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The soils of natural populations of *Gentiana tianschanica* Rupr. (Gentianaceae) in Ile Alatau, Kazakhstan

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Abstract
The article presents findings from field and laboratory studies conducted on the soils within the habitat of the *Gentiana tianschanica* Rupr. population. Various parameters including soil types, morphological characteristics, nutrient elements, humus content (Soil organic matter), absorbed bases, soil pH, granulometric composition, and salt content were analyzed through soil chemical analysis . A detailed analysis of the physical and chemical properties of soils sampled from three pedons (P-1, P-2, P-3) within the Kimasar gorge region. The soils were sampled at various depths ranging from surface layers (0–10 cm) to deeper layers (70–80 cm or 90 cm). Laboratory analysis of mountain meadow chestnut soils revealed moderate (soil organic matter) humus content (2.84% to 6.18%) and neutral to slightly alkaline pH values (6.0 to 6.66), indicating a balanced soil environment. Total calcium carbonate (CaCO3) content varied across pedons, with moderate levels in P-1 (27–44 g kg^{-1}) and higher values in P-2 (44 mg-eq/100 g in soil), suggesting a moderate lime content. Organic matter content was notably higher in P-2, especially at the surface (18.8%), compared to P-1 (6.18%) and P-3 (10%). Cation exchange capacity (C.E.C.) was also higher in P-2 (50.2 mg-eq/100 g in soil), indicating a greater nutrient-holding capacity, while nitrogen content was highest in P-1 (42 mg/kg at the surface). Phosphorus levels were particularly elevated in P-2, especially in the surface layer (140 mg/kg), whereas potassium levels were moderate across all pedons. The granulometric composition showed significant variation, with P-1 exhibiting a mix of sandy clay and clay loam, P-2 showing clay loam and sandy clay loam, and P-3 consisting of silt loam and loamy sand. a characteristic shared with the dark chestnut soils of the Big Almaty and Kaskelen gorges. As a result of the study, all soil types studied were found to have a non-saline composition based on total salt content analysis. These variations in soil texture and nutrient content reflect the complex interactions between local geological and hydrological factors, influencing soil formation, structure, and fertility, which in turn affect plant **growth** and ecosystem dynamics in the region.

Keywords: *soil, morphology, absorbed bases, G. tianschanica , salinization.*

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Introduction

Gentiana tianschanica (Gentianaceae) is a rare species found in the mountainous regions of Central Asia, including the Ile Alatau range in Kazakhstan. This perennial herbaceous plant grows up to 30 cm tall. Its leaves are linear-lanceolate, and the flowers are large, funnel-shaped, and vividly blue. The species belongs to a group of high-altitude endemics adapted to harsh climatic conditions (Tynybekov *et al.,* 2024). *G. tianschanica* inhabits rocky slopes, alpine meadows, and grasslands. It is most found at elevations ranging from 2000 to 3000 meters above sea level, where it is adapted to extreme environmental conditions, including low temperatures and intense solar radiation. The plant prefers slightly acidic soils (pH 5.5–6.5) rich in organic matter. It is moderately drought-tolerant but thrives in well-drained soils that retain moisture from snowmelt. Optimal growth conditions include rocky or sandy soils with high air permeability (Balkybek, *et al.,* 2025). This plant plays a vital role in stabilizing soils and maintaining the biodiversity of alpine ecosystems. Its roots help prevent erosion, while its flowers provide nectar for pollinators, including rare species of butterflies and bees..*G. tianschanica* possesses a robust taproot system that penetrates deep into the soil, enabling access to water even during dry periods. The root cross-section reveals a well-developed cortex and central cylinder with distinct vascular bundles. The roots contain cells rich in calcium oxalate crystals, a characteristic feature of the genus *Gentiana*. The linear-lanceolate leaves are covered with a thin waxy layer that minimizes water loss through evaporation. The mesophyll is differentiated into palisade and spongy parenchyma, optimizing photosynthesis under high-altitude conditions. The epidermis has stomata predominantly on the lower leaf surface (hypostomatic type), surrounded by two or more irregularly polygonal subsidiary cells. The upright stem has a well-defined ring structure. Vascular tissues (xylem and phloem) exhibit wide vessels typical of plants in regions with variable moisture. Mechanical tissues (sclerenchyma) near the phloem enhance stem strength (Fromm, 2019). The large funnel-shaped flowers exhibit bright blue coloration due to anthocyanins in the epidermal cells of the petals (Fig. 1a, b, c). The perianth is multilayered, protecting reproductive organs from cold temperatures. Stamens are attached to the corolla tube, and the gynoecium consists of two fused carpels with a superior ovary. Seeds are small, with a dense seed coat rich in sclereid cells, providing resistance to mechanical damage and environmental stress. *G. tianschanica* is well-adapted to alpine conditions, such as low temperatures, high UV radiation, and limited moisture. Comparative anatomi-

A B C

Figure 1 *Gentiana tianschanica* in the Kimasar gorge (A), Big Almaty gorge (B) and Kaskelen gorge (C) population.

