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Investigating the relationship between soil properties and morphological traits and volatile oil components of *ferula assa-foetida* L. under habitat conditions in Kerman province, Iran

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Abstract:

Ferula assa- foetida L. is an endangered and important medicinal plant in Iran. The knowledge of its ecological relationships will lead to plant conservation and reproduction objectives and better economic performance. This research was aimed to investigate the relationship between soil factors and plant morphology and oil components of the *F. assa- foetida* under habitat conditions in Kerman province in 2021. Morphological and latex traits of 20 plant stands were evaluated in a plain area. Soil samples were also taken from a depth of $0-30$ cm under plant stands for analyzing its physiochemical properties. In order to identify the ecological relationships between soil and plant factors, the data were subjected to Pearson correlation and Principal Component Analysis (PCA). The results showed that morphological traits of the *F. assa- foetida* stands and quantitative and qualitative traits of latex had significant relationships with soil fertility traits (i.e. Nitrogen, Phosphorus and Organic Matter). Plant factors i.e. leave diamete, thousand seed weight, root diameter, and seed production per plant were positively correlated with soil fertility factors ($P < 0.01$). Moreover, from 21 components identified in the *F. assa- foetida* volatile essential oil, Bicyclo 3.1.1, heptane, 6, 6−dimet ..., Carbonothioic dihydrazide, Thiopropionamide and Naphthalene, 1, 2, 3, 5, 6, 8 a- hexahy were positively correlated with soil fertility factors ($P < 0.01$) and in contrast, n- Propyl sec-butyl disulfide and 1, 3, 6 − 0 ctatriene, 3, 7- dimethyl were negatively correlated with soil fertility factors ($P < 0.01$). In general, the morphological traits and the quality of plant latex are under the direct influence of both the fertility and the physical traits of the soil; so, the results are important for management and economic purposes.

Keywords: Ecological relationships; Latex; Soil fertility; Volatile oil components

Introduction

Ferula assa- foetida L. is an endangered endemic and important perennial medicinal herb which produces asafetida with local names of “anghuzeh” is native to Iran and central Asia (Saadatfar et al., 2020; Zomorodian et al., 2018). Exudes from the plant root/stem, asafetida is important for pharmacological and industrial applications (Hassanabadi et al., 2019; Moghaddam and Farhadi, 2015) as well as food and beverages, etc. (Malekzadeh et al., 2018; Pavela et al., 2020).

Almost all parts of the asafetida have medicinal effects and are used for different purposes. However, asafetida performance could be improved through proper selection and management of the plant growth condition. Generally,

growing the plant in soils with better conditions in terms of nutrients will improve the plant performance (Saydi et al., 2016; Abreu Pestana et al., 2020). Therefore, improving plant growth conditions or selecting better conditions will increase plant performance, especially the quality and quantity of essential oil (Ardakani et al., 2023).
The plant growth/ mechanism and development are usually elicited or inhibited by different environmental conditions (Li et al., 2020; Ardakani et al., 2023), and it is necessary to identify ecological attributes and also, enhance the quantity and quality of plant products (Saadatfar et al., 2020; Shanjani and Hoseini, 2022). Generally, the environment consists of a set of relationships between living and nonliving things where each species influences its environment and in turn, gets influenced by it (Xie et al., 2019). Therefore, by investigating the effect of environmental factors on plants, ecological and economical goals may be achieved (Souza et al., 2017; Li et al., 2020).
Among the environmental variables, edaphic factors play an important role in plant community structure and function (Bazanjani et al., 2017; Ward et al., 2016; Niari et al., 2022). In general, through variations of the physical and chemical soil properties, variability in microclimate creates micrositess with specifici edaphic factors for plants (Redelstein et al., 2018; Su et al., 2019). On one hand, a micro change is enough to change ecosystem functions in terms of physical, chemical, and biological traits (Branton and Robinson, 2019; Zibulski et al., 2016).
So far, most of the studies have been conducted on the relationship between environmental parameters, i.e. soil and climate, and the formation of plant populations/types, and the range of variations in the evaluated traits has been reported to be very wide i.e. (El-Wahab et al., 2018; Haight et al., 2019; Huang et al., 2020; Li et al., 2021).
In almost all of these studies, the scale of the investigated variations in soil or other environmental factors was very wide; for example, the elevation change factor in an investigated area had a wide range of several hundred m or the changes of some soil properties have been reported to be more than 50% at times. Therefore, it should be noted that micro changes in environmental traits also cause drastic changes in the vegetation or performance of plants (Zibulski et al., 2016; Joly et al., 2017). Also, so far ecological studies regarding the relationship between the quality of secondary productions of medicinal- industrial plants and soil traits under natural conditions have not been conducted. On the other hand, the relationship between variations in soil quality traits and plant performance in their origin habitat was rarely seen. However, in any case, investigating the relationship between soil properties and the performance of plant species in the origin habitat of plants can be taken into consideration in making decisions for the cultivation and propagation of plant species, especially medicinal species, and guarantee the success of biological trials (Jahantab et al., 2022; Yazdanshenas et al., 2019).
According to the above mentioned, medicinal and industrial ferula plant is important from various aspects so that the economy of local communities in many rural areas depends on this plant, and improving the performance of the plant by considering the empowerment of communities can be effective in improving the ecological conservation and livelihood of the local people. Thus, the aim of this study was to investigate the relationship between the functional (morphological traits, i.e. height, canopy cover, number of leaves, seed production) and physiological traits (i.e. biomass, plant's organ moisture and essential oil components) of the *F. assa-foetida* and soil properties in the origin habitat of the plant in the arid areas of Iran's Kerman province. The results of this research can be useful for proper rangeland management in terms of plant conservation, restoration and utilization.

