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Polymorphism of morphological characteristics of *Ferula foetida (*Bunge) Regel in the natural populations of the Mangyshlak peninsula

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Abstract.

A study of the polymorphism of *Ferula foetida* (Bunge) Regel growing in natural populations of Mangyshlak was performed and the basic morphological growth indicators and correlations both between themselves and with the basic soil-amelioration parameters of the growing habitat were found. The possibility of determining the medicinal raw material reserves of *Ferula foetida (*Bunge) Regel by the salinity and particle-size distribution of the soil was revealed. The extrapolation dependences, determined as a result of the research, may be used to forecast reserves of medicinal raw materials of *Ferula foetida (*Bunge) Regel.

Keywords: correlations, *Ferula foetida (*Bunge) Regel, forecast, medicinal raw materials, polymorphism, populations, regression.

INTRODUCTION

The Mangyshlak peninsula is the territory of an ancient civilization, an open-air archaeological reserve. In the first millennium BC, the Great Silk Road from Khorezm and Khiva to Europe and the Middle East passed there. The economic rise of the region was due to the discovery in the early 1950s of the largest deposits of uranium, rare-earth elements, oil and gas in the depths of the Mangistauskaya Oblast situated on the territory of the Mangyshlak peninsula. Proven oil reserves in the region are estimated at 3 billion tons. On the surface throughout the region, limestone-shell rock is very common and widespread distribution of strontium has been revealed. The largest deposits are Aurtashskoye, Ungozinskoye, and Uchkuyukskoye. In the mountainous part of the region, phosphate rocks, iron ores, and manganese were found. The explored reserves of the latter are estimated at 2.7 million tons. Deposits of copper, salt, mirabilite, thenardite, and chalk were also revealed [1].

Along with the minerals, the natural flora of Mangistau features *Ferula foetida (*Bunge) Regel, *F. dubjanskyi* Korovin ex Pavlov, *F. lehmannii* Boiss, and *F. nuda* Spreng. The most economically promising for practical use as a medicinal plant and spice in cooking is *Ferula foetida (*Bunge) Regel, which forms natural populations with commercially valuable resource reserves in the Mangyshlak peninsula's environment [2-5].

Figure 1. *Ferula foetida (*Bunge) Regel

*Ferula foetida (*Bunge) Regel is a perennial herb of Apiaceae (Umbelliferae) family (Figure 1). The plant's root juice is used to produce a spice and medication [6]. Dried latex extracted from the plant's roots is used as a spice in cooking.

The plant's height can reach up to 1.5 m. Every year, there is a short period of its rapid growth and development. The growth rate of generative shoots is 17 cm per day. The underground part of the plant typically has a very overgrown napiform root. In the 7–9th year, a thick tapered stem of *Ferula foetida* (Bunge) Regel develops. During this period, the plant forms a basal rosette. Leaves are triangular, long-petiolate, pinnately dissected in multiple places with oblong-lanceolate end segments. The number of leaves depends on the plant's age. Apical leaves have a shorter petiole and sometimes are represented with a single sheath. Flowers of the plant are pale yellow, clustered in umbels, without the wrapper, and forming large inflorescence. The plant's fruit is a cremocarp, split into two one-seeded pericarps with very wide boundary edges when ripening.

Finding it in mid-April, the fruit pickers of *Ferula foetida* (Bunge) Regel dig around the plant, exposing the roots, remove dry leaves, and clean the roots' apex. After that, they cover the roots with loose soil and then with a rock from the top. The first stage of preparation for harvesting is completed. About a month later, in the second half of May, they expose the roots again and cut off the top part just below the junction with the leaves. At the cut-off, the juice appears, which turns brown in the air and hardens in the form of latex. Above the cut-off, a shelter is made in order to protect it from sunlight and dust. 2 days later, latex is collected and a new cut is made. Next time, latex is collected after 5 days. The third time, the operation is repeated after 10 days, etc., until the juice no longer oozes. Each plant can produce from 900 to 1300 g of fresh latex. The root juice of *Ferula foetida* (Bunge) Regel is used to make spice [7].

The spice is made from the dried milky juice of the plant root that is a brown plastic mass. *Ferula foetida* (Bunge) Regel is usually sold as dried pure resin or as so-called compounded or mixed *Ferula foetida* (Bunge) Regel, which consists of a fine powder of ground latex mixed with rice flour and gum arabic. In this form, *Ferula foetida* (Bunge) Regel is easy to dose. At the same time, compounded *Ferula foetida* (Bunge) Regel quite quickly loses its flavor, while resin can be stored for years. Active ingredients of the plant are resin, containing up to 60% of ferulic acid ester, azariassitannol, coumarins, essential oil, vanilla, and other substances [6].

Representatives of *Ferula foetida* (Bunge) Regel genus grow in the east of the Mediterranean region, in Central Asia, Afghanistan, Pakistan, Iran, Turkey, Italy, and China [8]. In total, this generic

family numbers 170 species around the world, of which 52 grow on the territory of Kazakhstan [9].

The ecological group of *Ferula foetida* (Bunge) Regel is xerophyte, psammofit, geliofit, indifferent and ephemeroid [10].

