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COMPARATIVE ANATOMICAL ANALYSIS OF *EREMURUS ROBUSTUS* AND *E. TIANSCHANICUS* GROWING IN THE ZAILIYSKIY ALATAU

The genus *Eremurus* (Asphodelaceae) represents one of the characteristic groups of the flora of Central Asia, distinguished by its ornamental value and practical significance in traditional medicine. However, the anatomical structure of its representatives under different ecological conditions remains insufficiently studied. The aim of this study was to conduct a comparative anatomical analysis of two species occurring in the Ile Alatau. Leaves and stems were used as study material, fixed in 70% ethanol and processed according to a standard histological protocol with paraffin embedding. Transverse sections 40 μm thick were prepared using a rotary microtome and examined by light microscopy with digital photodocumentation. Morphometric measurements included epidermal thickness, the size of palisade mesophyll, the diameter of water-storage cells in the leaf, as well as epidermal thickness, the size of primary cortex cells, and the diameter of water-storage cells in the stem. The study revealed that both species exhibit xeromorphic traits: a uniseriate epidermis with a thickened cuticle and sunken stomata, the presence of palisade mesophyll and water-storage cells in the leaves, and well-developed vascular bundles. In the stem, a dense epidermis, a distinct primary cortex, and collateral vascular bundles with water-storage cells were observed. Interspecific differences were also identified: the first species had larger primary cortex cells and water-storage elements, reflecting a water-accumulating adaptive strategy, while the second exhibited a more developed palisade mesophyll and greater stability in tissue dimensions, indicating a photosynthetic type of adaptation. The results contribute to a better understanding of the ecological plasticity and intraspecific variability of *Eremurus* in the mountainous and foothill ecosystems of Central Asia.

Keywords: Asphodelaceae, Adaptations, Anatomy, *Eremurus*, Ile Alatau.

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Іле Алатауында өсетін *Eremurus robustus* және *E. tianschanicus* түрлерінің салыстырмалы анатомиялық талдауы

Eremurus (Asphodelaceae) туысы – Орталық Азия флорасының сәндік мәні жоғары және халық медицинасында қолданылуы жағынан маңызды топтарының бірі. Алайда бұл туыс өкілдерінің әртүрлі экотоптардағы анатомиялық құрылысы жеткілікті деңгейде зерттелмеген. Жұмыстың мақсаты – Іле Алатауы аумағында өсетін екі түрдің салыстырмалы анатомиялық талдауын жүргізу болды. Зерттеу материалы ретінде 70%-дық спиртте бекітіліп, парафинге құюдың стандартты гистологиялық әдісі бойынша өңделген өсімдіктердің жапырақтары мен сабақтары алынды. Қалыңдығы 40 мкм көлденең кесінділер микротомның көмегімен дайындалып, жарық микроскопиясы әдісі арқылы зерттелді және сандық фотобекіту жүргізілді. Морфометриялық өлшемдерге эпидермис қалыңдығы, палисадты мезофилл өлшемдері, жапырақтағы су жинаушы жасушалардың диаметрі, сондай-ақ сабақтағы эпидермис қалыңдығы, алғашқы қабық жасушалары мен су жинаушы элементтердің мөлшері кірді. Зерттеу нәтижесінде екі түрдің де ксероморфтық белгілерге ие екені анықталды: қалың кутикуласы бар бір қабатты эпидермис және терең орналасқан устьицалар, палисадты мезофилл мен жапырақтағы су жинаушы жасушалар, жақсы дамыған өткізгіш шоқтар. Сабақ бөлігінде тығыз эпидермис, алғашқы қабық және су жинаушы жасушалары бар коллатеральды шоқтар анықталды. Түрлер арасында айырмашылықтар байқалды: бірінші түрде алғашқы қабық жасушалары мен су ылғал қорын сақтауға бейімделу стратегиясын көрсетеді; ал екінші түрде палисадты мезофилл жақсырақ дамыған және ұлпа өлшемдерінің тұрақтылығы байқалады, бұл фотосинтетикалық типтегі бейімделуді білдіреді. Алынған нәтижелер *Eremurus* туысының экологиялық икемділігі мен түрішілік өзгергіштігін Орталық Азияның таулы және таулы етегіндегі экожүйелер жағдайында нақтылауға мүмкіндік береді.

Түйін сөздер: Asphodelaceae, адаптация, анатомия, *Eremurus*, Іле Алатауы.