Materials and methods

Study area

The experiment was carried out in a natural habitat of *F. assa- foetida* in Ravar rangelands in Kerman province (31.2633° N, 56.8072° E). Study area with 11535 km^2 is located in the northeast of the Kerman province. This site located at elevation of 1700 − 1770 m above sea level. The area is located in an arid climate with long-term mean precipitation of 98 mm and the mean annual temperature of 16.5 °C. This area is covered mainly by asafetida plant stands, which is harvested by local communities for various purposes, especially to sell asafetida latex for livelihood (Figure 1).

Methodology

The experiment was carried out at the beginning of July in 2021. In order to eliminate the effects of topography on the performance of plants, a plain area (UTM; 3333256 −

(A) (B) (C)

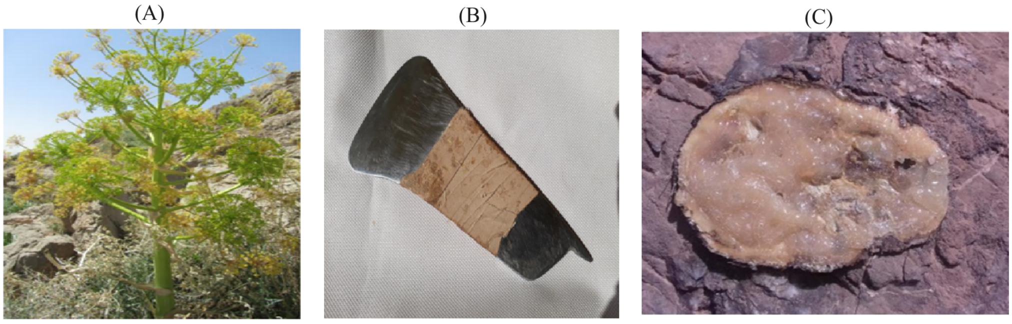

Figure 1. General view of the *F. assa- foetida* (A), the special tool for gathering the plant latex (B), and the latex secreted from the cut place on the root (C).

557086) with an elevation of 1730 m above sea level and slope of 2% was selected for sampling. Due to the fact that ferula species reproduce and produce seeds in the last year of their life, in this study, plant stands with inflorescence were used for comparison so that the selected bases do not differ from each other in terms of age. Sampling was done by selecting 20 plant stands in the natural habitat of Ferula in the study area. Moreover, latex of plant stands was sampled to study oil components. Soil samples were also collected from plant stand undersory from a depth of 0 – 30 cm and were transferred to the soil laboratory of the Islamic Azad university, Tehran.

Data collection

Morphological traits

Morphological traits of asafetida stands were evaluated in the origin habitat of asafetida. Traits included aerial biomass (AB), aerial parts moisture content (APMC), number of leaves (NL), leaf diameter (LD), leaf length (LL), inflorescence height (IH), inflorescence diameter (ID), diameter canopy cover (DCC), number of compound umbrellas (NCU), number of seeds per umbrellas (NSU), thousand seed weight (TSW), root diameter (RD) and seed production per plant (SPP).

