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AI: analyzed and interpreted the data, wrote the manuscript, and introduced the *Tulipa tarda* population in botanical garden (Almaty City); AT and DA: performed measurements; KA: analyzed and interpreted the data and helped to write and edit the draft

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SHORT COMMUNICATION in MORPHO-ANATOMY OF USABLE PLANTS – FUNCTION AND ADAPTATION

Morphological Variability of Generative Individuals of Rare Decorative Ephemeroids of the Northern Tien Shan As Evidence of Their Adaptive Potential

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Abstract

We assessed the adaptive potential of two rare decorative species listed in the *Red Book of Kazakhstan*: *Tulipa tarda* Stapf (Liliaceae) and *Gymnospermium altaicum* (Pall.) Spach (Berberidaceae) by studying the morphological variability of generative individuals of the species. Our studies were carried out in natural populations in the Northern Tien Shan and introduced populations of the botanical garden and urban green areas of Almaty. These species showed a high degree of adaptation under the conditions of the introduction. Moreover, *Gymnospermium altaicum*, accidentally introduced into the urban green area of Bukhar Zhyrau Boulevard (Almaty), had formed a naturalized population that persisted for more than 8 years. The naturalized population of *Tulipa tarda* in the botanical garden (Almaty), introduced more than 20 years ago by one of the authors of this article, has been in existence even longer. In the latter case, individuals of seed origin showed higher adaptive capabilities than those transferred by the bulbs of generative plants.

Keywords

Tulipa tarda; *Gymnospermium altaicum*; morphological parameters

1. Introduction

Two main methods are used for preserving the gene pool of rare plants: protection of the species in nature (in situ) and creation of introduced populations (ex situ) (Convention on Biological Diversity, 2012). When introducing species into cultivation, some species adapt quickly and easily to new conditions; some adapt slowly, while others have a low survival rate and quickly fall out, i.e., show a negative result.

In several regions, *T. tarda* has been studied only in cultivation; hardly any data on natural populations of this species are available, except for recent publications by the authors of the present study (Ivashchenko & Belyalov, 2019; Tolenova et al., 2021). In addition, there are no reliable data on the development of this species in different light environments. The morphological features of *G. altaicum* in nature and the introduction have not been studied in detail, except for the studies by Kokoreva (2011) carried out in a hawthorn forest in the gorge of the Zailiyskiy Alatau ridge. For this reason, in 2020, we initiated a detailed study of natural and introduced populations of these species (Abidkulova et al., 2021; Tolenova et al., 2021).

This study aimed to analyze and summarize some aspects of the morphological variability of generative individuals of the species studied by assessing their adaptive potential under the introduction conditions.

2. Material and Methods

2.1. Study Plants and Study Area

The object of our research was two species of ephemeroids notable for their high decorative qualities and are listed in the *Red Data Book of Kazakhstan* (2014): *Tulipa tarda* Stapf (Liliaceae) and *Gymnospermium altaicum* (Pall.) Spach (Berberidaceae) (Figure 1).

Figure 1 Study plants *Tulipa tarda* (left) and *Gymnospermium altaicum* (right).

The study was carried out in natural populations located in the mountains of the Northern Tien Shan (Zailiyskiy Alatau ridge) and in introduced populations of Almaty (botanical garden and Bukhar Zhyrau City Boulevard).

The natural populations studied were located in the lower part of the forest-meadow belt (1,300–1,600 m above sea level), mountain forest, and chernozem-like soils. At the study sites, the average annual air temperature was approximately 4 °C, and the annual precipitation was 843 mm. Naturalized populations in Almaty were located in loess soils in the steppe foothills belt (850–900 m above sea level). The average annual air temperature was approximately 7.5 °C with significant fluctuations. The annual precipitation was 559 mm (Rachkovskaya et al., 2003).

The *T. tarda* population was established from seeds and bulbs in the botanical garden by one of the authors of this article in 1988. Over 11 years, it developed under conditions of minimal agronomic maintenance and without irrigation; in the following years, the collection site was abandoned and left without any maintenance.

The population of *G. altaicum* on Bukhar Zhyrau Boulevard, 0.5 km away from the botanical garden, emerged spontaneously in 2013. The soil brought from the foothills to improve the growth of trees and shrubs on the boulevard also carried seeds and tubers.

2.2. Statistical Analyses

Statistical data processing was carried out using the Descriptive Statistics MS Excel 2007 program.

3. Results and Discussion

Tulipa tarda is a bulbous ephemeroid. It is endemic to Northern Tien Shan with a limited distribution range in the western part of the Zailiyskiy Alatau ridge and adjacent areas of northern Kyrgyzstan. The species grows on dry gravelly and stony slopes of steppe and shrub-forest-meadow elevation belts at 1,100–1,900 m above sea level. It is one of the 42 species of wild-growing Kazakh tulips, which differs from others by many close, almost joint, whorl leaves (Ivashchenko & Belyalov, 2019; Tolenova et al., 2021). Our studies have demonstrated that the number of leaves in

Table 1 Distribution of generative *Tulipa tarda* individuals by the number of leaves and flowers in natural and cultivation populations.