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Сравнительный анатомический анализ видов *Eremurus robustus* и *E. tianschanicus* произрастающих в Заилийском Алатау

Род *Eremurus* (Asphodelaceae) является одной из характерных групп флоры Центральной Азии, отличающейся декоративной ценностью и прикладным значением в народной медицине. Однако анатомическая структура его представителей в различных экотопах изучена недостаточно. Целью работы был сравнительный анатомический анализ двух видов, произрастающих в пределах Заилийского Алатау. В качестве материала использованы листья и стебли растений, фиксированные в 70% спирте и обработанные по стандартной гистологической методике с парафиновой заливкой. Поперечные срезы толщиной 40 мкм были изготовлены с помощью микротома и изучены методом световой микроскопии с цифровой фотодокументацией. Морфометрические измерения включали толщину эпидермиса, размеры палисадного мезофилла, диаметр водоносных клеток листа, а также толщину эпидермиса, размеры клеток первичной коры и водосборных клеток стебля. Исследование показало, что оба вида обладают ксероморфными признаками: однослойный эпидермис с утолщённой кутикулой и погружёнными устьицами, наличие палисадного мезофилла и водоносных клеток в листьях, хорошо развитые проводящие пучки. В стебле выявлены плотный эпидермис, первичная кора и коллатеральные пучки с водоносными клетками. Между видами обнаружены различия: у первого более крупные клетки первичной коры и водоносные элементы, что указывает на влагозапасающую стратегию, у второго – более развитый палисадный мезофилл и стабильность размеров тканей, отражающие фотосинтетический тип адаптации. Полученные результаты позволяют уточнить экологическую пластичность и внутривидовую изменчивость рода *Eremurus* в условиях горных и предгорных экосистем Центральной Азии.

Ключевые слова: Asphodelaceae, адаптации, анатомия, *Eremurus*, Заилийский Алатау.

Introduction

The genus Eremurus M. Bieb. (Asphodelaceae) is one of the most characteristic groups of Central Asian flora, differing from closely related taxa in its unique morphological features, in particular its leafless inflorescence consisting of more than 50 flowers, as well as its developed rhizome (Naderi Safar et al., 2014; Hadizadeh et al., 2021). Two subgenera are distinguished within the genus. The subgenus Eremurus is characterized by light brownish-green or cream-colored tubular and bell-shaped flowers with concave perianth leaves, on the underside of which there are three or five veins; the staminal filaments are protruding in most cases. Subgenus Henningia, on the contrary, includes species with white, pink, or yellow flowers of the rotary type, usually with enclosed stamen filaments and perianth leaves with one vein (Chukavina, 1985; Ahmad et al., 2014; Hadizadeh et al., 2020; Farhadi et al., 2023; Koohkesh et al., 2020; Jang et al., 2024).

Species of the genus Eremurus are highly decorative and are known in cultivation as «foxtail lilies» or «desert candles» due to their large and bright spike-like inflorescences (Abdulwahid-Kurdi, 2025). Along with their decorative use, they also have practical significance: some species are used to produce bio-oil (Aysu et al., 2015), adhesives, and as a source of pharmacologically active compounds with antibacterial, anti-inflammatory, and anti-protozoal properties (Gaggeri et al., 2015; Zare et al., 2018). In traditional medicine in Central Asian countries, the roots and leaves of Eremurus are used as a remedy for a number of diseases (Dushchanova et al., 2023a).

Foreign researchers have conducted a series of comprehensive studies on the morphological, phylogenetic, and phytochemical characteristics of

Central Asian representatives of the Eremurus genus. Iranian scientists have conducted a comprehensive review of the species of the genus, including an analysis of their phytochemical composition, pharmacological properties, and traditional uses (Alhalak & Sekerler, 2025). In addition, specialized phytochemical studies of the roots of Eremurus luteus have been carried out (Shahrampour & Razavi, 2022, 2023). Earlier, about a decade before these studies, phylogenetic studies of the genera Eremurus, Asphodelus, and Asphodeline were conducted in Iran, based on the analysis of trnL-F plastid sequences and nuclear ITS DNA loci. Researchers from Uzbekistan, in particular D. Mahmudiev and co-authors, have carried out morphological, anatomical, and molecular genetic studies, as well as developed identification keys for species growing in the Republic of Uzbekistan. Based on a comparative analysis of distribution areas, the authors concluded that the probable center of origin of the genus Eremurus is Central Asia (Makhmudjanov et al., 2022, 2024). In India, a comprehensive study was conducted on the species Eremurus persicus (Jaub. & Spach) Boiss. — an indigenous medicinal plant of the Western Himalayan flora (Verma et al., 2023).