Latex traits

Amount of latex was evaluated and the obtained information was recorded. The moisture content was measured after cutting plant aerial parts for measuring biomass. The latex samples were taken from the plant stem (Figure 1). The latex was sampled, kept in closed cans and transferred to the lab and the components of volatile oils were measured using GC-MS method described previusly (Joshi, 2017). The essential oil was analyzed using model 6890 gas chromatography coupled with an Agilent model 5973- N mass spectrometry, equipped with an HP-5MS capillary column and phenyl methyl siloxane phase (30 m × 0.25 mm i.d. × film thickness 0.25 µm). The ionization energy was 70 eV. The temperature was programmed from 60 to 246 °C with a rate of 3 °C/min. Injector and detector were maintained at 250 °C. Samples (1 µL) were injected with a split ratio of 1:50. Helium used as a carrier gas with a flow rate of 1.5 mL/min. Retention indices were determined using retention times of nalkanes (C8-C25) which were injected after the essential oils under the same chromatographic conditions. The essential oil components were identified based on data published in the literature. 21 components that had the highest percentage were selected for analysis.

Soil analysis

The soil samples were dried at shadow and sieved through a 2 mm filter. Factors of pH (using Swiss Metrom 826 pH meter apparatus), potassium (K) (using soil potassium filimeter), electrical conductivity (EC) (using PET 103 EC meter), lime ($CaCO_3$) (using calcimeter instrument), gypsum ($CaSO_4$) (using sodium carbonate method), phosphor (P) (using Hach model dr2800 spectrophotometer), organic matter (OM) (using Walkley- Black method), nitrogen (N) (using Kjeldahl method), soil moisture (SM), texture (sand, silt, and clay%) (using hydrometer method) were measured.

Data analysis

Data were checked for normality through the Kolmogorov–Smirnov test; then, data were submitted to a PCA to summarize variations in plant traits, oil components and soil variables using the PC- ORD. Pearson correlation was also performed between the studied parameters for soil and plant.

Results

PCA for morphological traits vs. soil properties

Evaluating the morphological traits of the asafetida showed significant variations in some vegetative factors i.e. AB, LD, IH and ID. The relationships between soil and asafetida vegetative traits and oil components were significant ($P < 0.05$). For instance, some factors such as the OM showed significant differences so that the maximum and minimum amount of OM was evaluated as 0.88 and 0.32%, respectively.
Based on the findings, the first 3 axes justify the values of 34.52, 50.20 and 63.66% of the variance and the relationship between the vegetative traits of the plant and soil traits (Table 1).
Some factors such as N, K, P, SM and clay% have been placed in one group in terms of their impact and relationship with the functional traits of the asafetida. Moreover, traits such as the amount of silt, $CaCO_3$ and $CaSO_4$ have shown a negative relationship with the ferula stands traits. The result showed that in PC1, most of the plant traits with eigenvector values more than 0.7 were correlated with soil fertility factors (N, P and K). In PC2, APMC showed a significant correlation with K. Factors OM, P and clay were positively correlated with almost all plant factors evaluated. Lime and sand factors also showed significant negative correlations with plant traits (Table 2, Figure 2). In PC1 and PC2, factors LD and K had the longest gradient length with 0.84 and 0.78, respectively. Also, in PC1 and PC2, K and P/$CaCO_3$ have the lowest gradient lengths with lengths of 0.22 and 0.03, respectively.

Table 1. Variance extracted for first 5 axes for soil and plant factors in the study area.

	Axis	Eigenvalue	% of Variance	Cum.% of Var.	Broken-stick Eigenvalue
	1	4.143	34.52	34.52	3.103
	2	1.881	15.67	50.20	2.103
Plant-soil relationships	3	1.684	13.46	63.66	1.603
	4	1.077	8.97	72.64	1.274
	5	0.977	8.08	80.72	1.020

Table 2. Eigenvector of the plant and soil traits for the first three PCA axes.

Parameter	Abbrv.	PC1	PC2	PC3
Aerial biomass	AB	**-0.76**	0.12	0.09
Aerial parts moisture content	APMC	-0.28	**-0.77**	-0.35
Number of leaves	NL	**-0.73**	0.46	-0.21
Leave diameter	LD	**-0.84**	-0.17	0.26
Inflorescence height	IH	**-0.70**	-0.30	-0.13
Inflorescence diameter	ID	**-0.72**	-0.19	-0.25
Diameter Canopy cover	DCC	**-0.79**	-0.08	-0.15
Seed production per plant	SPP	**-0.82**	0.38	-0.07
Number of compound umbrellas	NCU	-0.66	-0.16	-0.59
Number of seeds per umbrellas	NSU	**-0.70**	0.19	-0.42
Thousand seed weight	TSW	**-0.77**	0.22	-0.01
Root diameter	RD	**-0.80**	-0.13	0.16
Leave length	LL	**-0.74**	-0.23	0.51
Soil parameter		PC1	PC2	PC3
Electrical Conductivity	EC	0.44	0.55	0.42
Soil Acidity	pH	0.49	0.52	-0.04
Organic Matter	OM	**-0.70**	0.42	0.08
Nitrogen	N	**-0.73**	-0.20	0.37
Phosphorus	P	-0.57	-0.03	-0.48
Potassium	K	-0.22	**0.78**	0.45
Sand	Sand	0.43	-0.56	0.57
Silt	Silt	**0.76**	0.21	-0.42
Clay	Clay	-0.69	-0.07	-0.16
Calcium carbonate	$CaCO_3$	0.43	0.03	0.15
Soil Moisture	SM	-0.52	-0.14	0.52
Calcium sulphate	$CaSO_4$	**0.79**	-0.30	0.21