Currently, the demand for drugs of natural origin significantly increases in developed countries, despite the high level of industrial production of synthetic pharmaceutical drugs. In Kazakhstan, herbal remedies are also in the high light. Up to 40% of pharmaceutical products contain the substances of natural origin.

The world vegetation numbers about 300 thousand species of higher plants, but the humanity only uses one hundredth of them. The world natural flora has a large reserve of useful plants, among which there is a significant proportion of medicinal herbs.

The market price of the root of *Ferula foetida* (Bunge) Regel reaches USD1200 per ton. The price of the resin of *Ferula foetida* (Bunge) Regel is USD 20-40 per kilogram. The price of seeds of *Ferula foetida* (Bunge) Regel is up to USD80 per kilogram [7]. The high cost of *Ferula foetida* (Bunge) Regel processing products is due to the fact that they are widely used as fodder, mellifluous, medicinal materials, primitive building material.

In 2010 alone, according to the Ministry of Agriculture of the Republic of Kazakhstan, the yield of *Ferula foetida* (Bunge) Regel in the country reached about 300 tons. The processing products of this plant are estimated at USD10-15 million [7].

Given the economic attractiveness and feasibility, ease of industrial processing of *Ferula foetida* (Bunge) Regel, we selected different age (1–7-year) natural communities of *Ferula foetida* (Bunge) Regel. These communities are located in the Tuyesu and Karynzharyk sand areas, the western and southern parts of the Tynymbay Shoky hill, Karaadyr plot, and on the northern slope of the Burma mountain.

The article deals with the study of the 17 aboveground part and 16 root growth rates (Table 1). At the depth of the bedrock in the dense gravelly-pebbly level (80–100 cm), we performed stratified soil sampling followed by determination of the main indicators of the state of its salt, solonetz, nutrient, and water-physical conditions. The experimental data were processed by mathematical statistics methods using the statistical software package Statgraphics Centurion XVI.I.

The Tuyesu sand area is located in the southern part of Mangyshlak peninsula, where *Ferula foetida* (Bunge) Regel grows in *Haloxylonaphyllum – Ferula foetida – Artemisia sanltolina, Ferula foetida – Herbaxerophytica – Haloxylonaphyllum,* and *Haloxylonaphyllum – H.persarum – Ferula foetida – Krascheninnikowia ceratiode* communities. The dominant plant in the community is *Haloxylonaphyllum,* the codominant plant is *Ferula foetida*. The object features sandy and sandy loam soil, saturated with shallow fresh waters, including drinkable perched water. The groundwater depth is from 3–5 to 41 m. The thickness of the watery part of aeolian sand areas ranges from 5.0 to 33.3 m. The Tynymbay Shoky hill is located near the Kunabay mountain. The population of *Ferula foetida* (Bunge) Regel there appears as part of *Artemisia terrae-albae – Ferula foetida – Anabasis salsa* and *Artemisia terrae-albae – Ferula foetida – Arthrophytum lehmannianum* communities. At depths of 30 cm and less, the soil is sandy loam, from 30 cm to 50 cm, it is loamy, and between 50 and 100 cm, the soil is moderately loamy. Soil salinity is low at the depth of 50 cm, moderate at the depth of 50–80 cm, and high of 80–100 cm. Watering in this area is low, so plants receive moisture from precipitation and groundwater of various salinity.

The Karynzharyk sand area is located in the southwestern part of the Karynzharyk basin. The soil there is sandy and sandy loam, non-saline throughout the genetic profile. The Karynzharyk sand area is substantially anhydrous. In some areas, there is groundwater. *Ferula foetida* (Bunge) Regel is widespread there as a part of the composition of *Haloxylonpersicum – Artemisiasantolina – Herbaxerophytica – Ferula foetida, Artemisiakemrudica – Ferula foetida – Herbaxerophytica– Haloxylon persarum,* and *Carex physode – Artemisia santolina - Art.kemrudica – Ferula foetida – Haloxylonpersium* communities.

At a distance of 8–10 km to the east from the Karaadyr plot, *Ferula foetida* (Bunge) Regel was found on sandy loam areas in *Artemisia terrae-albae - Art.arenaria – Ferula foetida – Haloxylonpersium – Calligonumleucocladum* communities. At a depth of up to 80–100 cm, salinity is low. Soil permeability is high. Watering of natural populations is very low, plants receive moisture only from precipitation.

On the territory of the Burma mountain, *Ferula foetida* (Bunge) Regel was found at low eroded slopes with slightly saline loamy soils of medium density. These places are characterized by sparse *Artemisia terrae-albae – Ferula foetida – Agropyron fragile* communities. The water content in this area is very low. Plants receive moisture mainly from precipitation. The soil at depths of up to 50 cm belongs to the non-saline category. Salinity is moderate at a depth of 50–80 cm and low at 80–100 cm. Water permeability of the soil is classified as moderate (https://foragro.ru/catalog/spice/asafetida).

