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Bio-morphological properties of *Ferula tadshikorum* Pimenov and *Ferula foetida* (Bunge) Regel under plantation conditions

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Abstract

Ferula foetida (Bunge) Regel and *Ferula tadshikorum* Pimenov are widely used in folk medicine and in the pharmaceutical industry. As a result of their use in the pharmaceutical industry, their populations are widely declining. This article presents the bio-morphological characteristics of *F. foetida* and *F. tadshikorum* under plantation conditions. In 2014-2021, plantations of *F. foetida* and *F. tadshikorum* were established on 20 hectares of arable land in Arnasay district, Jizzakh region, Uzbekistan. In February, March, April, and May 2018-2020, the growth dynamics, size of leaves and the morpho-biological classification of roots of 2 to 6-year-old *F. foetida* and *F. tadshikorum* were studied under plantation conditions. In the second year, both species had 2 whole normal leaves and from the third to the sixth-year different numbers of leaves were developed depending on the age of the plant and the remains of last year's leaf petiole were maintained at the base of the plant. The shape and color of the roots differed, with *F. tadshikorum* roots being cylindrical, dark brown and *F. foetida* barrel-shaped and light liver-colored. All experiments were carried out in arable and conditionally irrigated areas characterized by relatively low rainfall and gray and gray-grass-type soils. During the 1st to 6th year of growth of *F. tadshikorum* and *F. foetida* specific features of their bio-morphological characteristics under new growth conditions were studied and it was found that they could be planted in unirrigated areas.

Keywords

Apiaceae, *Ferula tadshikorum, Ferula foetida,* leaf, plantation, root, vegetation

Introduction

Due to the growing demand for medicinal plants as a result of the development of the pharmaceutical industry around the world, the conservation of their populations, identification of rare and economically important species, and the study of their bioecological properties have become important issues. Accordingly, the study of morphological characteristics of declining plant species, the development of conservation measures and recommendations for their sustainable use, and ultimately the establishment of plantations especially of sensitive species, are of great scientific and practical importance.

Ferula foetida and *F. tadshikorum* are heavily exploited medicinal plants, leading to a marked decrease of their populations. For both special attention needs to be paid to determining their growth and development under different conditions, dispersal modality and propagation of seeds, especially in the dry conditions of hills and deserts, including the establishment of plantations and the creation of quality raw materials.

In Uzbekistan, Guidelines were developed for the cultivation of *F. tadshikorum* in the conditions of southern Uzbekistan (1). The bioecology of *F. foetida* was studied in the Western Pamir-Alay (2) and Jizzakh region (3) and including the bio-morphological properties of plantations sown from seeds of *F. foetida* and *F. tadshikorum,* while (4) studies are on the anatomical and morphological features of *F. tadshikorum* in the pre-regenerative period.

The growth cycle of monocarpic *F. tadshikorum* begins in late February and early March, and their life cycle lasts 23-27 (30) years (5). The seedling phase lasted only 1 year, the juvenile phase 6-7 years, the immature phase 14-15 years, and the virgin phase 24-27 years.

According to one report, in the first year of the introduction of *F. tadshikorum* in the Tashkent Botanical Garden, 1-3% of plant individuals were in the immature phase (6). In the third year (2022), 70-75% of the plants were still immature (7, 8).

In folk medicine alcoholic and aqueous infusions from the roots and aboveground plant material of *F. foetida* are used to treat dyspepsia, diabetes, neuroses, rheumatism, bronchial asthma, pneumonia, as a laxative, anti-inflammatory and anti-epileptic agent, as well as for diseases of the lungs, liver, kidneys (9-13). The use of *F. tadshikorum* in folk medicine has also a long history as an analgesic in arthritis and joint problems. Pharmacological studies showed that this species serves to treat exudative diathesis, pulmonary tuberculosis and also exhibits anticonvulsant properties (14-18).

Materials and Methods

F. tadshikorum is a perennial herbaceous, monocarpic, gemiephemeroid plant. It has an arrow root, with an enlarged, tuberous, thickened upper part. The length of the thickened part of the tuber is 30-40 cm, all parts of the plant have a strong garlic odor, and the main root accumulates large amounts of organic matter and water. The stem reaches a height of 2.5-3 m, the diameter of the rhizome is 25-40 cm, the color is black, hairless (19, 20).

F. foetida is also a perennial monocarpic plant. The root is cylindrical, thick, and up to 1.5 m long, the diameter of the root reaches up to 15-20 (30) cm. Stems are erect, 1.0-1.5 m tall, slightly hollow inside, branched from the top, often forming a single (sometimes 2-3) generative twigs, flowering and fertilizing once every 7-9 years. The leaves are soft, rapidly fading, the upper part is hairless, the lower part is slightly hairy, the leaves at the root collar are short, thickly petioles, the leaves at the stem are small and form a groove. The shape of the leaves is pyramidal, the leaf blade divided twice, the leaf segments are lanceolate, edges are flat, 14.0-18.0 cm long and 5.0-7.0 cm wide (21).

