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Seed morphology and seed coat micromorphology of *Linaria cretacea* Fisch. ex Spreng. from chalk outcrops of Western Kazakhstan

The investigation of seed morphology and seed-coat micromorphology is important for taxonomy, ecology, and the conservation of rare endemic plants, particularly species restricted to specialized habitats such as chalk outcrops. In calciphilous plants with narrow distribution ranges, seed-coat micromorphology can serve as a useful diagnostic feature for species identification, clarification of taxonomic relationships, and the development of ex situ conservation measures. This study examined the morphological characteristics of the seeds and fruits of *Linaria cretacea* Fisch. ex Spreng., a rare calciphilous endemic species restricted to chalk outcrops in Western Kazakhstan, using scanning electron microscopy (SEM) and light microscopy. Macro- and microimages of the seeds were obtained, and their main morphometric parameters, including length, width, thickness, and shape index, were measured. Seed-coat sculpture was described at the primary, secondary, and tertiary levels following the classifications proposed by W. Barthlott and W. Stearn. The results showed that *L. cretacea* from the Aktobe Region is characterized by a cerebelliform primary sculpture with clearly defined anticlinal boundaries, a sharply tuberculate secondary sculpture with reticulate elements, and the absence of epicuticular wax. Comparison of the seed-coat traits identified in this study with published descriptions of the closely related species *L. vulgaris* and *L. genistifolia* revealed a set of diagnostically significant micromorphological differences. The possible adaptive role of seed-coat structure in chalk habitats with low water-retention capacity is also discussed. The findings are of both systematic and practical value, particularly for the identification of herbarium specimens and the development of protection and ex situ conservation protocols for this rare species.

Keywords: *Linaria cretacea*, Kazakhstan, calciphilous species, endemic species, seed morphology, scanning electron microscopy, light microscopy, features.

Introduction

The first information about the vegetation of chalk outcrops dates back to the works of I.A. Gldenstdt [1, 2]. In the 19th and early 20th centuries, the study of the flora of such habitats acquired a systematic character: significant contributions were made by Chernyaev [3], Litvinov [4, 5], Popov [6], Sagalaev [7], Sukachyov [8], Golitsyn [9], Klovov [10], Taliev [11–13], Kozo-Polyanskii [14–16], Kotov [17], Lavrenko [18] and others. The problem of the origin of chalk outcrops—natural or anthropogenic—was actively considered by classics of botany. Modern studies continue to clarify the composition of the flora and characteristics of chalk cliff communities, although a number of local and taxonomic issues remain insufficiently studied [19].

In carpological studies, seed macro- and micromorphology are considered key diagnostic characters in the taxonomy of angiosperms [20–22]. Of particular importance for taxonomic conclusions and evolutionary-functional interpretations are data on the ultrastructure of the seed coat obtained using SEM [23–26]. However, for a number of local, rare, and ecologically specialized taxa, data on seed microsculpture remain absent or are fragmentary.

Linaria cretacea Fisch. ex Spreng. is a perennial calciphyte with a taproot system that is strictly confined to chalk habitats within its Eastern European and Sub-Ural range. Its vegetative and reproductive traits (dwarfism, compact generative shoots, yellow corolla with a prominent spur) are consistent with life on steep chalk slopes and among rocky boulders.

Despite the recognized importance of seed traits in taxonomy and ecology, a comprehensive study of *L. cretacea*'s seed micromorphology, combining modern SEM techniques, quantitative morphometrics, and comparison with related species, remains lacking. The seed morphology of representatives of the section *Linaria* has been described in the literature. However, specific information on primary and secondary sculpture, the degree of exotesta tortuosity, the presence/absence of epicuticular wax, and their functional interpretation are lacking for *L. cretacea* in the regional context of Cretaceous habitats in Kazakhstan.

This study examines the seed morphology and seed coat micromorphology of *L. cretacea* from the chalk outcrops of the Aktobe Region using scanning electron microscopy (SEM), light microscopy, and quantitative morphometric analysis. The research focuses on the description of the primary, secondary, and tertiary sculpture of the seed coat according to established classifications, comparison with closely related *Linaria* species, and evaluation of the taxonomic and adaptive significance of the identified traits in chalk habitats. Field material was collected from chalk massifs of the Aktobe Region during 2023–2025. Seeds were prepared for SEM following standard procedures, including fixation and gold sputtering, and the different levels of seed coat sculpture were described using accepted morphological terminology.