RESULTS AND DISCUSSION

It was found (Table 1, Figure 1) that *Ferula foetida (*Bunge) Regel most intensively grows at elevated areas in the population of the Tuyesu sand area (49.4 cm), and slower in the Karynzharyk sand area (43.8 cm), Karaadyr plot (44.1 cm), and on the northern slope of the Burma mountain (42.3 cm). It has the smallest size on the sandy loam areas in the western part of the Tynymbay Shoky hill (36.0 cm). By root penetration depth, there is another proportion (Figure 1): the southern part of the Tynymbay Shoky upland (112.8 cm), the northern slope of the Burma mountain (111.1 cm), the western part of the Tynymbay Shoky upland (109.3 cm), the Karaadyr plot (109.1 cm), the Karynzharyk sand area (106.1 cm), and the Tuyesu sand area (91.6 cm). Rapid root growth in these populations on the Tynymbay Shoky upland is due to the adaptive response to a deeper groundwater level and the favorable impact of the ratio of the upper and lower unconsolidated sandy layers and moderately loamy, highly stony layers of the soil. Its high salinity does not limit the process.

The value of the stem diameter of *Ferula foetida* (Bunge) Regel correlates with the plant height values. There is no correlation between the root collar diameter and the general development of the root rhizosphere (Table 1, Figure 1). The order of the populations by the root collar diameter reduction is: the Tuyesu sand area (17.4 cm), the Karaadyr plot (15.0 cm), the Karynzharyk sand area (14.2 cm), the southern part of the Tynymbay Shoky hill (13.5 cm), the western part Tynymbay Shoky hill (12.9 cm), and the northern slope of the Burma mountain (12.2 cm).

By Student's *t*-test ($t_f<t_{05}$), the correlation of *Ferula foetida (*Bunge) Regel stem height and the root system depth in the natural population of Mangyshlak is not statistically valid, which to our view proves its belonging to a certain niche, in which it mainly develops similarly in morphological terms. As can be seen from Table 2, the difference in stem height is substantial by the significance 5% ($t_f>t_{05}$) only between the communities in the Tuyesu sand area and on the Tynymbay Shoky hill (t_f=2.51-3.74), as well as between the western part of the Tynymbay Shoky hill, the Karynzharyk sand area (t_f = 2.11), and the Karaadyr plot (t_f = 2.26).

Table 1. Isomers of the aboveground and underground parts of *Ferula foetida* (Bunge) Regel in natural populations of Mangyshlak

Indicator	Tuyesu sands	The western part of the Tynymbay Shoky hill	The southern part of the Tynymbay Shoky hill	Karynzharyk sands	The Karaadyr plot	The northern slope of the Burma mountain
Aboveground part						
Plant height, cm	49.4±3.2	36.0±1.7	39.4±2.4	43.8±3.3	44.1±3.2	42.3±4.1
Stem diameter, cm	14.7±1.4	15.4±2.6	19.2±2.4	15.8±0.8	14.9±1.0	10.9±1.4
Number of basal rosettes	4.0±0.4	4.2±0.5	4.0±0.4	4.0±0.4	3.9±0.3	4.3±0.5
Leaf length in the 1st rosette, cm	12.8±0.8	10.2±0.7	11.4±0.6	9.3±0.4	13.3±1.7	10.4±0.9
Leaf width in the 1st rosette, cm	4.6±0.3	3.5±0.4	3.4±0.2	3.1±0.1	3.3±0.1	3.7±0.3
Leaf biomass, g	329.2±48.6	222.4±43.0	-	449.6±71.9	481.0±72.4	142.9±39.2
Underground part						
Number of main root branching	4.0±0.3	4.0±0.3	3.7±0.4	3.9±0.4	4.0±0.3	3.6±0.5
Depth of the root system, cm	91.6±7.8	109.3±8.3	112.8±7.6	106.1±7.6	109.1±8.7	111.1±16.4
Length of the main root to branching, cm	34.8±2.9	34.99±3.0	39.0±3.2	38.7±2.8	45.1±2.7	30.1±1.8
Diameter of the root collar, cm	17.4±2.7	12.9±1.3	13.5±1.3	14.2±1.1	15.0±1.2	12.2±1.8
Diameter of the middle part of the main root, cm	18.0±1.1	15.92±1.2	17.7±1.2	21.1±1.7	18.9±1.8	13.8±1.4
Diameter of the end part of the main root, cm	2.4±0.2	2.8±0.3	2.1±0.2	2.4±0.2	2.8±0.3	2.8±0.4
Number of rootlets	4.8±0.48	5.6±0.9	4.4±0.4	4.6±0.4	4.3±0.5	3.7±0.4
Length of rootlets, cm	14.3±0.7	16.7±0.9	17.2±0.8	15.5±0.7	13.0±1.2	16.8±3.0
Length of roots of the 1st branching, cm	59.7±5.6	55.7±5.0	55.8±4.0	55.1±5.4	54.0±5.7	65.6±8.0
Root weight, g	2505.7±476.0	1013.0±245.1	1690.0±357.1	1010.0±162.9	1039.6±169.7	489.1±144.2

Table 2. The correlation ratio by Student's *t*-test of *Ferula foetida* (Bunge) Regel's stem height and root system depth for the Mangyshlak population (the critical value of Student's *t*-test at the significance level of 5% is 2.09)