In Uzbekistan, *F. tadshikorum* is found mainly in the mountainous areas of Kashkadarya and Surkhandarya regions (22). *F. foetida* is found in deserts and hills, and is distributed in the deserts of Kyzylkum, Mirzachul, Karnabchul, Samarkand, Jizzakh, Bukhara, Kashkadarya, Surkhandarya regions and the Republic of Karakalpakstan.

From 2014 to 2021, seeds of *Ferula* species were sown and plantations established on an area of 20 ha on unused arable lands of the farm "Shifo kovrak" of Arnasay district, Jizzakh region. Arnasay district consists of plains and low plains, the soils are mainly typical gray and gray-meadow soils, and in the north-eastern part there partially sand dunes. The climate is sharply continental.

The bio-morphological characteristics of 2 to 6-year -old *F. foetida* and *F. tadshikorum* plants in their plantation conditions were studied each year in February, March, April, May 2018-2020. During the study period the rainfall was 195.5 mm in 2018, 267.9 mm in 2019 and 235.3 mm in 2020 (23).

Using methods of plant ontogenesis (24), morphological features (25), phenology (26, 27), and age definition (5) were described. Statistical processing of quantitative data was carried out using MS Excel (28).

Results and Discussion

Seeds of the studied species ripened in May-July. The average weight of *F. foetida* seeds collected in July 2015 (1000 seeds) was 50.6-60.3 gms, the weight of seeds collected in Forish district of Jizzakh region was 33-40 gms and the weight of *F. tadshikorum* seeds collected from Dehkanabad district of Kashkadarya region was 33-40 gms (29-31).

In Arnasay district of Jizzakh region, the first leaf of *F. tadshikorum* was formed 80-90 days after sowing, while the second leaf was formed 5-10 days later. The first leaf of *F. foetida* 90-100 days after planting, while the second leaf began to form 5-10 days later. The third and fourth leaves developed very rarely in both species. The species went into dormancy in late May and June. The margins of the first-year leaves of *F. foetida* were not trimmed, the leaf margins of *F. tadshikorum* were finely trimmed.

During the second to sixth year the vegetative of plants of *F. tadshikorum* and *F. foetida* developed in early spring and began to form tuberous thickening in the leaves and roots (Fig. 1-5). The growth dynamics of the leaves of *F. tadshikorum* and *F. foetida* during the second to sixth year of growth are given in Table 1.

Two-year old plants of both species had 2 small whole simple leaves, from the third to the sixth year, several leaf lobes were developed on the rosette depending on the age of the plant, and the remains of the last year's leaf petioles remained on the base of the stem protecting the recovery bud from cold and other adverse conditions. During the observation period ordinary leaves were formed in early February and dried out in late March. For 6 years, the number of leaves per plant was 2-3, becoming larger and more complex every year.

According to the results, the annual live cycle of different age stages of *F. tadshikorum* and *F. foetida* lasted longer in 2018, because in early February, due to the air temperature being lower than $+5^0$ C, germination occurred later than in 2019-2020. The main reason for this was that

Table 1. Growth dynamics of leaves of the second to the six-year *F. tadshikorum* and *F. foetida* **(n=100)**

Ages	Month					
	1 dec. February, cm, M±m	2 dec. February, cm, M±m	3 dec. February, cm, M±m	1 dec. March, cm, M±m	2 dec. March, cm, M±m	3 dec. March, cm, M±m
	F. tadshikorum					
2	3,5±0,08	9±0,33	15±0,63	20,5±0,57	22,5±0,90	25±1,05
3	4±0,10	8±0,20	12±0,45	21,5±0,81	21,5±1,07	20,5±0,96
4	6±0,15	9,5±0,33	13,5±0,39	18,5±0,77	36±1,37	40,5±1,86
5	5±0,17	10±0,26	18,5±0,48	29±1,04	42,5±1,99	47,5±1,80
6	7±0,09	11,5±0,32	19,5±0,54	27±1,02	39±1,40	49,5±2,2
Ages	**Month**					
	1 dec. February, cm, M±m	2 dec. February, cm, M±m	3 dec. February, cm, M±m	1 dec. March, cm, M±m	2 dec. March, cm, M±m	3 dec. March, cm, M±m
	F. foetida					
2	4±0,11	7±0,32	13±0,58	15,5±0,57	17,5±0,80	30±1,35
3	7±0,23	5±0,21	10±0,44	17,5±0,61	22,5±0,85	26±1,01
4	5±0,19	7,5±0,33	9±0,22	11±0,49	22,5±0,94	31±1,17
5	5±0,21	8±0,40	14±0,53	21,5±0,73	28-42±	39,5±1,66
6	4±0,17	7±0,26	17,5±0,73	25±1,05	30-37±	45±1,89

A B

Fig. 1. Two-year-old *F. foetida* (A) and *F. tadshikorum* (B) plants.

