica*. In present study Bulgaria and Uzbekistan accessions with mean temperature 10 °C and 12.05 °C respectively showed better plant growth in comparison with cooler areas. Also some studies have reported that the highest biomass yield in *Mentha piperita* L. (Telci et al., 2006) and *Thymus vulgaris* (Ghasemi Pirbalouti et al., 2013) were obtained in warmer regions.

Table 10
Variation of the essential oil components resulted from *S. hortensis* accessions.

Composition	RI	Bulgaria	Germany	Czech	Georgia	Syria	Hungary	Karaj	Poland	Rasht	Italy
α-Tujene	928	5.9	1.27	2.14	9.32	1.53	5.48	6.84	1.69	1.52	1.43
Sabinene	965	0.14	–	0.03	0.02	–	0.08	0.17	0.02	0.08	0.06
β-Pinene	979	3.9	0.28	0.55	0.34	0.58	1.51	–	0.69	1.74	1.7
Octen	983	0.43	–	0.13	0.38	–	0.11	0.46	0.16	0.32	0.07
Phellandrene	1004	1.6	0.27	0.46	0.43	0.32	4.75	1.84	0.43	0.34	0.39
α-Terpinene	1008	21.4	3.57	5.7	4.9	5.67	3.37	–	5.18	2.05	4.92
Cineole	1018	0.39	–	0.08	0.16	–	–	0.35	0.09	–	0.15
Octatriene	1020	0.38	–	0.93	0.08	0.08	0.27	0.44	0.09	0.06	0.06
p-Cymene	1028	31.2	14	18.6	10.23	19.65	2.54	5.8	13.59	6.41	8.25
Trans Sabinene hydrate	1063	3.33	0.07	–	0.37	0.05	–	1.76	0.39	0.8	–
Cis Sabinene hydrate	1069	3.51	–	0.12	0.37	0.12	0.32	0.12	0.13	0.05	0.16
α-Terpinolene	1089	1.01	3.57	9.72	18.53	0.04	0.26	0.66	0.04	0.05	0.03
Borneol	1170	0.74	0.07	0.06	0.08	0.09	0.27	0.51	0.06	0.43	0.11
Cyclohexen	1172	6.1	0.15	0.13	0.59	0.17	0.96	2.26	0.16	0.03	0.15
β-Fenchyl alcohol	1189	–	0.5	0.25	0.21	–	0.34	–	0.39	0.55	0.72
αTerpineol	1192	1.37	–	0.25	–	–	–	0.81	0.13	–	0.18
Carvacrol methyl ether	1246	0.23	0.18	0.04	0.21	0.04	–	1.32	0.1	0.43	0.1
Cis Dihydrocarvone	1282	–	0.15	–	0.13	0.14	0.08	0.28	–	–	0.04
Thymol	1294	41.13	24.38	28.22	32.2	34.98	–	11.01	24.31	3.53	18.27
Phenol five methyl	1305	1.57	0.07	0.02	0.06	–	0.17	0.29	0.08	0.11	0.08
Carvacryl acetate	1374	3.47	–	0.67	0.21	0.17	0.27	0.58	0.83	0.07	0.07
Trans Caryophyllene	1415	5.34	0.28	1.23	2.09	0.24	5	2.29	7	0.28	0.56
(+)-Aromadendrene	1446	0.27	0.15	0.03	–	0.14	0.1	0.41	0.14	0.22	0.45
α-Humulene	1460	0.38	0.11	0.14	0.08	0.21	0.06	0.11	0.56	0.13	0.05
Alloaromadendrene	1469	–	0.11	0.03	0.12	0.04	–	0.08	–	–	0.08
Ledene	1500	0.39	–	–	0.18	–	0.15	0.52	0.14	0.29	0.1
B-Bisabolene	1510	5.75	0.28	1.32	2.17	0.21	0.88	2.2	0.59	0.14	0.58
Spathulenol	1585	1.35	0.13	–	0.11	0.14	0.14	0.56	0.03	–	0.07
Caryophyllene oxide	1591	0.99	0.14	0.04	0.12	0.25	0.11	0.32	0.08	0.17	0.1