Number of leaves	Share of individuals (%)		Number of flowers	Share of individuals (%)	
	In nature	In cultivation		In nature	In cultivation
2	0.6	-	1	89.7	55.1
3	34.5	2.0	2	9.7	28.3
4	37.3	20.0	3	0.6	13.8
5	21.7	31.0	4	-	1.4
6	5.9	26.0	5	-	0.7
7	-	19.0	6	-	0.7
8	-	2.0	-	-	-
Average per individual	3.95	5.46	Average per individual	1.11	1.66

Table 2 Distribution of generative *Tulipa tarda* individuals by the number of leaves and flowers in different habitats.

Number of leaves	The proportion of individuals in the populations from different gorges (%)			Number of flowers	The proportion of individuals in the populations from different gorges (%)		
	Karakastek	Kastek	Shubarbaytal		Karakastek	Kastek	Shubarbaytal
2	1.2	0.0	1.1	1	100.0	84.4	91.0
3	40.5	11.8	76.4	2	0.0	15.0	7.9
4	51.2	38.2	22.5	3	0.0	0.6	1.1
5	5.9	39.2	0.0	-	-	-	-
6	1.2	10.8	0.0	-	-	-	-
Average per individual	3.68	4.49	3.21	Average per individual	1.00	1.14	1.16

generative individuals in natural populations ranged between two and six (with an average of 3.95), while it was between three and eight (with an average of 5.46) under long-term cultivation conditions. The number of flowers in individuals of the natural populations surveyed did not exceed three, and in cultivation, six, with an average of 1.11 and 1.66, respectively. The proportions of various individuals (percentage of the total number) are presented in Table 1.

In natural populations from different habitats, the leaf and flower numbers in generative individuals were also quite variable. However, the differences were not significant, as shown by the results of our surveys under similar conditions (dry steppe slopes, 1,100–1,300 m above sea level) for the three gorges: Karakastek, Kastek, and Shubarbaital (Table 2).

When studying the introduction potential of the species under the conditions of Almaty, we found that individuals of seed origin had higher adaptive potential than those transferred from nature as mature plants (bulbs). The first flowering of individuals grown from seeds was observed in 5-year-old plants. They always had three leaves and a single flower. In the second year of flowering (when the plants were 6 years old), the proportion of generative individuals increased to 8%–10%, and some of them developed shoots with two flowers and five leaves. Detailed data were obtained on the morphological characteristics of 8-year-old generative individuals of seed origin (Table 3).

Thus, in the eighth year of life (fourth year of flowering) of the introduced population, its morphological parameters (the number of leaves and flowers) exceeded those of the individuals from natural populations (Table 1), which suggests a high adaptive potential of the species.

The same can be said about the level of adaptation using seed productivity as an example. Table 4 presents data on the size of fruits and seed productivity of individuals from the natural population (No. 1), introduced populations created from the bulbs of generative individuals (No. 2, first year of introduction; No. 3, fifth year of introduction), and population of seed origin (No. 4, first year of fruiting).

Table 3 Morphological parameters of 8-year-old generative *Tulipa tarda* individuals from the introduced population.

Number of flowers	Distribution of individuals by the leaf number (%)				
	3	4	5	6	7
1	10.0	29.0	16.0	-	-
2	-	6.0	5.0	9.0	4.0
3	-	-	3.0	5.0	2.0
4	-	-	-	1.0	-
Average number of flowers per individual: 1.62					
Average number of leaves per individual: 5.0					

Table 4 Indicators of seed productivity of *Tulipa tarda* from natural and introduced populations.

Population No.	Fruit size (mm)		Number of seeds			Productivity Index (%)
	Length	Width	Normal	Underdeveloped	Total	
1	23.42 ± 0.68	11.67 ± 0.50	52.18 ± 5.97	53.14 ± 6.51	105.32 ± 7.84	36.8
	19.1–29.3*	8.8–17.5*	11.0–111.0*	11.0–108.0*	52.0–177.0*	
2	27.97 ± 1.21	14.32 ± 0.51	68.61 ± 5.73	50.72 ± 4.99	119.33 ± 7.01	57.5
	21.0–41.2*	10.2–18.8*	30.0–174.0*	19.0–99.0*	72.0–181.0*	
3	33.08 ± 1.24	18.23 ± 0.69	101.15 ± 9.32	60.92 ± 4.46	162.08 ± 9.67	62.4
	23.0–38.0*	12.0–21.0*	28.0–148.0*	36.0–93.0*	64.0–215.0*	
4	33.10 ± 1.58	18.1 ± 0.81	97.90 ± 12.46	70.20 ± 16.82	168.10 ± 13.07	58.2
	24.0–38.0*	15.0–22.0*	40.0–139.0*	24.0–205.0*	116.0–258.0*	

* Limits of variation.