Indicator of ferrule population	Tuyesu	The western part of the Tynymbay Shoky hill	The southern part of the Tynymbay Shoky hill	Karynzharyk sands	The Karaadyr plot	The northern slope of the Burma mountain
Stem height						
The Tuyesu sands		3.74	2.51	1.22	1.20	1.38
The western part of the Tynymbay Shoky hill	3.74		1.16	2.11	2.26	1.42
The southern part of the Tynymbay Shoky hill	2.51	1.16		1.08	1.17	0.61
The Karynzharyk sands	1.22	2.11	1.08		0.05	0.29
The Karaadyr plot	1.20	2.26	1.17	0.05		0.34
The northern slope of the Burma mountain	1.38	1.42	0.61	0.29	0.34	
Depth of the root system						
The Tuyesu sands		1.55	1.94	1.32	1.49	1.07
The western part of the Tynymbay Shoky hill	1.55		0.31	0.29	0.02	0.10
The southern part of the Tynymbay Shoky hill	1.94	0.31		0.62	0.32	0.09
The Karynzharyk sands	1.32	0.29	0.62		0.26	0.28
The Karaadyr plot	1.49	0.02	0.32	0.26		0.11
The northern slope of the Burma mountain	1.07	0.10	0.09	0.28	0.11	

While within one population, the correlation ratio between the majority of isomers of the aboveground and underground parts of *Ferula foetida (*Bunge) Regel is equal to 0.8–0.9, it decreases to the value of 0.5–0.7 for all the studied communities due to the influence of several soil-amelioration factors: moisture supply, soil texture, salinity, alkalinity, etc. (Table 3). All growth indicators are statistically valid ($r_f > r_{05}$) and correlate with the plant age. Plant height is most closely related ($r_f > 0.70$) with the number of basal rosettes and number of branches from the main root, as well as the penetration depth of the root system. The stem diameter, leaf size parameters, the length of the main root to branching and rootlets on lateral roots correlates less with other morphological parameters (r_f = 0.01–0.54). Most parameters of the aboveground and underground parts of *Ferula foetida (*Bunge) Regel have high correlation ratios ($r_f > 0.70$) with quantitative isomers, which in turn closely correlate with the age characteristics of the populations.

Table 3. The correlation matrix of isomers of the aboveground and underground parts of *Ferula foetida (*Bunge) Regel in the natural populations of Mangyshlak (the critical value of the correlation ratio at the significance level of 5% is 0.44)

Indicator	Age, in years	Plant height	Stem diameter	Number of basal rosettes	Leaf length of the 1st rosette	Leaf width	Number of branches from the main root	Depth of the root system	Length of the main root to the branching	Diameter of the root collar	Number of rootlets	Length of rootlets	Length of the roots of the 1st branch
Age, in years		0.78	0.44	0.94	0.48	0.54	0.92	0.86	0.46	0.66	0.73	0.45	0.69
Plant height, cm	0.78		0.32	0.75	0.38	0.47	0.77	0.71	0.34	0.60	0.50	0.37	0.62
Stem diameter, cm	0.43	0.32		0.34	0.12	0.05	0.39	0.39	0.11	0.35	0.29	0.13	0.28
Number of basal rosettes	0.94	0.75	0.34		0.48	0.60	0.88	0.80	0.43	0.63	0.68	0.43	0.71
Leaf length in the 1st rosette, cm	0.48	0.38	0.12	0.48		0.51	0.44	0.42	0.26	0.29	0.36	0.14	0.37
Leaf width in the 1st rosette, cm	0.54	0.47	0.05	0.60	0.51		0.52	0.43	0.41	0.38	0.48	0.13	0.46
Number of branches from the main root	0.92	0.77	0.39	0.88	0.44	0.52		0.82	0.40	0.63	0.72	0.45	0.68
Depth of the root system, cm	0.86	0.70	0.39	0.80	0.42	0.43	0.82		0.47	0.48	0.59	0.53	0.61
Length of the main root to branching, cm	0.46	0.34	0.11	0.43	0.26	0.41	0.40	0.47		0.29	0.37	0.01	0.28
Diameter of the root collar, cm	0.66	0.60	0.35	0.63	0.29	0.38	0.63	0.48	0.29		0.59	0.34	0.40
Number of rootlets	0.73	0.50	0.29	0.68	0.36	0.48	0.72	0.59	0.37	0.59		0.30	0.43
Length of rootlets, cm	0.45	0.37	0.13	0.43	0.14	0.13	0.45	0.53	0.01	0.34	0.30		0.46
Length of roots of the 1st branching, cm	0.69	0.62	0.28	0.71	0.37	0.46	0.68	0.61	0.28	0.40	0.43	0.46	

Table 4. Variability of main isomers of the aboveground and underground parts of *Ferula foetida (*Bunge) Regel in natural populations in Mangyshlak, %