Anatomical studies of representatives of the genus have been conducted repeatedly and have revealed both common and specific characteristics. Thus, Bahrim et al. (Bahrim et al., 2020), studying the anatomical structure of the leaves of E. himalaicus, E. robustus, and E. stenophyllus, revealed a phylloid leaf structure with reverse orientation of the conducting bundles, a single-layer epidermis with a thin cuticle and numerous stomata, as well as a mesophyll represented by large rounded parenchyma cells. At the same time, the stomatal apparatus in E. stenophyllus and E. himalaicus is located at the same level as the epidermis, while in E. robustus it is submerged below the surface. In addition, the assimilation parenchyma in the first two species is significantly better developed than in E. robustus.

Similar adaptive features have been identified in Eremurus lactiflorus, studied using plant material from the Tashkent Botanical Garden (Dushchanova et al., 2023b). In this species, the epidermis consists of a single layer of cells with a thin cuticle and numerous stomata, while the mesophyll consists of large parenchyma cells with extensive intercellular spaces, indicating xeromorphic adaptations to arid climate conditions.

Despite the available data, comparative anatomical studies of species of the genus Eremurus growing in the Zailiyskiy Alatau remain limited. Meanwhile, this region is one of the centers of their diversity and is of interest both for understanding plant adaptations to mountain xerophytic conditions and for clarifying intraspecific variability.

The aim of this study is to conduct a comparative anatomical analysis of two species of the genus Eremurus (E. robustus and E. tianschanicus) growing in the Zailiyskiy Alatau, identifying common and specific anatomical features that reflect their adaptation to the mountain ecosystems of the region and allowing us to clarify the taxonomic and ecological significance of these structures.

Materials and methods

The object of study are two closely related species of the genus Eremurus M. Bieb. (Asphodelaceae) growing within the Zailiyskiy Alatau – Eremurus robustus Regel and Eremurus tianschanicus Pazij et Vved. ex Pavlov. (Fig. 1). Both taxa are characteristic representatives of the mountain flora of Central Asia and play an important role in the formation of meadow and forest-edge communities in the foothills and lower mountain belts (Chukavina, 1985; Goloskokov, 1958).

Eremurus robustus is one of the largest plants of the genus, distinguished by its tall generative shoots, reaching 200 cm, and broad strap-like leaves up to 3–6(–8) cm wide. The inflorescence is dense, multi-flowered, up to 40–100 cm long. The flowers are large, bell-shaped, pink (rarely white), the perianth reaches 15–17 mm in length and has a yellow spot at the base of the lobes. The stamens are slightly shorter than the perianth. The fruit is a rounded, smooth, spherical capsule, relatively large, up to 20–30 mm in diameter. The seeds are gray, with a widely developed wing (Goloskokov, 1958; Townsend, 1980) (Fig. 2).

Eremurus tianschanicus is generally smaller than the previous species, reaching 50–150(–200) cm in height. The leaves are linear or linear-oblong, narrower, 1–3 cm wide, and bluish-green in color. The inflorescence is usually narrower and less dense than that of E. robustus. The flowers are pale pink, with a perianth 10–12 mm long, also with a yellow spot at the base of the lobes. A characteristic feature is the different length of the stamens: two filaments are noticeably longer than the perianth, while the others are equal to or shorter than it. The fruit is a spherical capsule, significantly smaller than that of E. robustus, up to 10 mm in diameter, which is one of the key diagnostic features. The seeds are gray, with a narrow wing (Chukavina, 1985; Goloskokov, 1958; Khokhryakov, 1965) (Fig. 2).