The leaves of both species were morphologically different. The leaf blade of *F. tadshikorum* was rhombic, while that of *F. foetida was* ovate. In both species, the second leaves appeared 10-15 days after the first leaf, but the second leaf was longer and wider than the first. The leaf segments of *F. tadshikorum* are large and bright green. Second-year individuals of *F. foetida* are characterized by the presence of trichomes under the leaves, while *F. tadshikorum* – barely noticeable. In addition, in juvenile plants of *F. tadshikorum*, the leaf petiole differs from *F. foetida* in ink color. The size and number of leaves for both species are given in Table 2.

A B

Fig. 2. Three-year-old *F. foetida* (B) and *F. tadshikorum* (A) plants.

A B

Fig. 3. Four-year-old *F. foetida* (B) and *F. tadshikorum* (A) plants.

B A

Fig. 4. Five-year-old *F. foetida* (B) and *F. tadshikorum* (A) plants.

A B

Fig. 5. Six-year-old *F. foetida* (A) and *F. tadshikorum* (B) plants.

the amount of precipitation and temperature were both lower than in an average year. In spring, high temperatures caused the leaves of both species to start yellowing and transition quickly to a dormant state. In plantation areas, *F. tadshikorum* and *F. foetida* mostly produced 2-3 leaves, and only rarely produced a 4th leaf. The leaf blades of *F. tadshikorum* were long, large, each leaf doubly pinnately dissected at a young age, the leaf lobes 10-15 cm long and 5-8 cm wide, while the leaves of *F. foetida* were doubly pinnately dissected at this stage, 5-12 cm long and 3-6 cm wide. The leaf blades of *F. foetida* were more divided than in *F. tadshikorum* and also differed in height and width. From the second to the sixth year, tuberous thickening was observed in *F. foetida* and *F. tadshikorum* roots, the length of which increased year by year. The morphological features of the roots of both species began to differ from each other. The morphological characteristics of the roots of both species are given in Table 3.

Table 3 shows that the total length of *F. tadshikorum* roots, reaching 60-90 cm and *F. foetida* roots reaching 50-90 cm. The species differed slightly from each other in root length. In *F. foetida*, the diameter of the tuberous thickened part of the root was larger than that of *F. tadshikorum* and also varied in color.

The root of *F. foetida* was barrel-shaped, the root of *F. tadshikorum* was cylindrical in shape. In both species, the number of hairs on the apical part of the root increased year by year, and they also formed 2-3-orders of ephemeral sucking hairs. In the 6th year of vegetative growth, ephemeral sucking hairs died with rising temperature.

In the sixth-year of vegetative growth *F. tadshikorum* and *F. foetida* showed enlargement of the leaf rosette and good development of the root system. The 2 species differed from each other in shape, length and color of the leaves and the leaf blades of *F. tadshikorum* were larger than those of *F. foetida* and the roots were longer. The roots differed in shape and in color. The root of *F. tadshikorum* was cylindrical, dark brown, the root of *F. foetida* barrel-shaped and light brown.

Conclusion

The study was carried out on arable and conditionally irrigated lands of the farm "Shifo kovrak," Arnasay district. The soils were gray and gray-meadow soils, and the area has relatively low rainfall. The biomorphological features of *Ferula foetida* (Bunge) Regel and *Ferula tadshikorum* Pimenov species were observed during the vegetation period of 1 to 6 years and it was found that both species can be grown in unirrigated areas.

F. tadshikorum and *F. foetida* plants differed from each other in terms of the shape, length and color of the leaf blades. It was observed that the hairs on the leaf underside of *F. tadshikorum* were less dense than those of *F. foetida*. The leaf blades of *F. foetida* were more divided compared to *F. tadshikorum*.

It was noted that the roots of the observed plants differed morphologically. The root of 6-year-old *F. tadshikorum* was radish-shaped and the root of *F. foetida* was barrel-shaped, however, the total length of the roots did not differ in principle.

Authors contributions

HMA collected and analyzed the data drafted, and developed the manuscript. KhDT searched literature, cooperated in data collection and adjusted the manuscript to the journal submission guidelines. BRW critically revised the manuscript. All authors contributed in the research proposing the problem, data collection and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no competing interests.