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cal studies with other *Gentiana* species reveal unique features specific to Ile Alatau populations. Research into the plant's vascular tissues highlights their role in water and nutrient transport under high-altitude climates (Zhang *et al.,* 2014). The species can serve as an indicator of alpine ecosystem health due to its sensitivity to changes in soil properties and climate.Laboratory studies have demonstrated the antimicrobial activity of *G. tianschanica* extracts against pathogenic bacteria and fungi . Additionally, its potential as an anti-inflammatory agent is under investigation (Zahra *et al.,* 2023). A 2023 study showed that root tinctures of the plant reduced oxidative stress levels in experimental animals (Prasher *et al.*, 2023). The roots of *G. tianschanica* are rich in iridoids, xanthones, and flavonoids, which possess anti-inflammatory, antioxidant, and antimicrobial properties. In traditional medicine, the plant is used to treat gastrointestinal disorders and boost immunity. Studies of its chemical composition highlight its p otential for developing new phytopharmaceuticals (Tynybekov *et al.,* 2013). The Ile Alatau is one of the ridges comprising the Northern Tien Shan, alongside the Kungei Alatau ridge. To the north, it is bordered by the Ili depression, a wide tectonic trough, while to the south, it is separated by the narrow valleys of the Chilik and Big Kemin rivers from the Kungei Alatau ridge. In its central part, it merges with the Kungei Alatau ridge, forming the Chilik-Kemen or Talgar mountain junction. Westward, after the Kastek Pass, the Ile Alatau transitions into the Kendyktas uplands, while to the east, it concludes with a series of low ridges after crossing the Chilik River (Fig.2.) The primary section of the protected area lies on the northern slope of the Ile Alatau. Its western boundary runs alongside the Left Talgar River, the northern boundary follows the Right Talgar River, and the eastern boundary aligns with the crest of a high spur that separates the valleys of the Esik and Turgen rivers. This formidable snow ridge extends nearly 300 kilometers from west to east and spans 30-40 kilometers in width. Peak elevations reach up to 5017 meters above sea level (Seitkali *et al.,* 2023; Jashen-ko *et al.,* 2023). The foothills of the Ile Alatau span an elevation belt ranging from 1000 to 1700 meters above sea level. These foothills consist of a thick layer of loess-like loam, featuring relatively flat peaks and steep slopes (Rakhimova *et al.,* 2021). The soil composition of the Ile Alatau exhibits distinct tiers, with various soil types distributed from top to bottom. These include mountain meadow, high-mountain meadow-steppe, high-mountain steppe, high-mountain dark-colored, mountain forest dark-colored, mountain forest dark-gray, mountain forest chernozemic, mountain forest-meadow, moun-

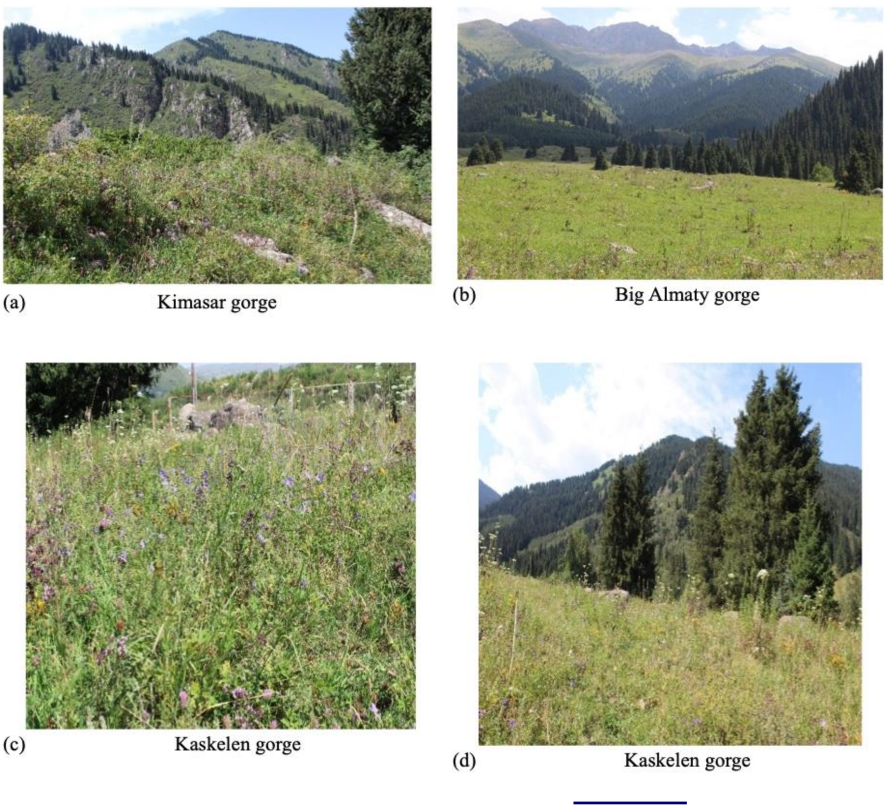

Figure 2. *Distribution of G. tianschanica populations in the gorges of Kazakhstan*

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tain meadow-steppe, mountain steppe thermocero-morphic, mountain and foothill steppe chernozems, mountain and foothill chestnut soils, foothill siero-zems, foothill brown, and desert soils (Kulymbet *et al.,* 2023). High-mountain steppe soils develop under re-latively more xerothermic conditions compared to the corresponding high-mountain meadow-steppe soils. Mountain forest-meadow soils are predominantly found in the middle mountain areas within the coni-ferous forest belt, primarily on less steep slopes with northern exposures (Pachikin *et al.,* 2014). The main purpose of the research is to assess the current soil conditions within the populations of *Gentiana tianscha-nica* located in the Ile Alatau.