As can be seen from the data in Table 4, the rate of adaptation of individuals in populations of seed origin was significantly higher than that of individuals grown from bulbs; in the first year of fruiting, the former were almost as well developed as the latter in the fifth year of cultivation in terms of fruit size and seed productivity.

We have been able to monitor the introduced populations of *T. tarda* in the botanical garden of Almaty for 26 years. By 2013, in two plots that had been completely abandoned over the past 13 years, naturalized populations of this species were supported by vegetative self-regeneration, and only generative individuals from different light environments differed in morphological parameters. Table 5 presents data on two populations: No. 1 was located in an area overgrown with shrubs, at the edge of the spruce tree crowns (*Picea schrenkiana* C. A. Mey.), and No. 2 was located in an open, sunny area.

Therefore, the cultivation of *T. tarda* in urban environments is one of the most promising options for preserving the gene pool of this rare species.

Gymnospermium altaicum is a tuberous ephemeroid with an Altai – Tien Shan distribution area. In the Northern Tien Shan it grows within the same two altitudinal belts as *T. tarda*, steppe, and forest-meadow in the range of heights (1,000–1,600 m) but does not grow above the lower margin of spruce forests. The main habitats of this species are confined to communities of wild fruit forests dominated by *Malus sieversii* (Ledeb.) M. Roem., *Crataegus songorica* C. Koch, and *Armeniaca vulgaris* Lam. Detailed descriptions of these communities have been published previously (Abidkulova et al., 2021). At the same time, morphological characteristics such as plant height, inflorescence length, and the number of flowers can be informative in species identification and assessing the state of plants in a population (Kokoreva, 2011; Tan et al., 2011). In this regard, it is necessary to pay more attention to such studies. Therefore, we carried out morphological studies of generative individuals of *G. altaicum* not only in natural communities on the northern slope of the Zailiyskiy Alatau but also in a naturalized population of the species growing in the city of Almaty. Thus, we obtained comparative morphometric data for *G. altaicum* from different populations (Table 6).

Table 5 Morphological parameters of generative individuals of *Tulipa tarda* from naturalized populations growing in different light environments.

Population No.	Shoot height (cm)	Distance between leaves (cm)	Leaf size (cm)				Peduncle length (cm)	Flower height (cm)
			Lower leaves		Upper leaves			
			Length	Width	Length	Width		
1	16.7 ± 0.74	2.5 ± 0.22	15.4 ± 0.69	1.7 ± 0.05	12.5 ± 0.48	0.7 ± 0.04	11.2 ± 0.51	3.1 ± 0.06
	18.3–23.5*	1.3–4.4*	10.6–23.1*	1.3–2.1*	9.1–16.7*	0.4–1.1*	6.4–14.0*	2.8–3.6*
2	13.6 ± 0.71	1.6 ± 0.13	13.0 ± 0.62	1.7 ± 0.05	11.4 ± 0.62	0.7 ± 0.05	8.5 ± 0.27	3.0 ± 0.1
	8.2–17.5*	0.8–2.4*	7.8–16.2*	1.3–2.0*	5.7–14.1*	0.4–1.1*	6.8–9.8*	2.3–3.5*

* Limits of variation.

Table 6 Morphological parameters of generative individuals of *Gymnospermium altaicum* in naturalized and natural populations.

Population	Plant height (cm)	Inflorescence length (cm)	Number of flowers per inflorescence
Bukhar Zhyrau Boulevard (2016)	12.6 ± 0.34	3.9 ± 0.12	10.0 ± 0.47
	7.0–17.0*	2.0–5.8*	4.0–15.0*
Bukhar Zhyrau Boulevard (2021)	10.6 ± 0.29	3.0 ± 0.8	9.4 ± 0.32
	5.0–16.7*	1.3–5.5*	5.0–19.0*
Gorge Kotur-Bulak	20.1 ± 0.58	4.7 ± 0.15	9.9 ± 0.47
	14.0–27.3*	2.7–7.0*	4.0–17.0*

* Limits of variation.

From the data presented, it can be inferred that there is practically no difference in the average number of flowers per inflorescence in *G. altaicum* plants from the natural and naturalized populations, despite a slight difference in the minimum and maximum numbers. The only noticeable differences are in the plant height and inflorescence length, which, in our opinion, are associated with the difference in the time of measurement, i.e., at the beginning or in the middle of flowering, and with the fact that linear values are always more variable compared to other indicators. Thus, *G. altaicum* has been successfully naturalized in urban conditions and, like the previous species, can be preserved in cultivation for a long time.

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