The bold and underlined coefficients have significant correlation with the relevant axes.

PCA volatile oil components vs. soil properties

Based on the findings, the first 3 axes justify the values of 43.24, 54.46 and 63.52% of the variance and the relationship between the vegetative properties of the plant and the soil properties, respectively (Table 3).

Also, volatile oil components of the first axes including Bicyclo[3.1.1]heptane, 6, 6-dimet ... (Eig. Value = 0.84), 1, 3, 6-0ctatriene (Eig = 0.85), 2- Methyl-1(Eig = 0.87), Disul (Eig = 0.83) and Carbonothioic dihydrazide (Eig = 0.87), and the second axes including (-)- Ari (Eig = 0.69), Limonen (Eig = 0.51) and Thioph (Eig = 0.53) showed the most values (Table 4).

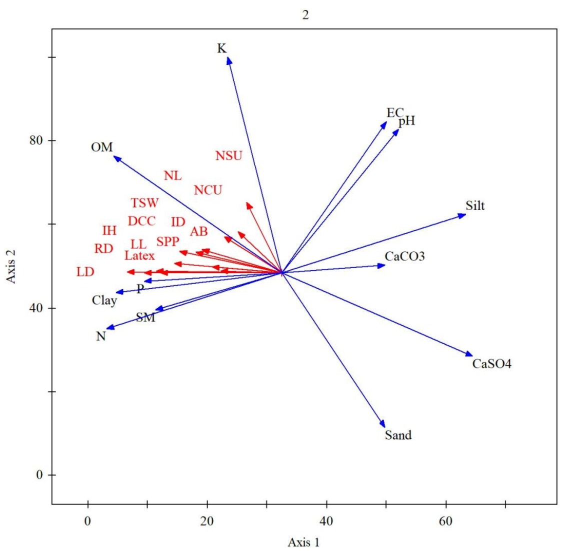

Figure 2. PCA two-dimensional ordination diagram for the soil and plant variables (Abbreviations of plant vegetative traits are presented in Table 2).

These compounds are related to the soil traits and the value of the gradient shows the intensity of the relationship and the positive or negative gradient of the direction of the relationship so that in the first axis, except lime and silt, fertility factors (such as N and OM) had a positive relationship with many essential oil compounds such as Thiopropionamide and Carbonothioic dihydrazide.

A total 21 compounds were identified in the latex samples. Some compounds.i.e. Carbonothioic dihydrazide and Bicyclo[3.1.1]heptane, 6, 6- dimet with 37.0 and 13.0%, respectively, had the highest percent values (data not shown). Bicyclo[3.1.1]heptane, 6, 6- dimet . . . (Eig $= -0.84$), Limonen (Eig $= -0.72$), 1, 3, 6 – 0 ctatriene (Eig = 0.85), n-Propyl sec-butyl disulfide (Eig = 0.83), Carbonothioic dihydrazide (Eig $= -0.87$), Disulfide (Eig $= -0.83$), 2- Methyl-1- isopropyl(dimethyl)si. (Eig = 0.87), Thiopropionamide (Eig $= -0.8974$) and Naphthalene, 1, 2, 3, 5, 6, 8a-hexahy ... (Eig $= -0.77$) had the most gradient length (Table 4).

Figure 3 shows the PCA analysis of the relationships between volatile oil components and soil factors in the study area. Based on the results, traits of K and the amount of sand had no relationship with the components of the volatile oil. On the other hand, some soil factors such as OM, P, and clay had significant relationships with Naphthalene, Disulfide, Carbonothioic dihydrazide components. Components

Table 3. Variance extracted for first three axes for soil factors and oil components in the study area.