Materials and methods

Study of the region

The research was conducted in March-April 2024 within the South-Eastern region of Kazakhstan, specifically in the Ile Alatau region, encompassing the Kimasar gorge (population 1), Big Almaty gorge (population 2), and Kaskelen gorge (population 3) (Fig. 3). Situated within the bed of the identically named river on the northern slope of the Ile Alatau, the Big Almaty gorge lies within the confines of the Ile-Alatau Nature Park. It comprises two branches: the Prokho-dnaya river and the Ozernoye gorge (Akhmetova *et al.,* 2015). Amongst the gorges of the Ile Alatau, the Small Almaty gorge is notably intricate, comprising numerous ravines and flaps. The largest among them is the Kimasar (Komissarovka) gorge, which houses the Kimasar camp and terminates with the Komissarovka Pass (Toktar *et al.,* 2017).

Relief. The Ile Alatau region boasts a diverse and complex terrain originating from various geological processes (Toktar *et al.,* 2021, Ydyrys *et al.,* 2013) distinguishes seven types of terrain united into two complexes: erosion-tectonic (mountainous) and accu-mulative - tectonic (plain). Overall, the entire Tien Shan range is relatively youthful, formed by tectonic uplifts and folding over existing, heavily eroded terrain. The western segment of the ridge, known as the Kendyk-Tass mountains, stretches from northwest to southeast, featuring level surfaces hosting low plateaus (such as Kurdai, Argaityn, etc.) with elevations up to 1,500 meters. The eastern extremity of the Ile Alatau occupies the interfluve of the Chilik and Charyn rivers, comprising two parallel ridges: the Syugaty Mountains in the north and the Tur-Aigyr mountains in the south (Ydyrys *et al.,* 2022).

Climate. The climate of the Ile Alatau, like that of many mountainous regions, varies with altitude, latitude, longitude, and distance from oceans (Zubairov *et al.,* 2018). Its central position within the Eurasian continent and its southern latitude contribute to heightened temperatures, reduced moisture, and pronounced continental characteristics. Nevertheless, as elevation increases in the foothills, moisture levels rise, moderating summer temperatures and ameliorating winters. Over a mere 100 kilometers from the foothill plains to snow-capped peaks, the climate transitions from hot and arid to humid and extremely cold (Panyushkina *et al.,* 2017). Elevations