Figure 1
Map of material sampling points for anatomical studies

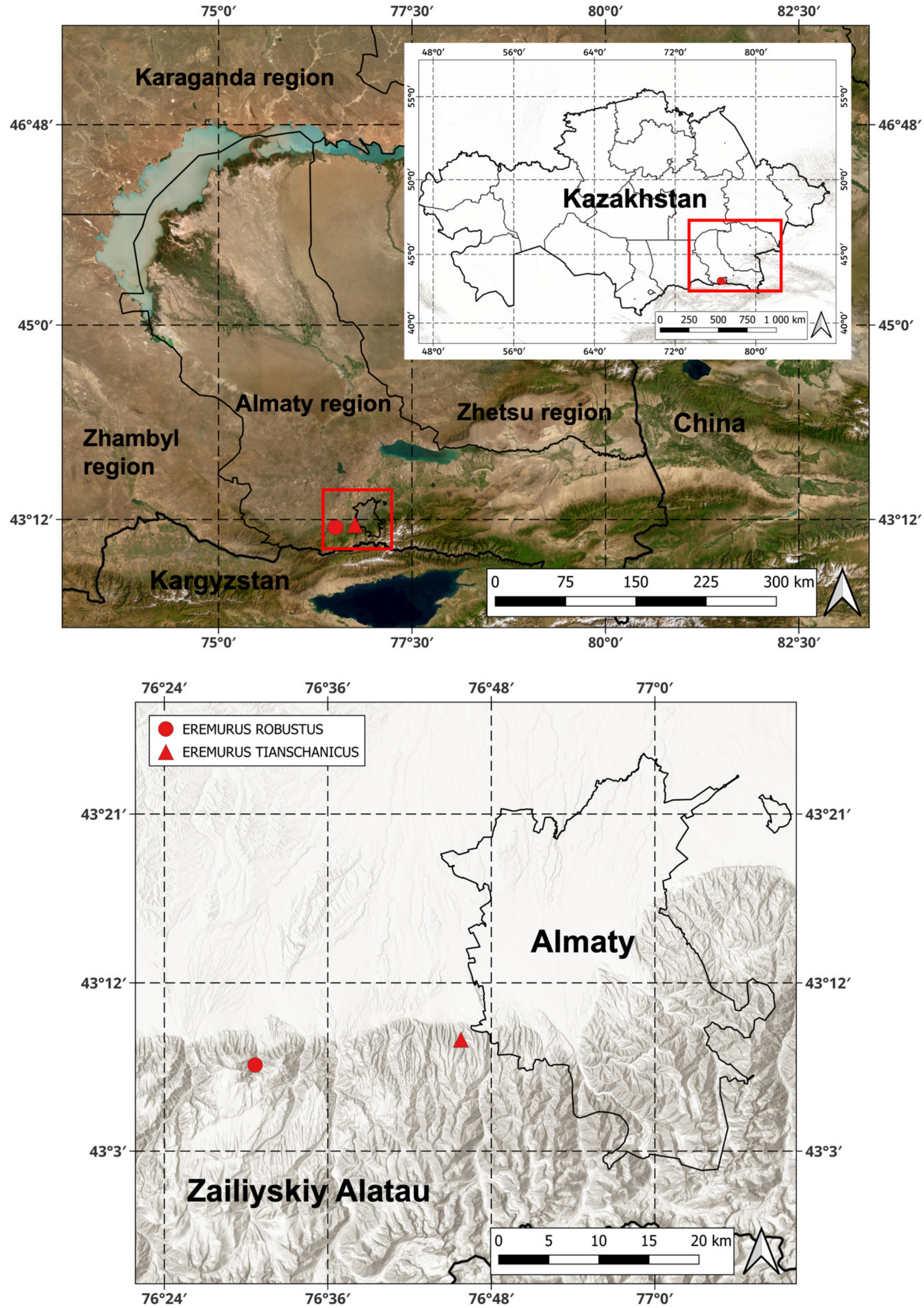


Figure 2
Species of the genus Eremurus. A – Eremurus robustus; B-E – tianschanicus

A

B

Both species bloom in June–July and are confined to various ecotopes of the Zailiyskiy Alatau. E. robustus is found mainly on meadow slopes and in subalpine communities, while E. tianschanicus is confined to rocky and loess foothill slopes with more xerophytic growing conditions.

Anatomical preparations were performed in accordance with standard histological protocols. Samples intended for sectioning were first fixed in 70% ethanol. To facilitate high-quality cross-sectioning, the material was frozen and then poured into histological paraffin poured into special 15×15 mm molds. Cross-sections were obtained using a rotary semi-automatic microtome (MEDITE M530, Burgdorf, Germany) with a section thickness of 40 µm. Microscopic examination of anatomical structures was performed using a digital microscope (Levenhuk Zoom&Joy, Hong Kong, China) equipped with a Levenhuk D740T 5.1 camera. Image acquisition and morphometric measurements were performed using LevenhukLite software, version 4.12.28273 (Levenhuk, Inc., Tampa, Florida, USA). Biometric parameters were statistically processed; mean values and standard errors were calculated using the Data Analysis function in Microsoft Excel (Islamgulova et al., 2025).