The identified seed-coat characters of *L. cretacea* were considered in comparison with published descriptions of selected representatives of the genus *Linaria*. This comparison was used to establish a general diagnostic framework and was not intended as a direct SEM-based species-to-species analysis of *L. vulgaris* and *L. genistifolia*. Because *L. cretacea* is a narrow chalk endemic, whereas related species of the genus occur in broader ecological settings, the literature data were employed only to indicate the possible taxonomic and ecological significance of the revealed seed traits.

The key result of the work is a deeper understanding of the micromorphology of a rare calciphilous species, the identification of diagnostic features for taxonomic purposes and herbarium identification, and the creation of a basis for subsequent studies of the ecology of germination and measures to conserve *L. cretacea* populations in chalk habitats.

Figure 1 presents images of *L. cretacea* growing on chalk slopes in the Aktobe Region, depicting the overall habit of the species and its typical habitat.

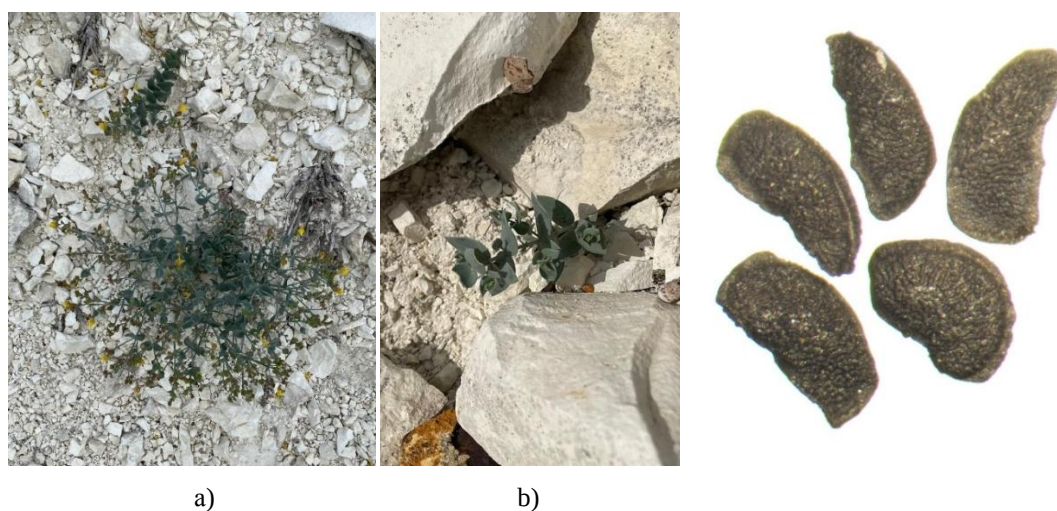


Figure 1. *Linaria cretacea* in the Aktobe region: a) view of the plant; b) view of the seeds

Experimental

Material for carpological analysis was collected during June–July of 2023–2025 on the chalk massifs of the Aktobe Region (Tab. 1). For each sampling site, the coordinates, collection date, elevation above sea level, slope exposure, and general habitat characteristics were documented. For the morphometric and micro morphological study, 1,000 seeds (thousand-seed weight 0.20 g) collected from mature capsules of the two populations were analyzed.

Table 1

Characteristics of the studied sites of *Linaria cretacea*

Point number	Coordinates (latitude, longitude)	Elevation above sea level, m	Location	Slope aspect	Habitat characteristic
1	N49°20'031'' E 054°30'024''	≈ 215 m	Akshatau Chalk	Southeast	A steep slope consisting of chalk marl and carbonate clays
2	N50°32'069'' E 054°54'341''	≈ 235 m	Ishkargan Chalk	South	A gravel slope with exposed chalk bedrock

In the Aktobe Region of Western Kazakhstan, all major chalk outcrops were surveyed for *L. cretacea*, but the species was detected only at a few, markedly isolated locations. Intensive fieldwork in 2023–2025 showed that stable, self-maintaining populations are confined to the Akshatau and Ishkargan chalk massifs. On other chalk exposures, *L. cretacea* was either absent or represented by single, scattered plants, from which seed sampling is prohibited for conservation reasons. As a result, carpological material was collected only from these two populations, which constitute the main chalk massifs of the study area for this rare calciphilous endemic.

This study primarily sought to deliver a comprehensive qualitative and quantitative description of seed and seed-coat micromorphology at the species level. In this context, a rigorous statistical comparison between the two local populations was not pursued, as it lay outside the objectives of this initial investigation.