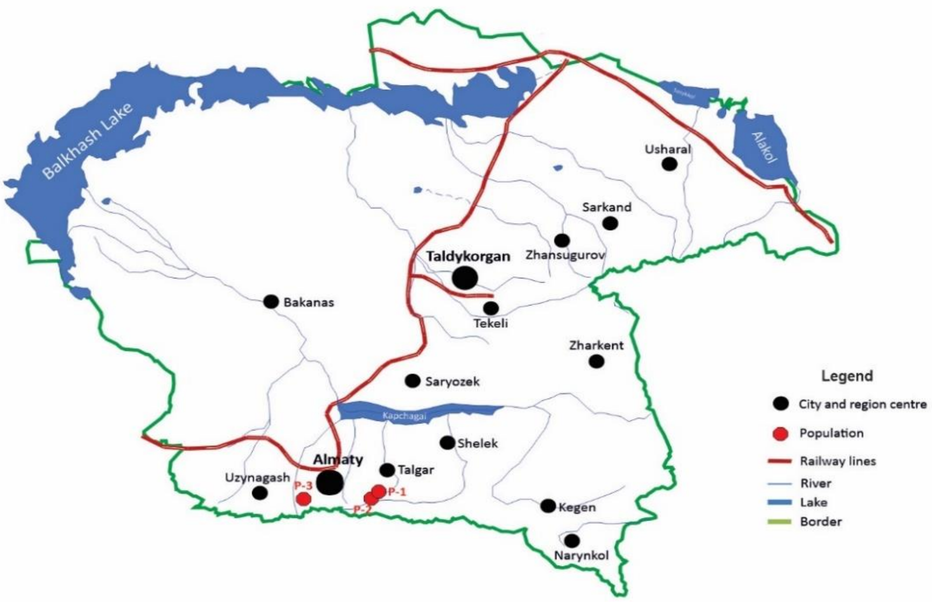

Figure 3.
Study region map

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ranging from 600 to 1700 meters above sea level experience an average annual temperature of +7.50°C, with July being the warmest month at +19.0°C. December registers as the coldest month, with an average temperature of approximately -7.0°C, and an average annual precipitation of about 850 mm. At altitudes of 1800 to 2700 meters above sea level lies the spruce-forest belt, characterized by a mountain climate with mild winters and abundant sunshine. Negative temperatures persist from November to March, with December being the coldest month at 6.30°C on average, and July the warmest, at an average of +15.0°C annually. Between 2700 and 3360 meters above sea level, snow cover remains for eight months of the year. February marks the coldest month, with an average temperature of 1.20°C. Summers are brief, with occasional frosts even in the warmest periods. July records an average temperature of +7.70°C, while the average annual temperature stands at -2.0°C. As altitude increases, climate severity intensifies, accompanied by unpredictable weather patterns. The average annual temperature reaches 6.40°C, with the coldest month averaging 15.50°C (Alibek *et al.,* 2024, Gass, 2011).

Research methods

The research employed a combination of field work and laboratory analysis to comprehensively study the soil characteristics of the *G. tianschanica* populations in the Kimasar, Big Almaty, and Kaskelen gorges. Field studies involved documenting the natural conditions of the study sites and establishing soil transect profiles to evaluate their morphological characteristics. Soil samples were collected systematically from varying depths for subsequent laboratory analysis. Field procedures, including sampling and sample preparation, followed standardized methodologies (Kobylina *et al.,* 2024) ensuring consistency and accuracy in data collection. Laboratory analysis was conducted to determine the chemical properties and granulometric composition of the collected soil samples. The following parameters were analyzed using established GOST standards (state standard): *Mobile nutrient elements:* Nitrogen, phosphorus, and potassium. Salt content and ionic composition: *Anions* (CO_3^{2-}, HCO_3^-, Cl-, SO_4^{2-}) and cations (Ca^{2+}, Mg^{2+}, Na^+, K^+). pH levels: Measured in aqueous soil extracts. Organic matter content: Humus. *Carbonates:* CO_2 content (Imanaliyeva *et al.,* 2024). The granulometric composition of the soil was also analyzed to classify its texture and understand its impact on soil fertility, water retention, and plant growth. This methodology involved detailed documentation of soil profiles, including their chemical and physical properties, and systematic soil sampling from varying depths for laboratory analysis. Standardized procedures ensured consistency and accuracy in data collection.

Results and Discussion

Soil morphological description

Population 1 (Fig.4e.), Kimasar gorge. Kimasar gorge is a gorge of the Komissarovka River, a left tributary of the Kishy Almaty. Towards its upper reaches, the gorge branches off.

Soil type : Mountain-meadow chestnut.

Population 2 (Fig.4f.), Big Almaty gorge. The gorge comprises both western and eastern branches. The western branch extends towards the Alma-Arasan valley, while the eastern branch leads to the Big Alma-

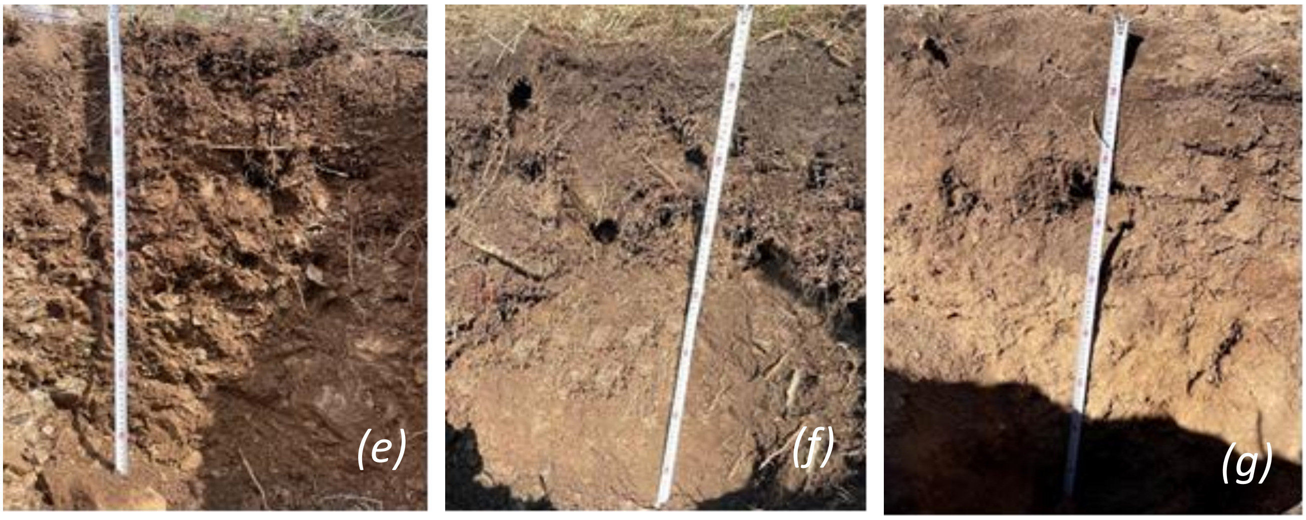

Figure 4. *Soil profiles: Population-1(e), Population-2(f), Population-3(g)*

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ty Lake, renowned as a prominent local natural attraction.