Indicator	Tuyesu sands	The western Part of the Tynymbay Shoky hill	The southern part of the Tynybay Shoky hill	Karynzharyk	The Karaadyr plot	The northern slope of the Burma mountain
Aboveground part						
Plant height, cm	37.5	26.6	35.7	43.4	41.3	44.5
Stem diameter, cm	57.1	97.9	72.4	27.9	37.8	57.8
Number of basal rosettes	54.0	62.4	55.6	56.1	49.5	57.6
Leaf length in the 1st rosette, cm	34.5	38.8	33.1	11.8	49.4	39.7
Leaf width in the 1st rosette, cm	36.5	59.5	40.4	25.9	18.2	36.6
Leaf biomass, g	86.1	91.2	-	91.9	86.4	95.9
Underground part						
Number of branches from the main root	41.9	45.5	56.4	52.9	47.7	62.1
Depth of the root system, cm	50.1	43.5	39.0	41.3	46.0	67.6
Length of the main root to branching, cm	37.8	38.6	37.9	30.9	24.1	17.7
Diameter of the root collar, cm	89.5	58.1	56.5	44.3	47.5	69.2
Diameter of the middle part of the main root, cm	35.9	42.0	40.8	46.4	54.0	47.6
Diameter of the end part of the main root	46.3	64.3	49.2	58.7	67.1	64.4
Number of rootlets	53.1	89.8	48.1	54.5	61.5	51.2
Length of rootlets, cm	29.5	30.3	28.3	25.3	51.9	81.4
Length of roots of the 1st branching, cm	54.9	52.0	42.3	56.7	60.8	55.7
Root weight, g	90.8	89.0	93.2	92.7	93.8	95.1

In all the studied populations, the vast majority of biometric parameters demonstrate very high variability (up to 54–98%)(Table 4), except for the leaf size and the main root length to the branching (12–49%), which is explained by the fact of almost proportional participation of different age plants in the formation of the populations' composition. At the same time, the variability of isomers of both aboveground and underground parts within each age group decreases by several times (<10%) and remains stable for the entire spectrum of the Mangistau habitat.

Regardless of the growing conditions, the typical feature of the age morphogenesis of *Ferula foetida (*Bunge) Regel is the annual formation of one basal rosette of leaves, root branching, and a rootlet on lateral roots, as illustrated by the example of the Tuyesu sand area population (Figure 2).

Ferula foetida (Bunge) Regel most actively develops by many morphological parameters, including the root height and depth, in the first 3–4 years (Figure 2). Starting from 5–6th year, in the period of accession to the generative phase, the growth gradually

slows down and even ceases, regardless of edaphic conditions of natural populations, in particular, it is typical of communities in the Karynzharyk sand area and the northern slope of the Burma mountain.

The opposite trend is observed for the root weight (Table 5). Roots most intensively form starting from 4th year and until the end of the plant's life, as evidenced by the exponential types of dependencies for all the surveyed populations in the Mangistau region.

The share of the weight of the underground pharmaceutically valuable part of *Ferula foetida (*Bunge) Regel is up to 40–85% of the total raw phytomass of plants (Figure 3, Table 6). Not in all cases, the development of the aboveground phytomass guarantees more intensive formation of the root system. In this case, *Ferula foetida (*Bunge) Regel adaptively responds to the formation of a larger succulent underground structure in order to accumulate moisture and consume it economically by means of the under-developed assimilation apparatus of the plants according to the specific environmental conditions.

Among all anatomical organs, the most interesting one in *Ferula foetida (*Bunge) Regel in terms of productivity and content of medicinal ingredients is the root system [10] (https://foragro.ru/catalog/spice/asafetida), the weight of which along with the aggregate salinity, alkalinity percentage, humus content, and the content of physical clay in the soil was selected within the research as dependent and independent variables in developing regression equations for the forecast of the medicinal raw materials reserves.

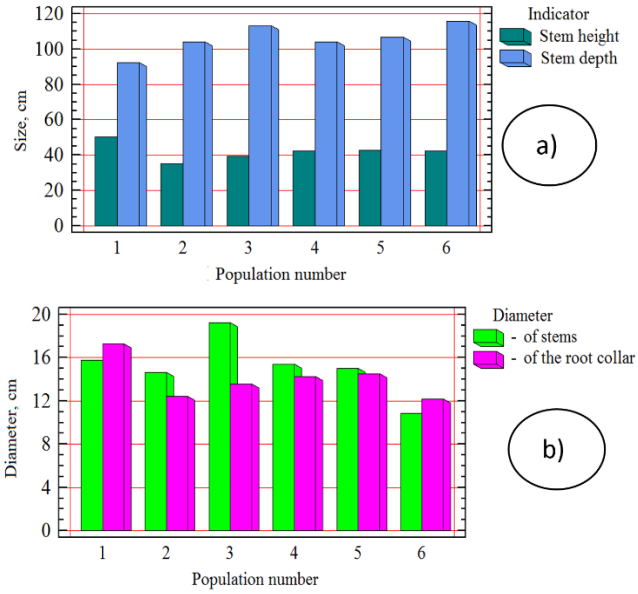


Figure 1. The correlation of indicator values between the natural populations of Ferula foetida (Bunge) Regel by the stem height and root system depth; b) by the diameter of stems and root collar (1 - Tuyesu sands, 2 - the western part of the Tynymbay Shoky hill, 3 - the southern part of the Tynymbays Soky hill, 4 - Karynzharyk sands 5 - Karaadyr plot, 6 - the northern slope of Burma mountain)

Table 5. Extrapolation dependence of the root weight (RW) on the age (A), (η_{kr05} = 0.32)