Results and discussion

The anatomical structure of the vegetative organs of Eremurus robustus and E. tianschanicus is characterized by typical features of xeromorphic plants, reflecting their adaptation to arid habitats. The leaves of both species have a clearly defined cuticle and a single-layer epidermis with stomata immersed in the tissue, which reduces transpiration. The mesophyll contains a palisade layer that provides photosynthetic activity and specialized water-bearing cells that accumulate moisture. The conducting bundles are well developed and evenly distributed, which ensures efficient transport of water and assimilates (Fig. 3).

The stem of both species is characterized by a dense cuticle and epidermis, under which there is a primary cortex with parenchyma cells. Inside, there are collateral-type conducting bundles with xylem and phloem, as well as well-developed water-conducting cells, which give the organs additional resistance to arid conditions (Fig. 4).

Figure 3

Anatomical structure of leaves of two species of the genus Eremurus. A-B: Eremurus robustus; C-D: E. tianschanicus: c – cuticle; ep – epidermis; sa – stomata; pal – palisade mesophyll; vb – vascular bundle; wc – water-conducting cells

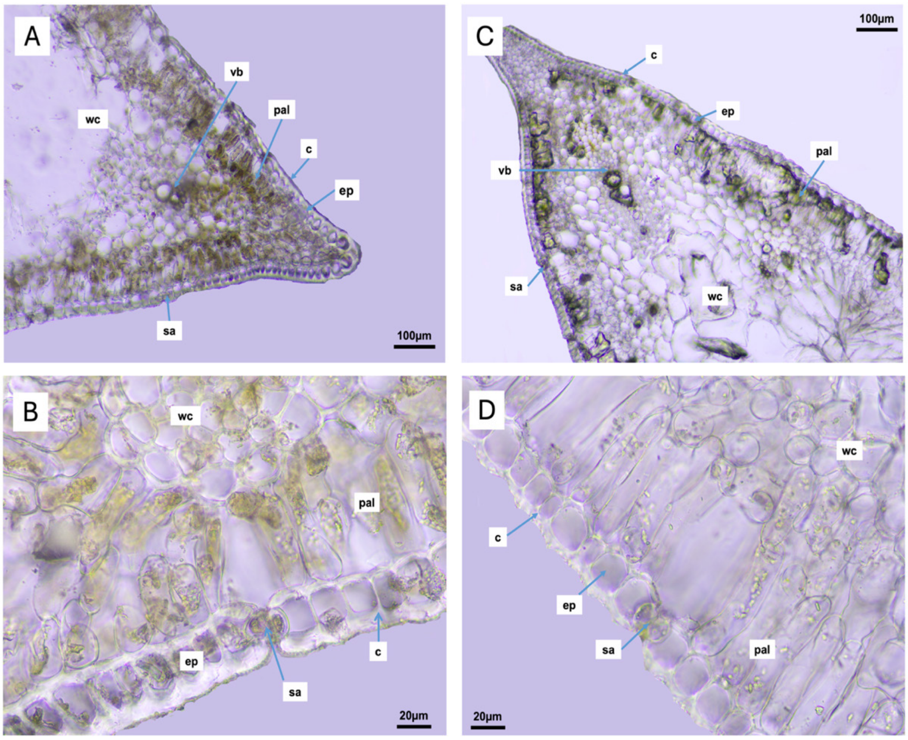
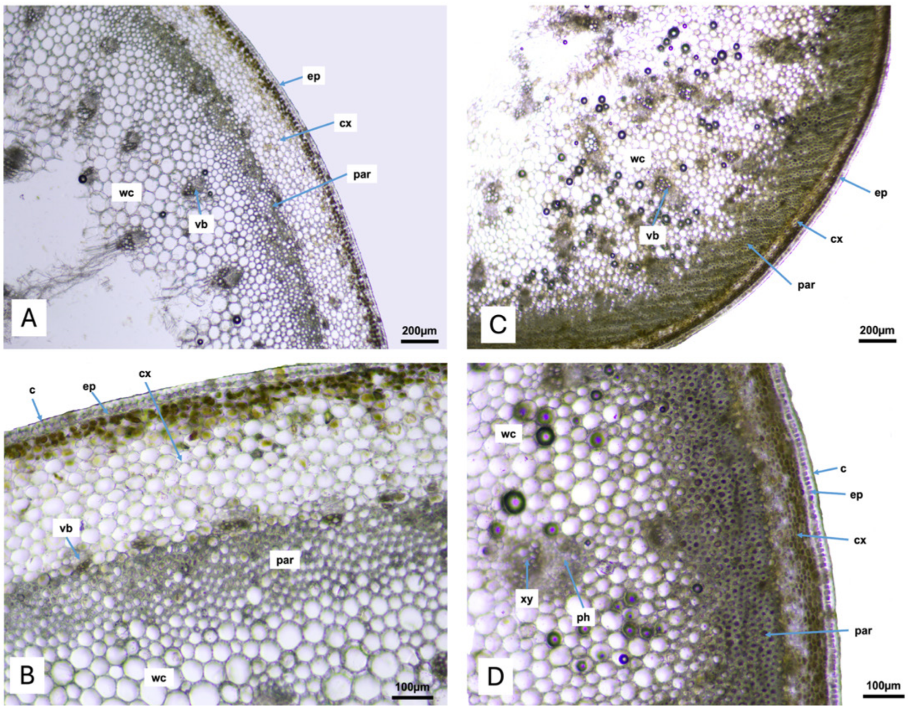