Soil type : Mountain-meadow sod dark chestnut.

Population 3 (Fig.4g.), Kaskelen gorge. The gorge represents the westernmost segment in the chain of forested spurs of the Ile Alatau. As one progresses further, the mountains gradually decrease in height, shedding their spruce cover and adopting a landscape more akin to steppes.

Soil type: Mountain-steppe thermoxeromorphic dark chestnut.

Analysis of physical and chemical properties of soils

The table includes data for three pedons (P-1, P-2, P-3), sampled at various depths, ranging from surface layers (0–10 cm) to deeper layers (70–80 cm or 90 cm) (table 1 and 2). Laboratory analysis of mountain meadow chestnut soils from the Kimasar gorge revealed medium humus content ranging from 2.84% to 6.18% within the 0-80 cm soil layer (Dergacheva, 2021). This refers to the soil pH measured in water (1:2.5 w/v). The pH values are mostly around neutral to slightly alkaline (ranging from 6.0 to 6.66 across the depths). These pH values suggest that the soil does not have severe acidity or alkalinity. This is the pH value measured in a calcium chloride solution, which is slightly lower than the pH in water, suggesting minor changes in the ionic environment due to the presence of salts. Values are similar across pedons. Total calcium carbonate (d $CaCO_3$ tot.) and active calcium carbonate (e $CaCO_3$act.) are measured in

Table 1. *Main morpho-descriptive and chemical features of the Mountain-meadow Kastanozems.*

Pedons	Horizon	Depth	aColour	bTexture	cStructure	pH	O:M:	Clay	$CaCO_{3tot}$	$CaCO_{3act}$
		cm					%		g kg^{-1}	
P-1	A	0-10	10YR3/2	SC	gr/sbk,f/m,3	6.01	6.18	130	27	13.2
	B	10-36	10YR4/3	CL	sbk,f/m,3	6.53	3.52	40	23	10.5
	BC	36-80	7.5Y3/2	SC	sbk/abk,m,3	6.49	2.84	404	17	7.6
P-2	A	0-8	10YR3/3	CL	gr/sbk,m/co,3	6.66	18.8	180	44	20.1
	B	8-32	7.5YR3/2	CL	sbk,m/co,3	6.48	12.1	120	27	12.3
	BC	32-80	7.5Y4/3	SCL	sbk/abk,m,3	6.50	7.36	330	33	14.3
P-3	A1	0-9	10YR4/2	SL	gr/sbk,f/m,3	6.0	10.0	290	47	21.4
	A2	9-40	10YR6/2	SL	sbk,f/m,2	6.1	3.90	330	23	11
	B	40-70	7.5Y4/3	LS	sbk/abk,m,2	6.3	1.42	80	23	11
	BC	70-90	5YR4/6	LS	sg ,m,2	6.22	0.64	80	20	9.6

aDry Munsell colour - bTexture: CL=clay loam; L=loam; SCL=sandy clay loam; SL=sandy loam; SC=sandy clay; LS =Loamy sand - cStructure: nd=not described; gr=granular; sbk=subangular blocky; abk=angular blocky; pr=prismatic; sg=single grain; pl=platy; m=massive; f=fine; m=medium; co=coarse; 1=weak; 2=moderate; 3=strong.

Table 2. *Main chemical and physical features of the Mountain-meadow Kastanozems.*

Pedons	Depth	apH		bTexture	Clay	$CaCO_3$		f C.E.C.	O.M.	N.	P_2O_5	K_2O
		H_2O	$CaCl_2$			d tot.al	e act.					
	cm					g kg^{-1}		mg-eq/100 g	%		mg/kg	
P-1	0-10	6.01	5.9	SC	130	27	13.2	25.2	6.18	100.8	42	430
	10-36	6.53	6.21	CL	40	23	10.5	26.3	3.52	70.0	26	200
	36-80	6.49	6.2	SC	40	17	7.6	27.7	2.84	47.6	22	140
P-2	0-8	6.66	6,3	CL	180	44	20.1	50.2	18.8	140	98	1000
	8-32	6.48	6,1	CL	120	27	12.3	43.3	12.1	126	58	560
	32-80	6.50	6,2	SCL	330	33	14.3	32.8	7.36	120.4	64	470
P-3	0-9	6.0	5.8	SL	290	47	21.4	36.8	10.0	72.8	134	490
	9-40	6.1	5.9	SL	330	23	11.0	22.7	3.90	70.0	86	240
	40-70	6.3	6	LS	80	23	11.0	12.8	1.42	42.0	48	160
	70-90	6.22	5.9	LS	80	20	9.6	10.4	0.64	33.6	28	110

apH: 1:2.5 (w/v) - bTexture: CL=clay loam;, L=loam; SCL=sandy clay loam; SL=sandy loam; SC=sandy clay; LS =Loamy sand - O.M % = Soil organic matter - d$CaCO_3$ tot. = gas-volumetric method - e$CaCO_3$ act. = $KMnO_4$ method - fC.E.C. = cation exchange capacity ($C_2H_3O_2NH_4$, pH 7) - O.M % = Soil organic matter; Nmob.= mobile nitrogen in the soil; P2O5mob.= mobile phosphorus in the soil; K2Omob.= mobile potassium in the soil.