Extrapolation dependence	Dislocation
RW=1/(-0.000385199+0.0303924/A)	*The northern slope of the Burma mountain(η =0.92)*
RW=exp(3.33083+2.43875lnA)	*The Karaadyr plot(η = 0.95)*
RW=exp(3.97524+1.94835lnA)	*The Karynzharyk sands (η = 0.96)*
RW=exp(3.85496+0.714394lnA)	*The southern part of the Tynymbay* Shoky hill *(η = 0.90))*
RW=exp(4.64141+1.9388lnA)	*The Tuyesu sands (η = 0.92)*
RW=exp(3.47597+2.02211lnA)	*The western part of the Tynymbay* Shoky hill *(η = 0.92))*

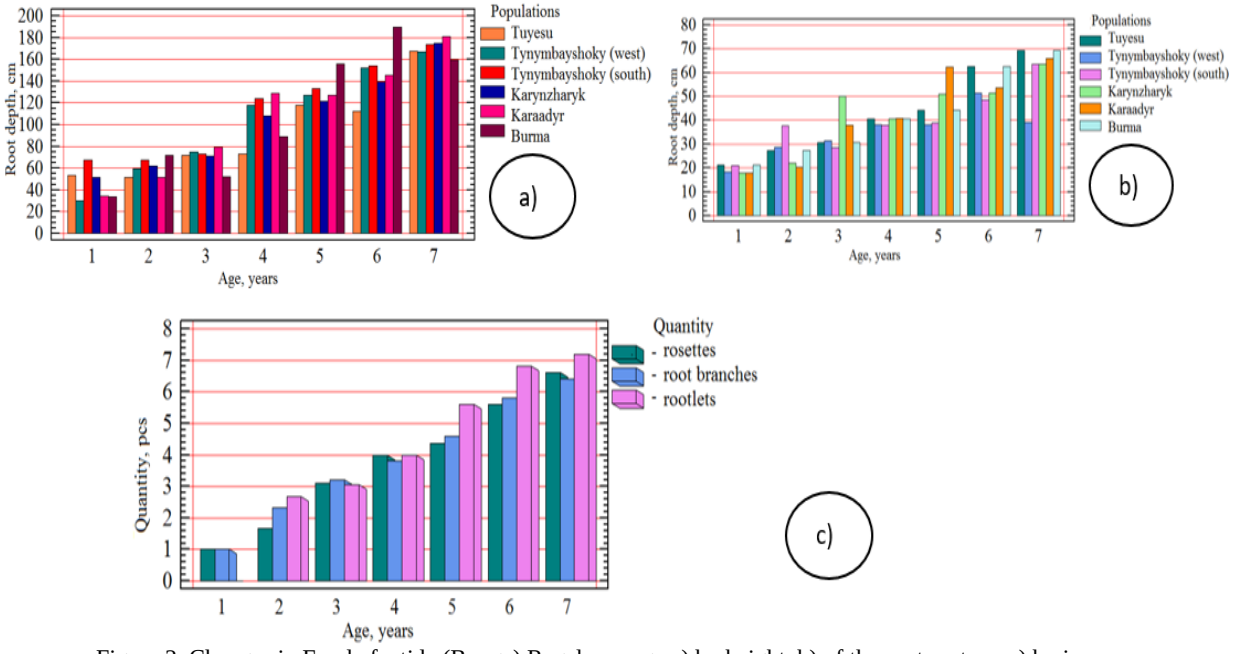


Figure 2. Changes in Ferula foetida (Bunge) Regel overage a) by height, b) of the root system, c) by isomers

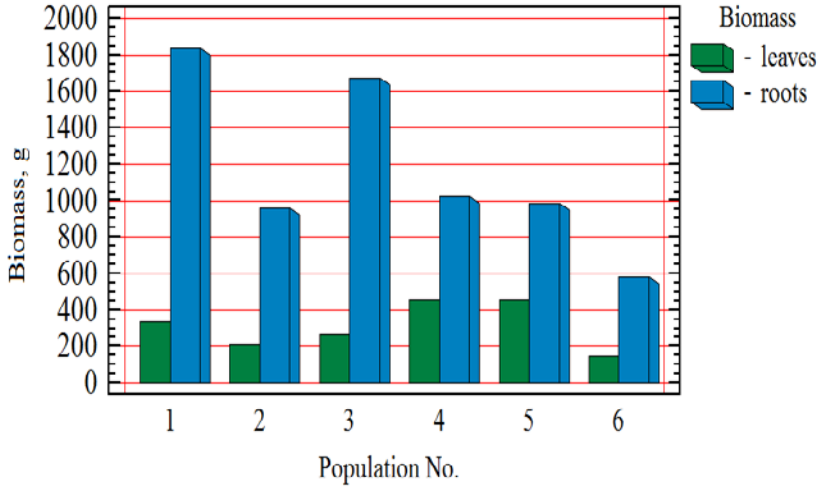


Figure 3. The relationship between natural populations of Ferula foetida (Bunge) Regel biomass of leaves and roots (1 - the Tuyesu sand area, 2 - the western part of the Tynymbay Shoky hill, 3 - the southern part of the Tynymbay Shoky hill, 4 - the Karynzharyk sand area, 5 - the Karaadyr plot, 6 - the northern slope of the Burma mountain)

