

A.E. Nurmanbek<sup>1\*</sup>, N. Akhtayeva<sup>1</sup>,  
L.N. Kiyekbayeva<sup>2</sup>, T.S. Ibragimov<sup>1</sup>

<sup>1</sup>Al-Farabi Kazakh National University, Almaty, Kazakhstan

<sup>2</sup>Asfendiyarov Kazakh National Medical University, Almaty, Kazakhstan

\*e-mail: aydyn.nurmanbek@gmail.com

## RESILIENT FLORA OF THE DESERT: A COMPREHENSIVE ANALYSIS OF *ARTHROPHYTUM*'S ADAPTATION AND THERAPEUTIC POTENTIAL

This article presents a comprehensive analysis of the genus *Arthrophytum* Schrenk (family Chenopodiaceae), which includes subshrub species adapted to arid regions of Eurasia and North Africa. The aim of the study is to summarize current scientific knowledge on the taxonomy, morphological characteristics, ecological adaptations, biogeographical distribution, and pharmacological potential of *Arthrophytum* species. Both modern scientific databases (SciFinder, Google Scholar, ScienceDirect, etc.) and traditional sources (botanical floras, herbarium collections, ethnobotanical reports) were used for data collection.

Special attention is given to species with notable ecological plasticity and endemic distribution in Kazakhstan (*A. iliense*, *A. balchaschense*, *A. pulvinatum*, among others). The article concludes data from morphological, anatomical, and molecular analyses that have identified systematic status of several species, comprising the reorganization of *A. balchaschense* into the genus *Haloxylon*. Results of the pharmacognostic study of species *A. schmittianum* and *A. scorparium* are discussed, allocating their high biological activities such as antioxidant, antimutagenic, neuroprotective, and antidiabetic activities.

The outcomes show the significance of *Arthrophytum* as a main component of desert biodiversity and a perspective source of bioactive natural compounds. This review contains modern research gaps and summarizes the importance for future interdisciplinary studies, comprising preservation, sustainable use, and pharmacological studies of the genus.

This article is useful for botanists, pharmacologists, ecologists, and medicinal plant experts, exploring plant and their life cycle in arid environments.

**Keywords:** *Arthrophytum*, arid ecosystems, morphological adaptation, *Amaranthaceae*, bioactive compounds, antioxidant activity, ethnopharmacology, C4 photosynthesis, Central Asia flora, desert halophytes.

A.E. Нұрманбек<sup>1\*</sup>, Н.З. Ахтаева<sup>1</sup>, Л.Н. Киекбаева<sup>2</sup>, Т.С. Ибрагимов<sup>1</sup>

<sup>1</sup>Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан

<sup>2</sup>С.Д. Асфендияров атындағы Қазақ ұлттық медициналық университеті, Алматы, Қазақстан

\*e-mail: aydyn.nurmanbek@gmail.com

### Шөлді аймақ өсімдіктерінің тұрақтылығы: *Arthrophytum* туысының бейімделу механизмдері мен емдік әлеуетіне кешенді шолу

Бұл шолу мақаласы *Arthrophytum* Schrenk туысына (Chenopodiaceae тұқымдасы) жататын, Еуразия мен Солтүстік Африканың құрғақ аймақтарына бейімделген жартылай бұталы өсімдіктердің жан-жақты талдауы ұсынылған. Зерттеудің мақсаты – *Arthrophytum* туысы түрлерінің таксономиясы, морфологиялық сипаттамалары, экологиялық бейімделу ерекшеліктері, биogeографиялық таралуы және фармакологиялық әлеуеті туралы қазіргі ғылыми мәліметтерді жүйелеу.

Мәліметтерді жинау үшін заманауи ғылыми дерекқорлар (SciFinder, Google Scholar, ScienceDirect және т.б.), сондай-ақ дәстүрлі көздер (ботаникалық флоралар, гербарийлік коллекциялар, этноботаникалық есептер) пайдаланылды.