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g/kg. P-1 has 27–44 g/kg total $CaCO_3$ at the surface to subsoil, indicating moderate lime content. P-2 has higher total CaCO3, especially in the surface (44 g/kg), while P-3 has relatively lower $CaCO_3$ content (Table 1 and 2). Organic matter content varies widely across pedons and depths. For example, P-1 has about 6.18% organic matter at the surface, which drops to 2.84% at the 36-80 cm depth. P-2 shows higher organic matter content, especially in the surface layer (18.8%), compared to P-3, which has about 10% organic matter in the surface layer (Table 1 and 2). Cation exchange capacity is measured in mg/kg, indicating the soil's ability to hold positively charged ions. P-1 has a C.E.C. around 25–27 mg-eq/100 g in soil, while P-2 has higher values, especially in the surface (50.2 mg-eq/100 g in soil), suggesting it has a higher nutrient-holding capacity. P-3 has moderate C.E.C. values. The nitrogen content with higher values in P-1 (42 mg/kg at the surface) compared to P-2 and P-3(table 1 and 2). Organic matter content varies widely across pedons and depths. For example, P-1 has about 6.18% organic matter at the surface, which drops to 2.84% at the 36-80 cm depth. P-2 shows higher organic matter content, especially in the surface layer (18.8%), compared to P-3, which has about 10% organic matter in the surface layer (Table 1 and 2). Cation exchange capacity is measured in mg/kg, indicating the soil's ability to hold positively charged ions. P-1 has a C.E.C. around 25–27 mg-eq/100 g in soil, while P-2 has higher values, especially in the surface (50.2 mg-eq/100 g in soil), suggesting it has a higher nutrient-holding capacity. P-3 has moderate C.E.C. values. The nitrogen content with higher values in P-1 (42 mg/kg at the surface) compared to P-2 and P-3(table 1 and 2). The mobility of these elements is measured in mg/kg, with P-2 showing very high phosphorus content, especially in the surface (140 mg/kg), and moderate potassium content. P-1 and P-3 have more variable concentrations, with moderate phosphorus and potassium. the dark chestnut soil of the Big Almaty gorge exhibited high levels of mobile nitrogen, phosphorus, and potassium, while the dark chestnut soil of the Kaskelen gorge demonstrated high levels of mobile phosphorus (table 1 and 2). The granulometric composition of soils in the studied populations reveals significant variation across the gorges, reflecting the influence of local geological and hydrological factors on soil formation and structure. The predominance of specific fractions in each population provides insight into soil texture, which directly impacts water retention, aeration, and nutrient availability—key factors for plant growth and survival. Soil texture is given as classifications like SC (sandy clay), CL (clay loam), SCL (sandy clay loam), SL (silt loam), and LS (loamy sand), which describe the relative proportions of sand, silt, and clay in the soil. The texture varies with depth (table 1). P-1 has a mix of sandy clay and clay loam at different depths. P-2 shows clay loam and sandy clay loam, with a texture change at deeper layers. P-3 has a mixture of silt loam and loamy sand, indicating a slightly lighter texture compared to the other pedons. The clay content varies across pedons and depths. For example, P-1 has around 130 g/kg of clay at the surface, decreasing to 40 g/kg at deeper layers. P-2 has much higher clay content, especially in the topsoil (180 g/kg), while P-3 shows high clay content in the surface layer but lower amounts in deeper layers (Table 1 and 2). These differences in granulometric composition highlight the diverse soil environments across the studied gorges, which influence the ecological niches and adaptive strategies of *G. tianschanica*. The dominance of coarse fractions across all populations underscores the importance of physical soil structure in supporting this species, particularly in mountainous regions with variable climatic conditions. Future research should explore the relationship between soil texture and plant physiology, focusing on how granulometric composition affects root structure, water uptake, and nutrient absorption. Understanding these interactions is crucial for the conservation of *G. tianschanica* and the management of its habitats under the pressure of climate change and anthropogenic activities. The granulometric composition of the soil and its porosity are closely associated with properties such as water retention, moisture permeability, moisture capacity, the capacity to accumulate organic substances, and air-thermal regimes (Ason *et al.,* 2022, Kosheleva *et al.,* 2015). The analysis of absorbed bases in the soils of *G. tianschanica* populations reveals notable variability across the studied locations. The predominance of absorbed calcium across all populations aligns with the known role of calcium in maintaining soil structure, fertility, and plant health. However, the variations in total absorbed bases and their distribution reflect the influence of local environmental and geological conditions. In Population 1, the relatively low total content of absorbed bases within the 0–80 cm soil layer, along with a consistent calcium concentration (20.8–23.76 mg-eq per 100 g), suggests limited nutrient availability, potentially constraining plant growth. Despite this, the dominance of calcium indicates a favorable condition for root development