Seed and fruit morphology was investigated by light microscopy and scanning electron microscopy. The seed surface micromorphology of *L. cretacea* from the Aktobe Region was examined with JEOL JEM-1400 and JEOL JSM-6060LV scanning electron microscopes (JEOL Ltd., Tokyo, Japan). The analysis was performed on mature seeds. A total of 15 seeds were studied by SEM. To remove the cuticular layer, the seeds were kept in a chloroform–methanol mixture (1:1) for 48 h and then transferred through a graded ethanol series of 70 % and 90 %. After drying, the seeds were fixed directly onto specimen stubs with double-sided adhesive tape. Imaging at ×80 and ×100 magnification was used to record overall seed morphology, whereas ×500, ×800, and ×1500 magnifications were applied to examine the exo testa surface.

The resulting digital images were processed in Adobe Photoshop CS4. Seed surface descriptions were based on the shape of the principal cells, the structure of the anticlinal walls, including their thickness, sinuosity, and elevation above the surface, as well as the relief of the periclinal walls. Seed ultrastructure (primary, secondary and tertiary sculpture) was described using the terminology and morphotype categories proposed by Barthlott [23, 24], Stearn [25] and Segarra-Moragues & Mateu [26].

The terminology of W. Stearn and W. Barthlott [23, 25] was used to describe the ultrastructure of the seed coat. The classification provides for the distinction of three levels of sculpture—primary, secondary, and tertiary—with diagnostic features indicated (Tab. 2).

Table 2

Classification of seed ultrastructure according to W. Stearn and W. Barthlott with examples of morphotypes

Sculpture Level	Diagnostic Features	Examples of morphotypes	Characteristic features of <i>Linaria cretacea</i>
Primary	Exotesta cell shape, general pattern, type of anticlinal walls, border relief, curvature of outer periclinal walls	Comb-shaped, medulla-shaped, tuberculate, smooth	Cerebelliform; convolutions of slightly concave isodiametric cells; height 0.1–0.15 mm; margins recessed
Secondary	Relief of outer periclinal walls, location and shape of small elements	Reticulate, tuberculate, smooth, honeycomb	Low, closely spaced, acutely tuberculate cuticle deposits; tendency toward a reticulated pattern
Tertiary	Epicuticular secretions (wax: granules/flakes or absence)	Granules, scales, waxless	Epicuticular wax absent

The following parameters were assessed: seed shape; presence/absence of a wing; type of primary sculpture (comb-shaped, medulla-shaped, tuberculate, smooth); nature of cuticular deposits on the cell surface (reticular, papillary); tertiary sculpture (type of epicuticular wax or its absence).

Comparative information on other representatives of the genus *Linaria*, including *L. vulgaris* and *L. genistifolia*, was not obtained from original SEM observations in the present study and was used only as literature-based background for diagnostic interpretation.

For the morphometric analysis, measurements were obtained from the examined seed material in repeated observations. The quantitative data were summarized using descriptive statistical methods. For each measured trait, mean values, standard errors (Mean $\pm$ SE), and the minimum and maximum ranges were determined. Since the study was designed to provide an initial carpological and micromorphological characterization at the species level, no statistical comparison was carried out between the two sampled populations.

Results and Discussion

The fruits of *L.cretacea* are dry, multi-seeded capsules of oblong-round shape, approximately 3 mm in diameter. The locules are equal in size and dehisce through teeth at the apex (Fig. 2). The seeds gradually spill out through the resulting openings, driven by wind and stem vibrations.

The number of seeds in one capsule is 12–15, which is consistent with the data of Sutton and Viano [27]. The fruit weight is 3–4 mg, no more.

The passive seed dispersal range is determined by plant height and averages 12–35 cm—at the level of generative shoots. As a result, seeds are distributed within the parent patch of the coenopopulation, while their distant dispersal remains limited.