Figure 4

Anatomical structure of the stem of two species of the genus Eremurus. A-B: Eremurus robustus; C-D: E. tianschanicus: c – cuticle; ep – epidermis; cx – primary cortex; par – parenchyma; vb – vascular bundle; xy – xylem; ph – phloem; wc – water-conducting cells



To identify interspecific differences in the anatomical structure of the leaf and stem in Eremurus robustus and E. tianschanicus, morphometric measurements of the main tissue components were performed. The table shows the thickness of the epidermis, the size of the palisade mesophyll and water-conducting cells of the leaf, as well as the thickness of the epidermis, the diameter of the primary cortex cells and water-collecting cells of the stem. The use of statistical parameters (mean value, standard error, standard deviation, minimum and maximum values, confidence interval) allowed us to objectively assess the degree of variation in traits and establish the characteristic differences between each species (Table 1).

Table 1
Morphometric measurements of the main tissue components of Eremurus robustus and E. tianschanicus

Eremurus robustus						
	Leaf			Stem		
	Thickness of the epidermis, µm	*Palisade mesophyll, µm*	*Diameter of water-bearing cells, µm*	*Thickness of the epidermis, µm*	*Diameter of primary cortex cells, µm*	*Diameter of water collection cells, µm*
Mean	21,54	65,61	62,12	22,38	32,99	55,69
Standard error	0,41	1,91	18,34	0,39	4,03	7,09
Standard deviation	0,92	4,27	41,02	0,87	9,01	15,86
Minimum	20,73	61,15	21,52	21,60	22,06	35,84
Maximum	22,94	70,95	126,21	23,73	44,26	78,14
Confidence level (95.0%)	1,14	5,30	50,93	1,08	11,19	19,69
E. tianschanicus						
	Leaf			Stem		
Mean	20,36	70,03	60,97	21,88	13,35	49,73
Standard error	0,96	1,93	10,81	0,68	1,04	7,32
Standard deviation	2,15	4,32	24,18	1,52	2,34	16,38
Minimum	17,46	65,81	34,62	19,39	10,80	29,27
Maximum	23,02	76,02	97,42	23,24	16,42	70,25
Confidence level (95.0%)	2,66	5,36	30,02	1,88	2,90	20,34

The anatomical structure of the leaves and stems of Eremurus robustus and E. tianschanicus demonstrates both common features characteristic of representatives of the genus and a number of interspecific differences reflecting their adaptive strategies.

Analysis of the leaf epidermis revealed that E. robustus has a slightly thicker epidermis (average thickness of 21.54 µm) compared to E. tianschanicus (20.36 µm). Although the difference is not significant, it indicates a denser outer cell wall in the former species, which may increase resistance to moisture evaporation. At the same time, E. tianschanicus has a wider range of epidermal thickness variation (from 17.46 to 23.02 µm), which reflects the higher ecological plasticity of this trait.