	Axis	Eigenvalue	% of Variance	Cum.% of Var.	Broken-stick Eigenvalue
Oil-soil relationships	1	9.080	43.24	43.24	3.645
	2	2.352	11.21	54.46	2.645
	3	1.902	9.06	63.52	2.145
	4	1.553	7.39	70.91	1.812
	5	1.452	6.93	77.85	1.562

of 1, 3, 6 – 0 ctatriene, n- Propyl sec- butyl disulfide and 2-Methyl-1- isopropyl(dimethyl)si have also been related to percent of $CaCO_3$, $CaSO_4$ and silt.

Correlation between traits

Based on the results, most of the plant factors, i.e. LD, LL, IH, ID, DCC, TSW, RD and SPP showed positive relationships with soil fereitiy (N, P and K). Moreover, there were negative correlations between $CaCO_3$ and $CaSO_4$ and plant traits ($P < 0.01$) (Table 5). Soil texture also had significant relations with plant traits where clay was significantly correlated with plant traits such as LD (R = 0.94).

The results of Pearson correlation between the soil factors and oil components are shown in Table 6. Components i.e. [Bicyclo[3.1.1]heptane, 6, 6- dimet...], [Carbonothioic dihydrazide], [Thiopropionamide], and [Naphthalene, 1, 2, 3, 5, 6, 8a- hexahy] were positively correlated with soil fertility factors ($P < 0.01$) and in contrast, [n-Propyl sec-butyl disulfide] and [1, 3, 6-0ctatriene, 3, 7-dimethyl-] were negatively correlated with soil fertility factors ($P < 0.01$).

Discussion

Knowledge of the ecological factors, i.e. soil properties and climatic factors influencing the plant performance is essential for the conservation, management, and rehabilitation of rangeland ecosystems conditions (Arrekhi et al., 2022). In this research, the results showed that there were significant relationships between growth factors of the ferula stands and soil traits. In other words, according to the soil traits, especially its fertility, the vegetative traits of the ferula had also changed. Although these variations influenced plant morphological factors, they had caused changes in the quantity and quality of the produced latex. Generally, growth of plant, after its germination, is under the influence of macro/micro-environmental factors, i.e. nutrient conditions (Joly et al., 2017) that formed the production and accumulation processes of plant primary and secondary metabolites (Bazanjani et al., 2017; Karimi et al., 2020).

Investigating the relationship between the asafetida plant growth traits under natural conditions in the origin habitat showed that soil fertility even at a very low scale (for example, the 5% of the difference) causes this herbaceous plant to grow in a short period of time and to produce seeds before the arrival of the dry season. In this way, in the places where the soil had better conditions in terms of fertility properties, asafetida growth traits such as IH, AB, NSU and TSW and also the latex production increased.

Overrally, even micro changes in environmental factors could influence plant functions (Peng et al., 2012; Solomou and Sfougaris, 2015). In this regard, soil traits play an important role in nutrient flow for vegetation (Moeslund et al., 2013). Moreover, depending on the soil conditions, higher humidity will result in more biomass in ferula (Jafari et al., 2019). Moisture is directly related to nutrient flow in soil. In fact, depending on the geographical location, available nutrients influenced plants primary and secondary functions through humidity flow (Zuleta et al., 2018).

Furthermore, in this area, the components of Bicyclo[3.1.1]heptane, 6, 6- dimet n- Propy, 3, 7- dimethyl-, Carbonothioic dihydrazide, Thiopropionamide, and Naphthalene, 1, 2, 3, 5, 6, 8a- hexahy... showed significant relaitonships with soil fertility ($P < 0.05$). Generally, the synthesis and accumulation of secondary metabolites are very complex, which are affected by many factors including internal developmental genetic circuits and by external environmental factors, i.e. light, temperature, water, salinity, etc. (Daneshkazemi et al., 2019; Li et al., 2020).

Similarly, Bazanjani et al. (2017) also studied the correlation between environmental factors with volatile oil components and reported that environmental variables significantly influence oil components, i.e. total phenolic content. Previous stadies also mentioned that essential oils of the asafoetida were directly influenced by macro and micro environmental variables (Sardrodi et al., 2017; Hassanabadi et al., 2019).