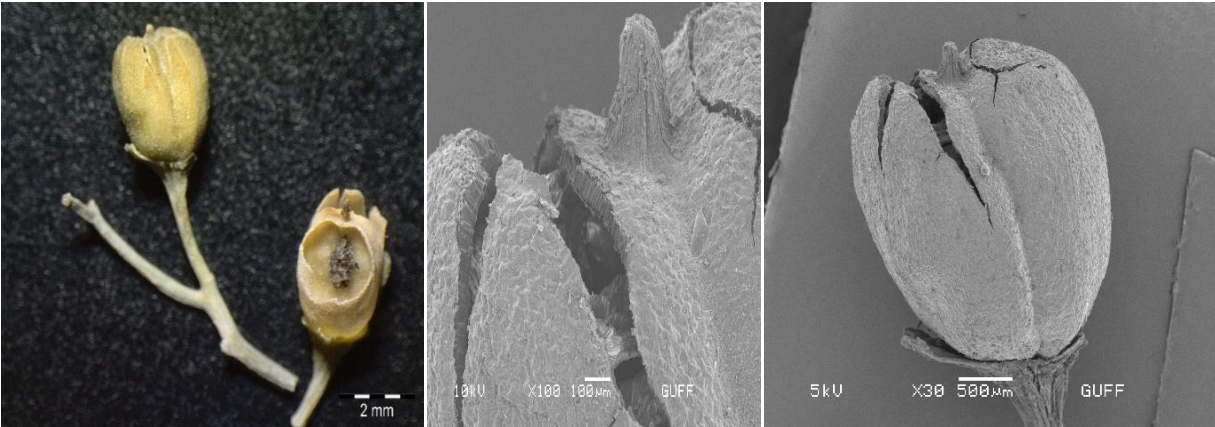


Figure 2. Macrophotography: general view of *Linaria cretacea* capsules

Morphometric characteristics of fruits are presented in Table 3.

Table 3

Morphometric parameters of *Linaria cretacea* fruits

Indicator	Mean $\pm$ SE	Minimum	Maximum
Capsule diameter, mm	3.02 $\pm$ 0.06	2.85	3.18
Number of seeds, pcs.	13.4 $\pm$ 1.1	12	15
Capsule length, mm	2.45 $\pm$ 0.08	2.30	2.60
Capsule width, mm	2.00 $\pm$ 0.07	1.80	2.20
Capsule weight, mg	3.5 $\pm$ 0.3	3.0	4.1
Shape	Oblong, rounded	—	—

The seeds of *L. cretacea* are small, elongate-reniform, and slightly curved; in cross section they are rounded with slight flattening on the dorsal side. Their mean dimensions are 1.20 $\pm$ 0.05 mm in length, 0.85 $\pm$ 0.04 mm in width, and 0.70 $\pm$ 0.03 mm in thickness (Tab. 4). The shape index (Length/Width) varies from 1.35 to 1.45, which indicates an elongated seed type (Fig. 3). The weight of 1000 seeds is 0.20 $\pm$ 0.01 g, confirming the very small size and low mass of the diaspores. Overall, the seeds are dark brown to black, slightly flattened, with a narrow marginal rim and a clearly expressed surface sculpture.

Table 4

Size and shape of *Linaria cretacea* seeds

Indicator	Mean $\pm$ SE	Minimum	Maximum
Length, mm	1.20 $\pm$ 0.05	1.00	1.85
Width, mm	0.85 $\pm$ 0.04	0.45	1.00
Thickness, mm	0.70 $\pm$ 0.03	0.25	0.55
Shape index (L/W)	1.41 $\pm$ 0.04	1.35	1.45
Form	Elongated, slightly reniform	—	—
Thousand-seed weight, g	0.20 $\pm$ 0.01	0.18	0.22

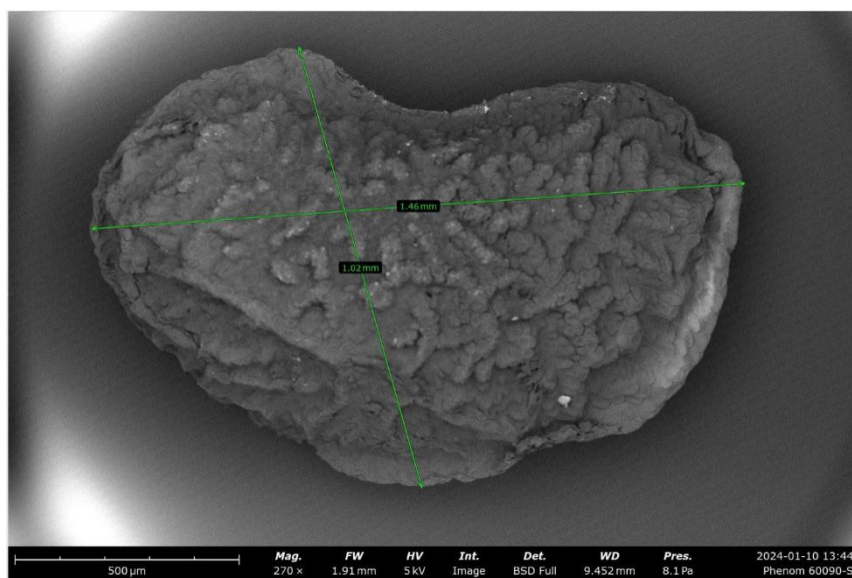


Figure 3. SEM image of *Linaria cretacea* seed, general view
(BSE mode, 5 kV, $\times 270$; scale bar = 500 μ m)