Table 6. The biomass of the aboveground and underground parts of *Ferula foetida (*Bunge) Regel in natural populations of Mangyshlak in the flowering stage, g of raw weight

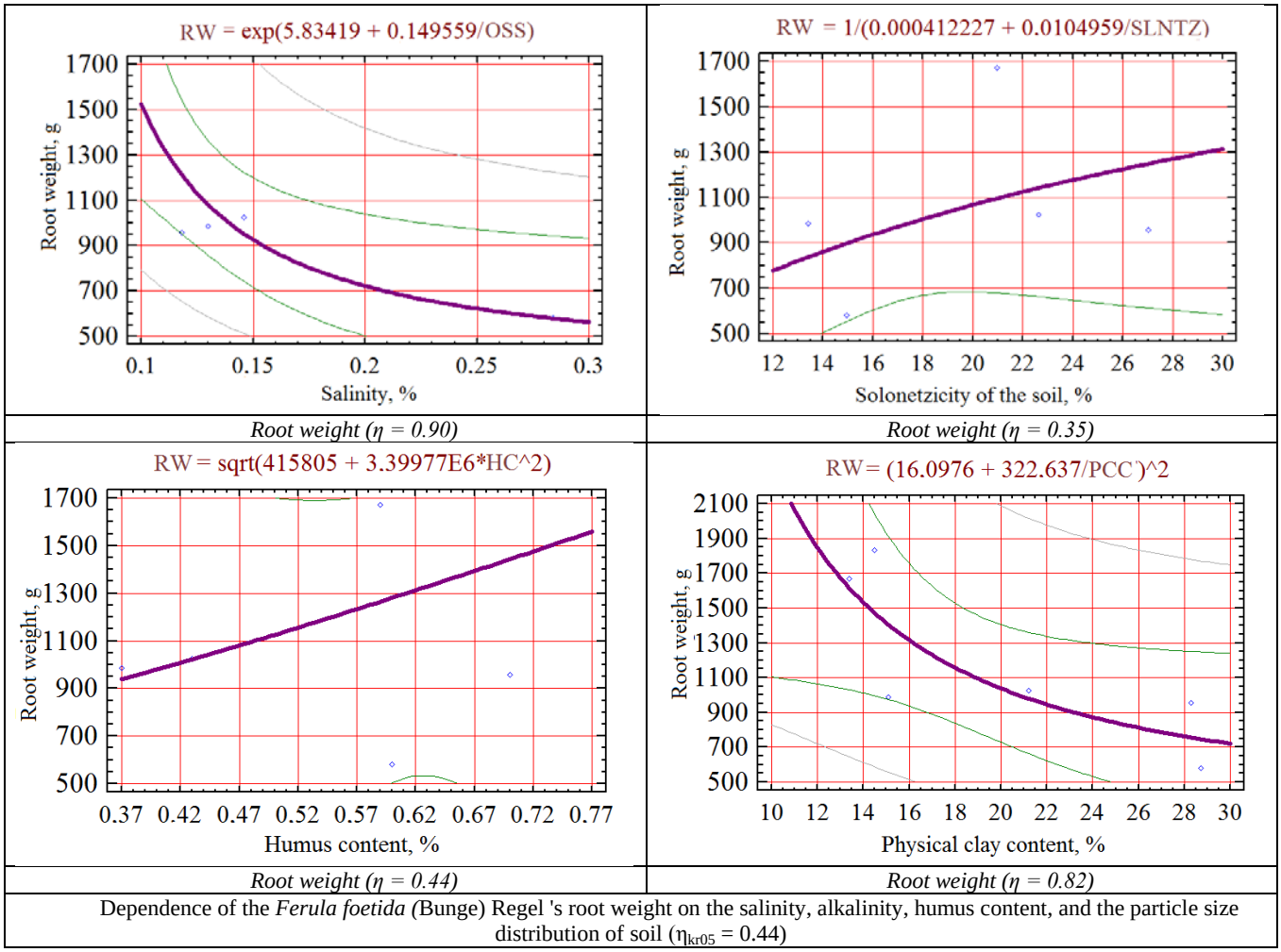
The sand area of of Tuyesu		The western part of the Tynymbay Shoky hill		The southern part of the Tynybay Shoky hill		The sand area of of Karanzharyk		The Karaadyr plot		The northern slope of the Burma mountain	
g	%	g	%	g	%	g	%	g	%	g	%
Leaf biomass											
521±7.7	18.0	75±1.3	6.1	376±7.1	5.2	613±7.3	15.8	523±3.4	9.2	148±0.7	5.0
Stem and inflorescence weight											
620±7.1	21.5	672±12.0	54.1	674±7.2	9.5	997±11.9	25.5	1619±7.9	28.5	1280±8.3	44.0
Aboveground part weight											
1141±14.7	39.5	747±13.4	60.1	1050±14.3	14.8	1615±19.2	41.4	2143±11.0	37.8	1428±8.7	49.1
Root weight											
1746±17.6	60.5	494±8.3	39.8	6060±69.0	85.2	1476±17.5	37.8	3536±22.7	62.2	1480±9.7	50.8
Total plant weight											
2887±32.0	100.0	1242±21.7	100.0	7110±83.2	100.0	3901±36.8	100.0	5680±33.2	100.0	2908±18.3	100.0