The palisade mesophyll in E. tianschanicus is significantly better developed: its thickness averages 70.03 µm, while in E. robustus this figure is 65.61 µm. The increased thickness of the mesophyll indicates a larger area of photosynthetically active tissue, which may contribute to more intensive absorption of solar radiation in the mountain and foothill biotopes where this species is widespread.

The water-bearing cells of the leaf in both species have similar average values (62.12 µm in E. robustus and 60.97 µm in E. tianschanicus). However, in E. robustus, this indicator has a high amplitude of variation (from 21.52 to 126.21 µm), which indicates heterogeneity of the structure and, probably, the ability to form reservoir cells of different sizes depending on hydrothermal conditions. For E. tianschanicus, the variations are less pronounced (34.62–97.42 µm), which indicates a more stable organization of this tissue.

The differences between the species are even more pronounced in the structure of the stem. The thickness of the epidermis in both species is similar (22.38 µm in E. robustus and 21.88 µm in E. tianschanicus), which corresponds to the general pattern for the genus. However, the cells of the primary cortex in E. robustus are significantly larger (32.99 µm) compared to E. tianschanicus (13.35 µm). This indicates a more pronounced development of parenchyma tissues in the former species, which perform the function of mechanical support and storage of nutrients.

The diameter of the water-collecting cells in the stem is also higher in E. robustus (55.69 µm versus 49.73 µm in E. tianschanicus). The increased size of these cells allows them to accumulate a greater volume of moisture, which is an important sign of xeromorphic adaptation. In E. tianschanicus, the water-collecting cells are smaller but more uniform in structure, which may be associated with the optimization of moisture distribution when growing in conditions of more stable moisture.

Anatomical differences in the structure of the leaves and stems of Eremurus robustus and E. tianschanicus are closely related to the characteristics of their ecological niches.

Eremurus robustus is a more robust and larger species found in the foothill plains and lower elevations of the Zailiyskiy Alatau. These areas are characterized by a continental climate with sharp temperature fluctuations and long periods of drought. In such conditions, the plant's ability to accumulate and conserve moisture becomes crucial. This explains the larger diameter of the primary cortex cells and water-collecting cells in E. robustus. Their size allows them to store significant amounts of water and nutrients, which ensures resistance to dry periods and maintains turgor in the tissues. The wide variability in the size of water-bearing cells indicates the high plasticity of this trait, reflecting the species' adaptability to uneven moisture and seasonal fluctuations in water balance.

At the same time, the thicker epidermis of E. robustus leaves provides additional protection from intense solar radiation and reduces transpiration losses. Thus, the anatomical structure of this species forms a xeromorphic complex of adaptations focused primarily on moisture storage and resistance to the stressful conditions of arid ecosystems.

Eremurus tianschanicus, on the contrary, is confined to the mountainous and foothill areas of the Zailiyskiy and Kungey Alatau ranges, where moisture conditions are relatively more stable due to higher precipitation and snowmelt feeding the soil. In these habitats, the key factor for adaptation is not so much moisture storage as the increased efficiency of photosynthetic processes under conditions of strong solar radiation. The more developed palisade mesophyll in E. tianschanicus reflects this strategy: the increased thickness of photosynthetically active tissue ensures more complete utilization of light energy and promotes the accumulation of organic matter.

This species has smaller diameter primary cortex and water-collecting cells, which is compensated by their structural stability and more uniform distribution. This indicates that E. tianschanicus does not so much store moisture in large volumes as optimize its use under relatively favorable moisture conditions. The wider range of variation in the thickness of the epidermis and palisade mesophyll indicates the high ecological plasticity of the species, which allows it to adapt to various microclimatic conditions of mountain slopes.

Conclusion

A comparison of the anatomical features of the two species leads to the conclusion that E. robustus exhibits a «moisture-storing» strategy typical of plants in arid ecosystems. Its structure is geared toward moisture accumulation and survival in conditions of severe seasonal aridization. E. tianschanicus implements a «photosynthetic type» strategy, typical of more humid mountain habitats, where the emphasis is on productivity and efficient use of solar radiation. Differences in the anatomical structure of the leaves and stems of these species reflect different adaptation pathways within the genus Eremurus, highlighting their ecological specialization within the arid and foothill ecosystems of Central Asia.

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