Observations under the light microscope showed that the seed surface is coarsely tuberculate and irregularly wrinkled, with a slight sheen. Examination by SEM provided a more detailed view of the seed coat ultrastructure and allowed the primary, secondary, and tertiary levels of sculpture to be distinguished.

In cross-section, the seed is characterized by a compact endosperm and a well-developed exotesta. The primary sculpture is cerebriform: the convolutions are formed by groups of slightly concave, isodiametric exotesta cells 0.10–0.15 mm high, often anastomosing. Cellular boundaries are deepened, with thin, discontinuous cuticular deposits.

The secondary sculpture is expressed by low, densely located, sharply tuberculate cuticular deposits, in places with a tendency to form a mesh pattern (Fig. 4).

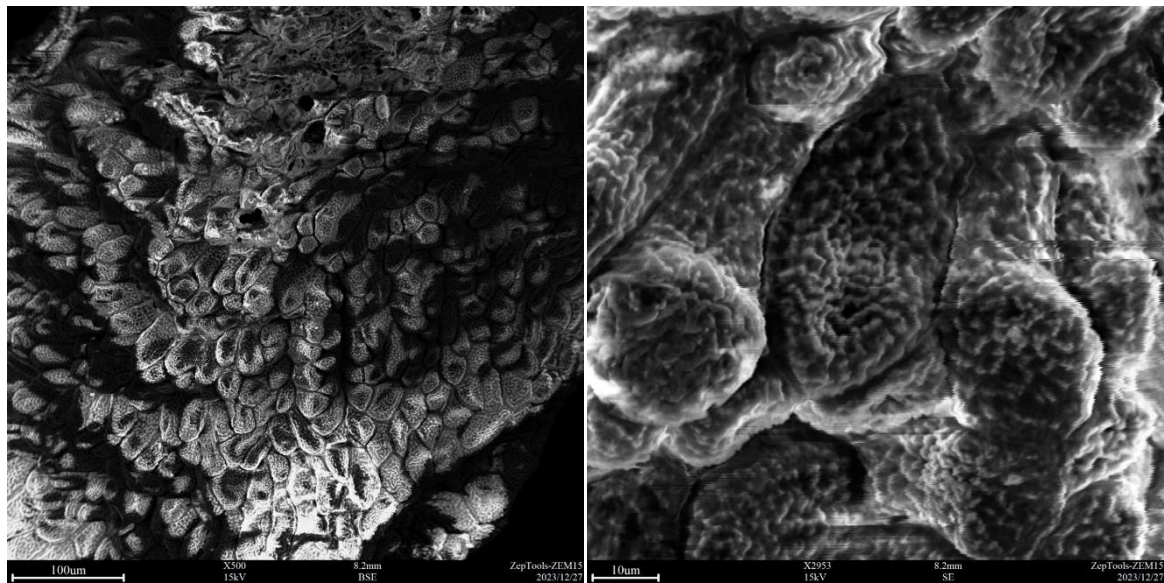


Figure 4. SEM images of the seed coat of *Linaria cretacea*, illustrating the cerebriiform primary sculpture and the distinctly tuberculate secondary sculpture (BSE mode, 15 kV, $\times 500$, scale bar = 100 μm ; SE mode, 15 kV, $\times 2953$, scale bar = 10 μm)

SEM images (Fig. 4) demonstrate the ultrastructure of the *L. cretacea* seed coat with a characteristic cerebellar type of primary sculpture. The exotesta cells are isodiametric, slightly concave; the anticlinal boundaries are clearly deepened and form a sinuous folded pattern. The convolutions of varying width often anastomose, forming a branched network; their height is approximately 0.10–0.15 mm. Secondary sculpture is represented by dense, low, sharply tuberculate cuticular deposits, in places imparting a reticulate-like relief to the surface. Epicuticular wax is not observed: wax granules and scales are absent, which is consistent with previously described characteristics of the species. This microrelief likely increases the mechanical strength of the coat and promotes moisture retention, which is important for germination in chalky substrates with low water holding capacity.