In addition to the studied plant factors, some soil properties showed a significant relationship with the secondary product

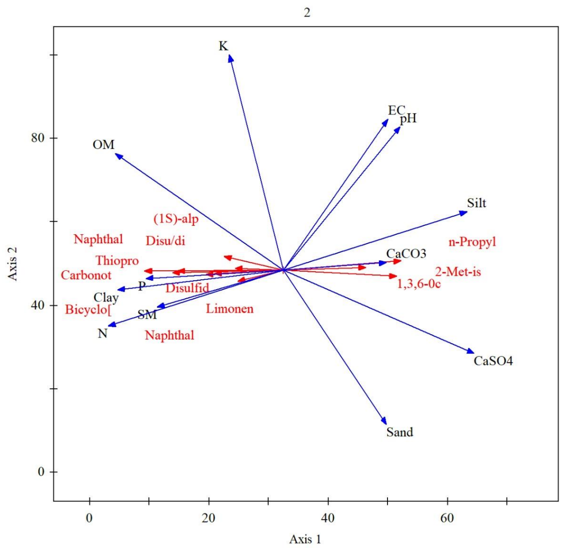

Figure 3. PCA two-dimensional ordination diagram for the volatile oil components and soil variables (Abbreviations are presented in Table 4).

Table 4. Eigenvector of the plant and soil traits for the first three PCA axes.

Parameters	Abbrv.	PC1	PC2	PC3
Amount of latex	Latex	-0.86	0.11	0.31
(1S)-alpha-Pinene,	(1S)-alph	-0.69	0.34	0.00
Bicyclo[3.1.1]heptane, 6,6-dimet	Bicyc	**-0.84**	-0.02	0.00
β-myrcene,	β-myrc	-0.62	0.35	0.23
Thiophene, 2,3,4-trimethyl-,	Thioph	0.66	-0.53	0.00
Limonen,	Limo	**-0.72**	-0.51	0.23
1,3,6-0ctatriene, 3,7-dimethyl-,	1,3,6-0ct	**0.85**	-0.03	0.00
n-Propyl sec-butyl disulfide,	n-Propy	**0.84**	0.22	-0.05
Carbonothioic dihydrazide,	Carbon	**-0.87**	-0.16	0.07
2-Methyl-1,3-dithiacyclopentane,	2-Methyl	0.21	-0.17	**-0.77**
Disulfide,	Disul	**-0.83**	0.11	-0.20
1,2-Dithiane, bis(1-methylpropyl),	1,2-Di	0.57	-0.36	0.10
2-Methyl-1-isopropyl(dimethyl)si.,	2-Methyl-	**0.88**	0.11	0.00
(-)-Aristolene,	(-)-Ari	0.39	**0.69**	0.08
Thiopropionamide,	Thiopr	**-0.90**	0.02	-0.12
Naphthalene, decahydro-4a-methyl...,	Naphth	-0.65	0.40	-0.20
Disulfide, dibutyl,	Disud	-0.17	0.24	0.15
1,4,7,-Cycloundecatriene, 1,5,9,	1,4,7,-Cy	-0.67	-0.40	0.03
(+)-Epi-bicyclosesquiphellandrene,	(+)-Epi-	0.16	0.30	**0.76**
1,2-Benzenediol, 3,5-bis(1,1-dim	1,2-Ben	0.07	-0.51	0.24
Naphthalene, 1,2,3,5,6,8a-hexahy...,	Naph1,2	**-0.77**	0.20	0.27
cis-.alpha.-Bisabolene,	cis-.alpha	-0.17	0.28	-0.60
Soil parameter		**PC1**	**PC2**	**PC3**
Electrical conductivity	EC	0.44	0.55	0.42
Acidity	pH	0.49	0.52	-0.04
Organic matter	OM	**-0.70**	0.42	0.08
Nitrogen	N	**-0.73**	-0.20	0.37
Phosphorus	P	-0.57	-0.03	-0.48
Potassium	K	-0.22	**0.78**	0.45
Sand	Sand	0.43	-0.56	0.57
Silt	Silt	**0.76**	0.21	-0.42
Clay	Clay	-0.69	-0.07	-0.16
Calcium carbonate	$CaCO_3$	0.43	0.03	0.15
Soil moisture	SM	-0.52	-0.14	0.52
Calcium sulphate	$CaSO_4$	**0.79**	-0.30	0.21

The bold and underlined coefficients have significant correlation with the relevant axes.

Table 5. Pearson correlation between soil factors and plant traits.