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and nutrient uptake, critical for sustaining endemic plant species like *G. tianschanica*. Population 2 displayed a broader range of absorbed bases (19.8–38.61 mg-eq per 100 g of soil), with magnesium playing a secondary role after calcium. This variation may be attributed to differences in soil texture or the degree of weathering. The higher levels of absorbed bases in this population's soil profile may contribute to the observed diversity and density of plant communities in this area, highlighting its ecological importance (Fig.4). Interestingly, Population 3 exhibited a markedly lower total content of absorbed bases (0.22–0.40 mg-eq per 100 g), with absorbed calcium still remaining the predominant ion. However, magnesium showed a relatively higher range (2.48–11.39 mg-eq), indicating that while calcium dominates, magnesium may also significantly influence soil and plant interactions in this site. Such low nutrient levels suggest that this population thrives in relatively poor soils, which may point to adaptive mechanisms of *G. tianschanica* to nutrient-limited environments. These findings highlight the variability in soil chemical properties across the studied populations and their potential ecological implica-tions. The predominance of absorbed calcium across all populations emphasizes its critical role in the soil-plant system, particularly in supporting endemic and medicinally valuable species. Future studies should investigate the physiological adaptations of *G. tianschanica* to these soil conditions and explore seasonal and anthropogenic influences on soil chemistry. Such research is essential for devising conservation strategies to protect both the species and its unique habitat.

Analysis by the amount of salt in the soil

The analysis of salt content in different types of soils from three gorges—Kimasar, Big Almaty, and Kaskelen—provides valuable insights into the chemical characteristics and potential environmental conditions of these regions. The observed variations in ion concentrations and total salt content suggest differences in soil formation processes, water availability, and the influence of local vegetation and climate. Absence of Carbonates (CO3-). In all three soil types, carbonate ions (CO3-) were either undetected or present in trace amounts (e.g., 0.001% in Kaskelen). This absence might indicate the soils are not strongly alkaline and are instead neutral to slightly acidic. This finding is consistent with soils found in regions with moderate precipitation, which tends to leach out carbonates over time. Bicarbonates (HCO3-) in chestnut soils of Kimasar, bicarbonates were relatively low (0.08–0.12%), indicating lower buffering capacity against acidify-cation. In dark chestnut soils of Big Almaty, the bicarbonate concentration was significantly higher (0.20–0.40%), reflecting better buffering properties and perhaps higher biological activity or carbonate weathering in this region (Fig.5). In Kaskelen, the bicarbonate levels (0.12–0.28%) were intermediate, suggesting moderate environmental conditions between those of Kimasar and Big Almaty. Chlorides (Cl^-) on concentrations were similar across the gorges (0.04–0.07%), except for a slightly higher range in Kaskelen (up to 0.15%). Chlorides often reflect soil salinity levels and water movement. Higher Cl^- levels in Kaskelen could indicate periodic irrigation or water stagnation, leading to salt accumulation. Kimasar soils had moderate sulfate levels (0.29–0.61%), suggesting some input from mineral weathering or local vegetation. Big Almaty soils had the highest sulfate concentrations (0.63–0.84%), which may indicate higher levels of gypsum or other sulfate minerals in the parent material or greater influence of external inputs like runoff. In Kaskelen, sulfates showed the broadest range (0.09–0.46%), implying variable conditions, such as alternating wet and dry periods that could influence sulfate leaching. Big Almaty soils had the highest Ca^+ content (0.19–0.29%), suggesting better nutrient availability or higher calcareous material. Kimasar and Kaskelen soils showed lower and similar Ca^+ levels (~0.10–0.19%), indicating potential nutrient limitations in these areas. Mg^{2+} levels varied widely, with Kimasar showing the broadest range (0.19–0.48%) and Big Almaty recording a fixed value of 0.48%. Magnesium plays a crucial role in plant metabolism, and its high availability in Big Almaty soils may support richer vegetation. Na^+ content ranged more widely in Kimasar (0.04–0.19%), suggesting potential salinity issues. Big Almaty and Kaskelen soils showed narrower ranges (0.10–0.16%), indicative of more stable conditions. Potassium levels varied significantly across regions, with Big Almaty showing the highest range (0.09–0.41%), reflecting better soil fertility. In contrast, Kimasar and Kaskelen had lower and narrower ranges (0.02–0.15%), potentially limiting plant growth (Fig.5.). Soils from Big Almaty gorge had the highest total salt content (0.059–0.098%), indicating a saline tendency Figure5. This could impact vegetation composition and soil health, requiring consideration for agricultural or conservation activities. Kimasar soils showed moderate salinity (0.027–0.054%), suggesting favorable condi-