No epicuticular wax was detected on the examined seeds, as neither wax granules nor wax scales were observed even at the highest magnification. The main characteristics of the primary, secondary, and tertiary levels of seed-coat sculpture in *L. cretacea* are summarized in Table 5.

Table 5

Characteristics of seed sculpture of *Linaria cretacea*

Sculpture Level	Diagnostic features	Morphotype	Characteristics of <i>L. cretacea</i>
Primary	Shape and relief of exotesta cells	Cerebelliform	Isodiametric cells are slightly concave; margins are indented.
Secondary	Microrelief of periclinal walls	Tubercular with reticular elements	Low, sharp tubercles; elements are often closely spaced.
Tertiary	Epicuticular secretions	Absent	Wax granules/scales are not detected.

Consequently, the morphological and anatomical features of the fruits and seeds of *L. cretacea* correspond to the conditions of chalk outcrops: they provide protection for diaspores, promote moisture retention, and limit long-distance transport, which supports the preservation of populations in highly specialized habitats.

The results obtained on the morphological and anatomical structure of the seeds of *Linaria cretacea* confirm several carpological characters previously reported for the genus and, at the same time, provide new diagnostic details for this rare chalk endemic [26, 27]. The cerebriiform primary sculpture, with deeply marked anticlinal boundaries and no epicuticular wax, corresponds to the range of seed-coat characters described for *Linaria species* from arid and petrophytic habitats [23, 24, 26]. The secondary sculpture of *L. cretacea*, expressed as dense, sharply tuberculate cuticular deposits with a local tendency toward reticula-

tion, can be considered diagnostically informative; however, the present study is not intended as a direct SEM-based comparison with particular related species.

Only *L. cretacea* is illustrated in this paper, as the study is based on original morphological and micromorphological observations of this species, whereas comparisons with related taxa are derived from published descriptions. Based on a combination of traits—including seed shape, the types of primary and secondary sculpture, and the presence or absence of wax secretions—*L. cretacea* occupies a distinct position among closely related taxa. These characteristics are useful for clarifying the species' intrasectional taxonomic status and for reliably distinguishing the species from morphologically similar taxa, including in the analysis of herbarium specimens lacking flowering shoots.

To assess the diagnostic significance of the observed traits, the seed morphology of *L. cretacea* was compared with published descriptions of the closely related species *L. vulgaris* and *L. genistifolia*. The results of this comparison are presented in Table 6.

Table 6

Diagnostic comparison of seed characters in *Linaria cretacea* and related species based on published sources

Trait	<i>L. cretacea</i>	<i>L. vulgaris</i>	<i>L. genistifolia</i>
Seed shape	Elongated kidney-shaped	Discoid, reniform	Tetrahedral
Primary sculpture	Cerebelliform	Pectinate	Comb-shaped
Secondary sculpture	Acute tuberculate, partially reticulated	Papillary, partially reticular	Reticulate
Epicuticular wax	Absent	Granules	Granules
Seed size, mm	1.0–1.5 × 0.7–1.0	2.5–3.2 × 0.9–1.0	0.8–1.2 × 0.6–0.9

Note. Compiled from sources [26, 27]

A comparison of the characters shows that *L. cretacea* differs from closely related species by a combination of an elongated kidney-shaped seed, a higher brain-shaped primary sculpture (0.10–0.15 mm), a sharply tuberculate secondary surface with elements of reticulation, and the absence of epicuticular wax, which makes this complex diagnostically significant for the identification of the species.

The unique structure of the *L. cretacea* seed coat can be interpreted as an adaptation to the conditions of chalk outcrops. The deep microrelief increases the mechanical strength of the coat and promotes the retention of a thin water film—an important factor for germination on low-water-holding substrates. These structural characteristics appear to influence not only protection, but also the course of germination. In *L. cretacea*, the pronounced cerebelliform primary relief, together with sharply tuberculate secondary elements and the absence of an epicuticular wax layer, affects both the rate and threshold of water uptake. Seeds are able to absorb moisture rapidly during short wetting episodes, while the water film retained in the surface sculpture slows drying and extends the time available for radicle emergence. In contrast, in related species with a smoother or wax-coated seed surface, comparable hydration may be reached only after longer or repeated moistening, which may partially account for interspecific differences in germination timing and success on chalk substrates. The absence of waxy secretions is likely due to the need for rapid moisture absorption during short-term precipitation. The sharp, tuberculate elements of the secondary sculpture likely enhance adhesion to microscopic irregularities, preventing seed washout and blowing away on steep slopes.