Factors	EC	pH	OM	N	P	K	Sand	Silt	Clay	$CaCO_3$	SM	$CaSO_4$
AB[1]	-0.32	-0.30	0.91**	0.44	0.74**	0.55*	-0.74**	-0.52*	0.76**	-0.65**	0.46	-0.91**
APMC	-0.02	-0.03	0.41	0.21	0.02	0.21	0.12	-0.02	0.01	-0.12	0.30	-0.11
NL	-0.02	-0.03	0.90**	0.37	0.65**	0.60*	-0.84**	0.38	0.63*	-0.44	0.41	-0.88**
LD	-0.52*	-0.51*	0.21	0.78**	0.93**	0.15	-0.21	-0.85**	0.94**	-0.65**	0.77**	-0.51*
IH	-0.42	-0.43	0.31	0.68**	0.77**	0.49*	-0.37	-0.72**	0.80**	-0.70**	0.70**	-0.41
ID	-0.38	-0.37	0.74**	0.52*	0.68**	0.55*	-0.61*	-0.52*	0.66**	-0.68**	0.50*	-0.89**
DCC	-0.41	-0.43	0.71**	0.60*	0.66**	0.51*	-0.52*	-0.54*	0.68*	-0.67**	0.62*	-0.79**
SPP	-0.52*	-0.50*	0.59*	0.61*	0.70**	0.49*	-0.50 *	-0.53*	0.74**	-0.75**	0.62*	-0.80**
NCU	0.21	0.23	0.68**	0.01	0.23	0.71**	-0.93**	-0.35	0.20	-0.23	0.06	-0.77**
NSU	0.31	0.33	0.63**	0.02	0.21	0.77**	-0.93**	-0.31	0.18	-0.28	0.04	-0.71**
TSW	-0.21	-0.23	0.74*	0.49*	0.61*	0.50*	-0.62*	-0.50*	0.66**	-0.66**	0.51*	-0.88**
RD	-0.54*	-0.52*	0.56*	0.74**	0.71**	0.36	-0.35	-0.90**	0.74**	-0.71**	0.71**	-0.61*
LL	-0.54*	-0.55*	0.53*	0.68**	0.73**	0.01	-0.43	-0.84**	0.73**	-0.85**	0.67**	-0.62*

[1]Abbreviations of traits are presented in Table 2; Significance: *=P<0.05;**=P<0.01.

components. Soil fertility properties such as N, P, OM, silt and SM were directly related to Naphthalene, decahydro-4a-methyl and 1, 3, 6-0ctatriene, 3, 7- dimethyl components. In previous study, Saadatfar et al. (2021) reported that there were positive and significant correlations between latex yield with the silt, OM, N and P, negative correlations between sulfurous compounds, α- Pinene, β- Pinene and Limonene with moisture, and positive correlations between these parameters with the amount of lime (Saadatfar et al., 2021). Generally, SM and soil physicochemical properties

Table 6. Pearson correlation between volatile oil components and soil traits.

Traits	EC	pH	OM	N	P	K	Sand	Silt	Clay	$CaCO_3$	SM	$CaSO_4$
(1S)-alph[1]	-0.61*	-0.58*	0.77**	0.47	0.57*	0.27	-0.37	-0.80**	0.59*	-0.74**	0.44	-0.74**
Bicyc	-0.81**	-0.78**	0.56*	0.78**	0.89**	0.11	-0.11	-0.87**	0.92**	-0.74**	0.77**	-0.23
β-myrc	0.14	0.12	-0.04	0.67**	0.33	0.08	0.11	0.14	0.42	0.13	0.66**	0.47
Thioph	-0.31	-0.33	0.52*	0.21	0.45	-0.20	-0.32	-0.45	0.34	-0.44	0.23	-0.75**
Limo	-0.71**	-0.82**	0.32	0.87**	0.72**	-0.32	-0.38	-0.78**	0.74**	-0.72**	0.88**	-0.44
1,3,6-0ct	0.52*	0.65**	-0.61*	-0.84**	-0.88**	-0.32	0.29	0.74**	-0.92**	0.85	-0.79**	0.39
n-Propy	0.61*	0.71**	-0.47	-0.88**	-0.87**	0.35	-0.10	0.77**	-0.85**	0.72**	-0.85**	0.44
Carbon	-0.72**	-0.77**	0.21	0.86**	0.72**	-0.28	0.18	-0.77**	0.76**	-0.72**	0.82**	-0.18
2-Methyl	0.52*	0.42	-0.31	-0.78**	-0.81**	0.33	-0.23	0.81**	-0.81**	0.79**	-0.76**	0.33
Disul	-0.61*	-0.72**	0.22	0.67**	0.58*	0.21	-0.05	-0.74**	0.55*	-0.76**	0.64**	-0.65**
1,2-Di	0.13	0.14	-0.21	0.31	0.21	0.03	0.13	0.07	0.13	0.04	0.33	0.14
2-Methyl-	0.62*	0.72**	0.34	0.44	0.38	0.07	0.12	0.92**	0.41	0.85**	0.42	0.23
(-)-Ari	0.01	0.11	0.21	0.12	0.11	0.02	0.13	0.08	0.08	0.12	0.13	0.21
Thiopr	-0.74**	-0.78**	0.77**	0.67**	0.66**	0.48	-0.46	-0.65**	0.62*	-0.66**	0.65**	-0.65**
Naphth	-0.62*	-0.69**	0.13	0.79**	0.77**	-0.32	-0.44	-0.87**	0.79**	-0.77**	0.77**	-0.52*
Disud	-0.34	-0.47	0.78**	0.72**	0.56*	0.61*	-0.71**	-0.77**	0.84**	-0.76**	0.68**	-0.48*
1,4,7,-Cy	0.11	0.21	0.32	0.15	0.02	0.11	0.10	0.08	0.08	0.07	0.14	0.21
(+)-Epi-	0.01	0.10	0.22	0.24	0.14	0.31	0.14	0.04	0.22	0.06	0.22	0.22
1,2-Ben	0.01	0.11	-0.12	0.31	0.22	0.12	0.21	0.03	0.23	0.11	0.30	0.31
Naph1,2	-0.67**	-0.71**	0.32	0.87**	0.76**	0.38	-0.18	-0.86**	0.74**	-0.88**	0.90**	-0.38
cis-.alpha	0.01	0.11	-0.10	0.12	0.03	0.02	0.03	0.02	0.11	0.12	0.08	0.14
Latex	-0.56*	-0.55*	0.54*	0.72**	0.77**	0.01	-0.42	-0.88**	0.75**	-0.88**	0.71**	-0.58*