Composition	RI	Greece	Uzbekistan	Zanjan	Kashmar	Kermanshah	Tabriz	Ardabil	Mazandaran	Kerman	Isfahan
α-Tujene	928	0.5	1.48	1.53	1.52	7.04	2.57	16.49	0.2	6.63	2.69
Sabinene	965	0.1	0.02	0.02	0.01	0.11	0.03	0.06	0.21	0.1	0.06
β-Pinene	979	1.43	0.63	0.52	0.4	3.23	0.47	1.46	–	1.85	1.22
Octen	983	0.24	–	0.15	0.04	0.34	0.15	–	–	0.42	0.2
Phellandrene	1004	1.46	0.37	0.35	0.32	2.15	0.63	1.64	–	1.75	0.61
α-Terpinene	1008	11.58	3.95	5.06	4.63	14.31	7.03	11.3	1.04	13.52	7.61
Cineole	1018	0.25	–	0.1	–	0.22	0.11	1.52	0.14	0.3	0.12
Octatriene	1020	0.34	0.06	0.06	0.05	0.45	0.12	0.33	–	0.4	0.2
p-Cymene	1028	20.4	23.25	9.31	14.9	11.21	5.3	7.98	3.29	4.38	14.3
Trans Sabinene hydrate	1063	1.34	0.36	0.33	–	1.02	0.43	1.3	0.21	0.71	–
Cis Sabinene hydrate	1069	0.34	0.14	–	0.17	0.36	0.03	0.43	–	–	0.6
α-Terpinolene	1089	0.19	0.08	16.16	0.05	14.86	12.88	0.2	–	0.9	12.81
Borneol	1170	0.19	0.89	–	0.05	0.33	0.06	0.2	–	0.75	0.1
Cyclohexen	1172	0.52	0.54	0.1	0.1	0.76	0.18	0.65	–	3.25	0.25
β-Fenchyl alcohol	1189	–	–	0.35	0.38	0.42	0.14	–	0.11	–	0.15
αTerpineol	1192	0.52	0.07	0.13	0.08	–	–	0.21	0.24	0.19	–
Carvacrol methyl ether	1246	–	0.15	0.21	0.31	0.69	0.21	1.2	0.39	0.77	0.28
Cis Dihydrocarvone	1282	0.17	–	0.05	–	–	0.06	–	–	0.2	0.06
Thymol	1294	9.26	13.96	9.52	24.08	10.67	–	24.08	1.95	9.81	15.39
Phenol five methyl	1305	0.29	0.14	0.25	0.11	0.38	0.04	8	–	1.41	0.07
Carvacryl acetate	1374	0.46	0.22	0.48	–	1.58	0.12	2.02	–	0.87	0.37
Trans Caryophyllene	1415	2.85	1.29	1.8	0.35	7.78	1.38	9.09	–	4.81	1.7
(+)-Aromadendrene	1446	0.09	0.06	–	0.87	1.65	–	1.28	–	0.97	–
α-Humulene	1460	0.24	0.58	–	–	0.44	–	0.49	0.21	–	0.21
Alloaromadendrene	1469	–	–	0.11	0.05	–	0.16	–	–	0.12	0.09
Ledene	1500	0.13	0.11	–	0.06	0.2	0.23	1.53	–	0.19	0.06
B-Bisabolene	1510	2.66	0.16	0.88	0.26	–	1.3	4.9	0.64	4.73	0.83
Spathulenol	1585	0.12	0.06	0.15	–	0.82	0.08	0.75	–	0.72	0.41
Caryophyllene oxide	1591	0.32	0.23	0.41	0.32	0.41	0.07	0.42	–	0.64	1.76

RI: retention indices based on HP-5MS column.
RI: retention indices based on HP-5MS column.

The essential oil production is considered a means of adaptation to environmental conditions (Caser et al., 2019; El-Gohary et al., 2020). Some studies reported that H_2O stress increased essential oil content of *Origanum vulgare* L. (Azizi et al., 2009) and *S. hortensis* (Baher et al., 2002). Kokkini et al. (1994) suggested that leaf secretory glands tended to increase in Mediterranean climatic conditions, which caused enhancement of essential oil content. Vokou et al. (1993) indicated that the altitude influenced the oil content and highest essential oil was achieved at low altitudes. In the present study, the high oil content of the Uzbekistan accession seems to be related to the lower altitude. Plants secrete more essential oil in warm conditions to protect them against water stress and intense light (Horwath et al., 2008).