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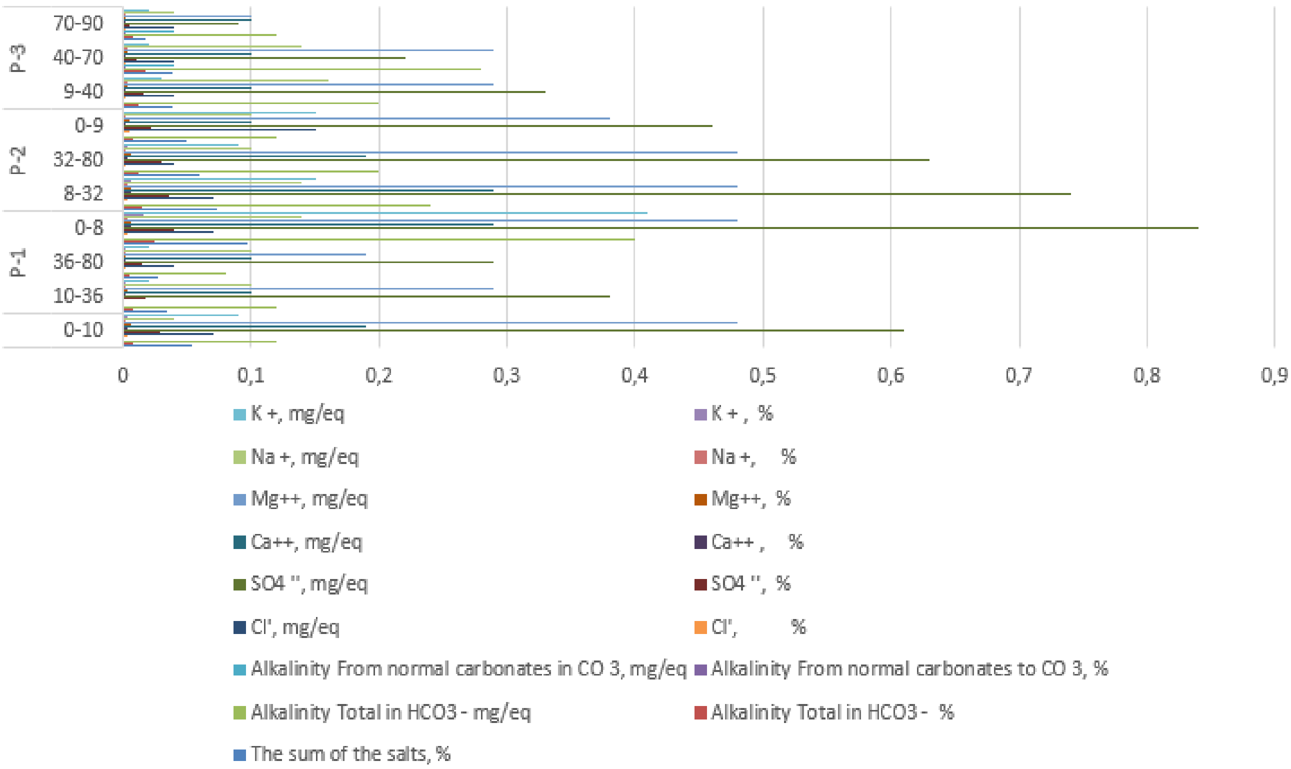

Figure5. *Salt profile of soils from the Kimasar*

tions for diverse plant growth without significant salinity stress (Fig. 5.). Kaskelen soils exhibited the lowest salinity (0.018–0.049%), likely supporting sensitive plant species that cannot tolerate high salt concentrations (Fig. 5.). The observed salt content and ionic composition highlight the ecological diver-sity of the three gorges: Big Almaty gorge soils are richer in salts and nutrients, potentially supporting a diverse and productive ecosystem but with a risk of salinization in agricultural use (Ivashcenko *et al.,* 2021). Kimasar gorge soils are moderately saline and nutrient-rich, suitable for robust vegetation and agricultural applications with minimal soil management. Kaskelen gorge soils have lower salt content, making them suitable for sensitive crops or natural vegetation adapted to low-salinity environments.

Conclusions

The study investigated the soil properties of *G. tianschanica* populations in three gorges of the Ile Alatau: Kimasar, Big Almaty, and Kaskelen. The findings emphasize the ecological and environmental importance of monitoring soils to sustain both natural ecosystems and agricultural activities in mountainous regions. This research highlights the diversity of soil types, which directly influence the growth and survival of endemic plant species such as *G. tianschanica.* For instance, the superior fertility of the dark chestnut soils in the Big Almaty gorge, with humus content reaching up to 18.78%, underscores the importance of this area for preserving rare and medicinal plants. The predominance of absorbed calcium and light loamy granulometric composition across all study sites suggests favorable conditions for plant root development. Despite slight variations in salinity, the soils are non-saline, which ensures suitability for both native vegetation and potential agricultural use. Furthermore, the observed differences in soil properties between gorges are shaped by local geological and climatic factors, making this study an essential contribution to understanding plant-soil interactions in the unique environment of the Ile Alatau. Future research could explore seasonal dynamics, human impact, and the potential of these soils for supporting adaptive land management strategies under changing climatic conditions. This research not only deepens our understanding of *G. tianschanica's* habitat requirements but also lays a foundation for broader conservation initiatives aimed at preserving the unique biodiversity of Kazakhstan's mountainous ecosystems.

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Supporting information

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