[1]Abbreviations of traits are present in Table 4; Significance: *=P<0.05;**=P<0.01.

are important in changing plant available nutrients, which can change plant functions (Suchodoletz et al., 2013; Yazdanshenas et al., 2018).

Although low fertility and moisture reduced the dry matter production, stressful conditions, i.e. soil propertices, and moisture stimulated the synthesis of secondary metabolites in plants (Bistgani et al., 2017; Moghaddam and Farhadi, 2015). In this research, soil texture also showed a significant relationship with the ferula volatile oil component. In this regard, Saydi et al. (2016) reported that the composition of the mineral and chemical fertilizer containing N and P significantly increases the volatile oil in Carum plant. In fact, fertilizer application improves all soil physical and chemical properties and plant performance as well. On the other hand, Ardakani et al. (2023) studied the effect of different soil textures on morphological traits and the amount of essential oil of Lippia citriodora medicinal plant and reported that the physical properties of soil determine how the plant interacts with the soil, absorption of water and nutrients, root penetration, and the activity of microorganisms which is important in supporting plant growth and essential oil.

Overall, different micro environmental conditions affect the metabolic pathways and biosynthesis of active substances, and as a result, various primary and secondary metabolites are biosynthesized under different environmental conditions (Souza et al., 2017; Shanjani and Hoseini, 2022). And a suitable environment for organisms is mainly defined soil physicochemical properties create a microhabitat that play an important role in plant functions (Ward et al., 2016; Abreu Pestana et al., 2020; Tajik et al., 2020). This information can be considered for selecting target points for the protection, cultivation, propagation and exploitation of medicinal plants with more target oil components. Suitable environmental condition can increase asafoetida performance used to select populations with specific volatile oil components (Karimi et al., 2020).

Conclusions

In this study, the relationship between soil and morphological traits and latex production of *F. assa- foetida* under habitat conditions was evaluated in an arid area. The results showed significant relationships between plant growth factors, oil components and soil traits. Based on the findings, the asafetida growth and the reproductive traits are directly affected by the soil fertility in the natural habitat of the plant. In other words, in places with higher SM and higher amount of P and N, the factors of AB, LD, SPP and TSW significantly were increased. Also, in relation to the changes in the quality traits of latex produced by the plant, components of Bicyclo[3.1.1]heptane, 6, 6-dimet n- Propy, 3, 7-dimethyl-, Carbonothioic dihydrazide, Thiopropionamide, and Naphthalene, 1, 2, 3, 5, 6, 8a-hexahy showed the highest values and were strongly influenced by soil fertility factors ($P < 0.01$). However, future researches are necessary to study the effect of soil compaction traits and root morphology on plant performance and quantitative and qualitative properties of produced latex in *F. assa- foetida* plant. Also, the effect of latex exploitation methods and the impact of exploitation times can be taken into consideration with economic goals in the future.

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Authors contributions
All authors have contributed equally to prepare the paper.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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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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