Table 7. Correlation of the *Ferula foetida (*Bunge) Regel root weight with the main soil-amelioration factors in natural populations in Mangyshlak (the critical value of the correlation ratio at 5% significance is 0.44)

Saline content, %				Solonetzicity in the 0–50 cm layer, %	Content of humus in the 0–50 cm layer, %	Content of physical clay, %				Depth of loose soil strata, cm
soil layer, cm						soil layer, cm				
0-30	0-50	50-100	0-100			0-30	0-50	50-100	0-100	
0.67	0.76	0.67	0.75	0.11	0.36	0.69	0.86	0.78	0.79	0.26

For the dependence of the root system weight on the basic soil-amelioration indicators, the statistically valid correlations ($\eta > \eta_{kr05}$) with the total salt and physical clay (particles less than 0.01 mm) content of, respectively, the exponential and quad form are of the greatest interest. Figure 4 presents regression equations with the indicators of salinity and particle-size distribution on the average across the entire studied soil layer, although their correlation is valid at the significance level of 5% also for other genetic-amelioration levels: 0–30, 0–50, and 50–100 cm (Table 7). Even with no or weak salinity, the increase in the salt content leads to a sharp decrease in productivity of the underground phytomass of *Ferula foetida (*Bunge) Regel, as well as the transition of the particle-size distribution from sandy loam to light loam.

The established correlations for alkalinity and humus content in the soil are not statistically valid and cannot be used for the forecast of medicinal raw material reserves in the underground part of *Ferula foetida (*Bunge) Regel (Table 7).



Root weight (η = 0.90) | *Root weight (η = 0.35)*

Root weight (η = 0.44) | *Root weight (η = 0.82)*

Dependence of the *Ferula foetida (*Bunge) Regel 's root weight on the salinity, alkalinity, humus content, and the particle size distribution of soil (η_{kr05} = 0.44)

Figure 4. Regression equations with the indicators of salinity and particle-size distribution on the average across the entire studied soil layer

CONCLUSION

The performed study found that a considerable difference (at 5% significance) in the stem height of *Ferula foetida (*Bunge) Regel is observed only between the communities in the Tuyesu sand area, Karaadyr plot, and Tynymbay Shoky hill, which markedly differ by watering and soil-particle distribution.

Within the same community, the correlation ratio between the majority of isomers of the aboveground and underground parts is very high (0.8–0.9). Although, in general, for all the studied populations, it decreases to a value of 0.5–0.7 due to the influence of soil-amelioration factors. The stem height is in correlation with the number of basal rosettes and branches from the main root, as well as the overall depth of the root rhizosphere. The length of the main root to branching and rootlets on lateral roots, stem diameter, and lamina length and width is associated with biometric indicators in the least extent. The growth parameters of Asafoetida are statistically correlated with its age. This type of Asafoetida is exposed not to interpopulation (and/or intraspecific), but age variation, unlike certain representatives of desert ephemeroid flora.

Plants of all ages take part in the composition formation of *Ferula foetida (*Bunge) Regel populations, which explains very high variability (up to 54–98%) of growth isomers, although within each age group, the variability of morphological parameters is much lower (<10%) and stays at a constant level for the full range of habitat conditions in the Mangistau region. A characteristic feature of the age morphogenesis of *Ferula foetida (*Bunge) Regel is the annual formation of leaves on the basal rosette, root branching, and rootlets on lateral roots. The morphological isomers of *Ferula foetida (*Bunge) Regel most intensively develop in the first three to four years. During the entry into the generative phase (5–6 years), there is a gradual deceleration of growth regardless of soil-amelioration conditions in the natural communities. A totally opposite trend was revealed for the root weight, the formation of which reaches its maximum activity from the 4th year and to the end of the plant life.

It was found that the weight of the most valuable, underground, part of *Ferula foetida (*Bunge) Regel makes up to 40–85% of the total phytomass and its maximum relative share is observed in moderately rocky sandy and sandy loam soils with deep-seated groundwater. The intensive development of the aboveground part of *Ferula foetida (*Bunge) Regel ensures the intensive formation of the root rhizosphere, as adaptive response takes place by the way of the succulent root structure formation for moisture accumulation and balanced evaporation through the less-developed leaf apparatus.

The revealed regularities of the morphological characteristics change between natural populations depending on the age confirm the characteristic of this type in the Mangistau environment, as a weakly salty ephemeroid, psammophyte, oligotroph, and petrophyte, which allows successfully competing with other desert plants, occupying specific habitats. The established dependences between the root system weight and the salinity and particle-size distribution of the soil may be used in the forecast of the reserves of medicinal raw materials in the underground part of *Ferula foetida (*Bunge) Regel in natural populations of Mangyshlak

desert. Having the density of plants determined during field works, we can easily estimate centner and ton based on the weight of a single plant. Based on the total area we can easily recalculate the researched natural population.

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