In this research 35 components of essential oils were detected, and carvacrol, ɣ-terpinene, delta-3-carene, myrcene, camphene, and α-pinene appeared to be the most important components (Fig. 6). All of the accessions showed ɣ-terpinene and carvacrol as the main component at a high percentage. The carvacrol and its precursors, *p-cymene* and ɣ-terpinene, were present in high concentrations in Bulgaria accession.

Carvacrol is a monoterpenoid phenol and produced following aromatization of ɣ-terpinene to *p*-cymene and subsequent hydroxylation of *p*-cymene. Carvacrol and its precursors were the major components in essential oils of the Lamiaceae family (Di Pasqua et al., 2007).

The carvacrol content was higher in Karaj (28.07 %) and Bulgaria (27.91 % showed by dark blue). The maximum (84.03 %) and minimum (2.15 %) amounts of ɣ-terpinene were achieved from Bulgaria and Germany accessions (dark blue and red color), respectively. Karaj showed the highest level of delta-3-carene (13.19 %), and Germany was the lowest (0.001 %). Myrcene varied between 5.83 % (in Kerman) to 0.02 % (in Czech). Among accessions, the Kerman accession had the highest camphene (0.4 %), while Germany showed the lowest content (0.05 %). The α-pinene content varied between 10.6 (in Ardabil) to 0.31 % (in Mazandaran) (G). This variability in concentration of its major components suggested the existence of different chemotypes (Milos et al., 2001).

Among other compounds, the thymol content varied between 1.95 % (Mazandaran accession) to 41.13 % (in Bulgaria accession). Borneol varied between 0.05 % (in Kashmar) to 0.89 % (in Uzbekistan). Among accessions, the Uzbekistan accession had the highest essential oil content, Borneol and α- Humulene (Table 10). This is consistent by (Khadivi-Khub et al., 2014). The Bulgaria accession essential oil was lower than Uzbekistan, but showed the maximum amount of β-pinene, α-terpinene, *p*-cymene, ɣ-terpinene, trans Sabinenehydrate, cis Sabinenehydrate, α-terpineol, thymol, Phenol 5-methyl, carvacryl acetate, β-bisabolene, and spathulenol. The Ardabil accession exhibited the highest α-tujene, α-pinene, cineole, trans caryophyllene, and ledene, despite a low amount of essential oil. The Karaj accession was the best in sabinene, octen, delta-3-carene, carvacrol methyl ether, cis dihydrocarvone, and carvacrol content. The genetics and environmental factors affect the essential oil content (Li et al., 2020). Ghasemi Pirbalouti et al. (2013) reported that decreasing the temperature causes the improvement of the essential oil production. Dardioti et al. (2012) investigated the diversity of *Satureja pilosa* essential oil compounds and reported that the thymol, *p*-cymene, and carvacrol amount had the highest variation.

5. Conclusion

In this study, the agro-morphological and essential oil properties of *S. hortensis* accessions that originated from Iran and some Asian and European countries were evaluated. Different accessions were grown in the uniform climatic and cultivation conditions; thus, the variation in plant characteristics is related to genetic factors. The considerable pharmacological attributes and the need for low input properties in *S. hortensis* has made it desirable plant for domestication and cultivation in Iran's harsh environmental conditions. This study showed a high level of diversity of the morphological and phytochemical traits among *S. hortensis* accessions. This needs a breeding approach during the domestication process to obtain homogenous cultivars with suitable agricultural properties, yield, favored growth forms, resistance, etc., with the aim of exposure a favorable new crop to industry and agriculture applications. The essential oil of *S. hortensis* is considerable due to the antioxidant and antimicrobial activity and being safer than chemical counterparts, and this study represented a novel suggestion for the use of *S. hortensis* global potentials to use in plant breeding programs.

CRediT authorship contribution statement

Roghayeh Fathi: Conceptualization, Methodology, Writing - original draft. **Mehdi Mohebodini:** Data curation, Supervision, Writing - review & editing, Conceptualization, Funding acquisition. **Esmaeil Chamani:** Visualization, Investigation. **Naser Sabaghnia:** Software, Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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