A morphoanatomical analysis of *L. cretacea* seeds revealed a complex of diagnostically significant traits: an elongated kidney-shaped form, a pronounced brain-shaped primary sculpture with deep anticlinal boundaries, a dense, acutely tuberculate secondary sculpture, and the absence of epicuticular wax. These features simultaneously distinguish the species from related taxa and possess obvious adaptive value for survival on chalk outcrops (increased seed coat strength, retention of a microfilm of moisture, and improved adhesion to the substrate). The results confirm the high informative value of seed coat micromorphology for the systematics of the section *Linaria* and enable the use of seed characters in taxonomic differentiation when working with herbarium material. The practical significance of the obtained data lies in the use in planning conservation measures for relict populations and in the design of experiments to assess seed viability (hydration, germination under conditions of limited moisture). To further clarify the evolutionary-ecological relationships, it is advisable to expand the sample by population, perform a comparable SEM analysis of closely related taxa, and conduct combined studies of the morphology and physiology of germination under different humidity and temperature conditions.

Conclusion

The fruits of *L. cretacea* are small, round-oblong capsules (≈ 3.2 – 3.4 mm in diameter), usually containing 12–15 seeds; the weight of one capsule is 3–4 mg or less. The seeds are small (length 1.0–1.5 mm; width 0.7–1.0 mm), elongated-reniform; the shape index $L/W \approx 1.35$ – 1.45 indicates a pronounced elongation.

The primary sculpture is cerebellar: convolutions of slightly concave, isodiametric exotesta cells approximately 0.10–0.15 mm high with deeply anticlinal boundaries. Secondary sculpture consists of dense, sharply tuberculate cuticular deposits with a local tendency toward reticulation; tertiary sculpture (epicuticular wax) is absent in the specimens studied.

A combination of characters—the elongated kidney-shaped seed, the high brain-shaped primary sculpture, the nature of the secondary sculpture, and the absence of wax secretions—distinguishes *L. cretacea* from closely related taxa (e.g., *L. vulgaris*, *L. genistifolia*) and makes these micromorphological characters suitable for taxonomic differentiation, especially when analyzing herbarium material without flowers.

The structure of the seed coat—a pronounced microrelief and the absence of epicutinal wax granules—probably reflects adaptation to chalk habitats: deep relief increases the mechanical strength of the coat and retains a microfilm of moisture, while sharply tuberculate elements enhance adhesion to the microroughness of the substrate, reducing the risk of seeds being washed away or blown off slopes.

The short range of passive transfer (12–35 cm) combined with strict confinement to chalk substrates indicates limited potential dispersion and high local dependence of recruitment, which increases the vulnerability of populations to habitat disturbance.

The obtained micromorphological and morphometric information is suitable for monitoring and conservation of the species: it can be used for accurate identification of specimens, planning of seed collection and development of ex situ conservation protocols.

Further studies should cover a larger number of populations across the entire Eastern European-Subural part of the range in order to assess interpopulation variability of seed traits.

It is recommended to expand the sampling geography, conduct SEM studies of closely related taxa, conduct seed viability and germination tests, and develop protocols for seed collection and storage. The data obtained should be integrated into regional monitoring and management programs for chalk habitats to inform conservation and restoration measures.

The obtained data confirm the high informative value of seed coat micromorphological features for the taxonomy and ecology of calciphytes. Against the backdrop of declining suitable habitats, combining basic morphological research with practical conservation measures is key to the long-term conservation of *L. cretacea* and associated petrophyte communities.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The manuscript was written through the contributions of all authors. All authors have given approval to the final version of the manuscript. CRediT: **Bakytzhanova M.** — conceptualization, data curation, investigation, formal analysis, writing — original draft; **Makhmudova K.** — conceptualization, methodology, supervision, validation, writing — review and editing; **Aitymbetova K.** — investigation, methodology, data curation, formal analysis; **Murzatayeva T.** — supervision, project administration, resources, validation; **Yelubayeva A.** — investigation, visualization, data curation, technical assistance, editing.