Ethical issues: None.

Table 2. The size of the leaves of the species in *F. tadshikorum* and *F. foetida* **(n=100)**

F. tadshikorum

Age	number of leaves											
	first leaves			second leaves			third leaves			fourth leaves		
	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)
2	11±0,43	2,7±0,08	10±0,34	13±0,59	5,5±0,23	12±0,51	9,5±0,29	2,5±0,06	3,7±0,15	9±0,32	2,5±0,07	3,7±0,15
3	14,5±0,36	9,5±0,29	13,5±0,35	29±0,84	17,5±0,73	20±0,92	15±0,51	2,5±0,07	11±0,47	13±0,31	8,5±0,22	6,5±0,27
4	21,5±0,77	16,5±0,57	21±0,61	32,5±1,04	18,5±0,85	25±1,05	20±0,84	17±0,83	16±0,54	19±0,69	16,5±0,57	12,5±0,45
5	24,5±0,58	31,5±1,45	14,5±0,59	40±1,64	34±0,85	24,5±1,03	22±0,94	20±0,86	17,5±0,63	22±0,59	18,5±0,66	17±0,42
6	27±0,75	36±1,40	19±0,85	44±1,98	40±1,96	31±1,08	24±0,91	23,5±0,96	20±0,72	22,5±0,87	28,5±1,02	17±0,49

F. foetida

Age	number of leaves											
	first leaves			second leaves			third leaves			fourth leaves		
	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)
2	10,5±0,36	6±0,21	5±0,21	11±0,37	6,5±0,22	8,5±0,3	5,5±0,20	4±0,14	4±0,14	5,5±0,20	2,5±0,08	3,5±0,15
3	14,5±0,36	12±0,42	12±0,34	24,5±1,12	18,5±0,59	15±0,51	8±0,28	10±0,39	11±0,41	5,5±0,14	3,5±0,13	6,5±0,23
4	16,5±0,69	20±0,72	12±0,40	28,5±1,31	23±0,57	21±0,77	11,5±0,43	20±0,74	12±0,45	9,5±0,43	6,5±0,29	8±0,27
5	21,5±0,90	23,5±0,80	14±0,50	33,5±1,54	29±0,84	23±0,78	18±0,66	18±0,64	15±0,69	13,5±0,52	15±0,70	14±0,53
6	21±0,73	24±0,84	15±0,43	42,5±1,65	36±1,22	26±1,11	20±0,86	22±1,07	12±0,45	20±0,72	21±0,77	20±0,86

Table 3. Morphological features of roots in *F. tadshikorum* and *F. foetida***(n=100)**

F. tadshikorum

Age	Total length of the root (cm)	Length of the tuberous thickened part (cm)	Diameter of the tuberous thickened part (cm)	Root throat diameter (cm)	Side roots (cm)	Weight of wet substance (gr)	Dry weight (gr)	Dry matter content (%)
2	15±0,39	4,5±0,15	0,7±0,02	0,45±0,01	10,5±0,29	60±2,43	12±0,32	20±0,54
3	32,5±1,04	12,5±0,51	2,15±0,08	1,5±0,05	14±0,36	125±4,25	26±0,88	21±0,50
4	40±1,24	14,25±0,49	3,1±0,13	2,45±0,08	15,5±0,45	180±7,0	40±1,28	22±0,57
5	47,5±1,71	25±1,07	3,25±0,15	3,3±0,11	18±0,61	245±8,82	57±1,59	23±0,73
6	72,5±2,45	34±1,56	11±0,46	6±0,22	19±0,70	1420±48,3	619±17,95	44±1,39

F. foetida

Age	Total length of the root (cm)	Length of the tuberous thickened part (cm)	Diameter of the tuberous thickened part (cm)	Root throat diameter (cm)	Side roots (cm)	Weight of wet substance (gr)	Dry weight (gr)	Dry matter content (%)
2	9,5±0,35	5,5±0,18	1,75±0,06	1,25±0,04	6,5±0,18	62±1,80	13±0,35	21±0,56
3	31,5±1,07	13,5±0,45	2,25±0,08	1,6±0,06	10,5±0,26	132±6,6	30±0,81	23±0,55
4	37,5±1,31	16±0,60	3,35±0,11	2,6±0,09	14±10,7	194±7,17	46±1,42	24±0,67
5	40,5±1,25	18±0,77	4,5±0,15	4,0±0,14	15,5±0,40	250±9,25	65±1,95	26±0,80
6	70±2,45	25,5±0,88	12,5±0,43	8.5±0,24	19±0,59	1250±32,5	598±17,34	48±1,77

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