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**Батыс Қазақстанның бор шөгінділерінен алынған
Linaria cretacea Fisch. ex Spreng. тұқым қабығының
морфологиясы және микроморфологиясы**

Тұқым морфологиясы мен тұқым қабығының микроморфологиясын зерттеу сирек кездесетін эндемикалық өсімдіктердің, әсіресе кеуіп қалған жерлерде, арнайы мекендеу орталарында мекендейтін түрлердің таксономиясы, экологиясы және сақталуы үшін өте маңызды. Таралу диапазоны тар кальцийлі өсімдіктерде тұқымның ультрақұрылымы түрлерін анықтау, таксономиялық байланыстарды нақтылау және *ex situ* сақтау шараларын әзірлеу үшін пайдалы диагностикалық белгі

ретінде қызмет ете алады. Зерттеуде Батыс Қазақстандағы кеуіп қалған жерлердегі сирек кездесетін кальцийлі эндемикалық түрі *Linaria cretacea* Fisch. ex Spreng. тұқымдары мен жемістерінің морфологиялық сипаттамалары сканерлеуші электронды микроскопия (SEM) және жарық микроскопиясы арқылы зерттелді. Тұқымдардың макро және микроскопиялық суреттері алынды, сондай-ақ олардың ұзындығы, ені, қалыңдығы және пішіні негізгі морфометриялық параметрлермен өлшенді. Тұқым қабығының мүсіні В. Бартлотт пен В. Стерннің жіктемелеріне сәйкес бастапқы, екінші және үшінші деңгейлерде сипатталды. Нәтижелер Ақтөбе аймағынан алынған *L. cretacea* өсімдігінің антиклинальды шекаралары айқын анықталған мишық тәрізді бастапқы мүсінмен, торлы элементтері бар құрт туберкулезді екінші реттік мүсінмен және эпикутикулярлы балауыздың болмауымен сипатталатынын көрсетті. Анықталған тұқым қабығының ерекшеліктерін тығыз байланысты *L. vulgaris* және *L. genistifolia* түрлерінің жарияланған сипаттамаларымен салыстыру бірқатар диагностикалық маңызды микроморфологиялық айырмашылықтарды анықтады. Суды ұстау қабілеті төмен, кеуіп қалған жерлердегі тіршілік ету орталарындағы тұқым қабығы құрылымының бейімделу рөлі де талқыланды. Алынған деректердің жүйелік және практикалық маңызы бар, әсіресе гербарий үлгілерін анықтау және осы сирек кездесетін түрді қорғау және *ex situ* сақтау хаттамаларын әзірлеу үшін.

Кілт сөздер: *Linaria cretacea*, Қазақстан, кальцифилді түрлері, эндемикалық түрлері, тұқым морфологиясы, сканерлік электронды микроскопия, жарық микроскопиясы, ерекшеліктері.

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Морфология семян и микроморфология семенной оболочки *Linaria cretacea* Fisch. ex Spreng. из меловых отложений Западного Казахстана

Исследование морфологии семян и микроморфологии семенной оболочки имеет важное значение для таксономии, экологии и сохранения редких эндемичных растений, особенно видов, обитающих в специализированных местообитаниях, таких как меловые обнажения. У кальцифильных растений с узким ареалом распространения ультраструктура семян может служить полезным диагностическим признаком для идентификации видов, уточнения таксономических связей и разработки мер по сохранению *ex situ*. В данном исследовании с помощью сканирующей электронной микроскопии (СЭМ) и световой микроскопии были изучены морфологические характеристики семян и плодов *Linaria cretacea* Fisch. ex Spreng., редкого кальцифильного эндемичного вида меловых обнажений Западного Казахстана. Были получены макро- и микроизображения семян, а также измерены их основные морфометрические параметры, включая длину, ширину, толщину и индекс формы. Скульптура семенной оболочки была описана на первичном, вторичном и третичном уровнях в соответствии с классификациями В. Бартлотта и В. Штерна. Результаты показали, что *L. cretacea* из Актюбинской области характеризуется мозжечковидной первичной скульптурой с четко выраженными антиклинальными границами, резко бугорчатой вторичной скульптурой с сетчатыми элементами и отсутствием эпикутикулярного воска. Сравнение выявленных признаков семенной оболочки с опубликованными описаниями близкородственных видов *L. vulgaris* и *L. genistifolia* позволило выявить ряд диагностически значимых микроморфологических различий. Также рассматривается возможная адаптивная роль структуры семенной оболочки в меловых местообитаниях с низкой влагоудерживающей способностью. Полученные данные имеют как систематическое, так и практическое значение, особенно для идентификации гербарных образцов и для разработки протоколов защиты и сохранения *ex situ* этого редкого вида.

Ключевые слова: *Linaria cretacea*, Казахстан, кальцефильный вид, эндемичный вид, морфология семян, сканирующая электронная микроскопия, световая микроскопия, признаки.

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