Зерттеу барысында ерекше назар экологиялық бейімделгіштігі жоғары және Қазақстан аумағында эндемик түрлерге (мысалы, *A. iliense*, *A. balchaschense*, *A. pulvinatum* және т.б.) аударылды. Шолуға морфологиялық, анатомиялық және молекулалық зерттеулердің нәтижелері енгізіліп, олардың негізінде кейбір түрлердің таксономиялық мәртебесі нақтыланды. Атап айтқанда, *A. balchaschense* түрінің *Haloxylon* туысына қайта жіктелуі қарастырылды.

Сонымен қатар *A. schmittianum* және *A. scorparium* тәрізді түрлердің антиоксиданттық, антимитоздық, нейрорепараторлық және антидиабеттік белсенділігін сипаттайтын

Алынған мәліметтер *Arthrophytum* туысының шөл биоәртүрлілігінің маңызды компоненті әрі биологиялық белсенді табиғи қосылыстардың болашағы зор көзі екенін көрсетеді. Мақалада зерттеулердегі бар олқылықтар анықталып, келешек пәнаралық зерттеулер үшін (соның ішінде сақтау, орнықты пайдалану және фармакологиялық зерттеу) басым бағыттар ұсынылады.

Мақала ботаниктерге, биомедицина зерттеушілеріне, фармакологтарға, экологтарға, дәрілік өсімдіктер мен биоалуантүрлік саласындағы мамандарға, әсіресе құрғақ аймақтардағы өсімдіктердің бейімделу стратегиясын зерттейтіндерге арналған.

**Түйін сөздер:** *Arthrophytum*, аридті экожүйелер, морфологиялық бейімделу, *Amaranthaceae*, биологиялық белсенді қосылыстар, антиоксиданттық белсенділік, этнофармакология, С4 фотосинтез, Орта Азия флорасы, шөл галофиттері.

А.Е. Нұрманбек<sup>1\*</sup>, Н.З. Ахтаева<sup>1</sup>, А.Н. Киекбаева<sup>2</sup>, Т.С. Ибрагимов<sup>1</sup>

<sup>1</sup>Казахский национальный университет им. аль-Фараби, Алматы, Казахстан

<sup>2</sup>Казахский национальный медицинский университет им. С.Д. Асфендиярова, Алматы, Казахстан

\*e-mail: aydyn.nurmanbek@gmail.com

### Устойчивая флора пустыни: комплексный обзор адаптации и терапевтического потенциала *Arthrophytum*

В данной обзорной статье представлен комплексный анализ рода *Arthrophytum* Schrenk (семейство Chenopodiaceae), включающего субкустарниковые виды, адаптированные к аридным регионам Евразии и Северной Африки. Цель исследования – обобщить современные научные знания о таксономии, морфологических характеристиках, экологических адаптациях, биогеографическом распространении и фармакологическом потенциале видов *Arthrophytum*. Для сбора данных использовались как современные научные базы данных (SciFinder, Google Scholar, ScienceDirect и др.), так и традиционные источники (ботанические флоры, гербарные коллекции, этноботанические отчеты).

Особое внимание уделено видам с заметной экологической пластичностью и эндемичным распространением в Казахстане (*A. iliense*, *A. balchaschense*, *A. pulvinatum* и др.). В обзор включены результаты морфологических, анатомических и молекулярных анализов, позволивших уточнить таксономический статус ряда видов, в том числе переклассифицировать *A. balchaschense* в род *Haloxylon*. Также обсуждаются фармакогностические свойства таких видов, как *A. schmittianum* и *A. scoparium*, подчеркивая их антиоксидантную, антимиотическую, нейропротекторную и антидиабетическую активность.

Полученные данные подчеркивают важность *Arthrophytum* как ключевого компонента биоразнообразия пустынь и перспективного источника биологически активных природных соединений. В обзоре выявлены существующие пробелы в исследованиях и намечены приоритеты для будущих междисциплинарных исследований, включая сохранение, устойчивое использование и фармакологическое изучение рода.

Статья предназначена для ботаников, биомедицинских исследователей, фармакологов, экологов, специалистов по лекарственным растениям и биоразнообразию, особенно для тех, кто изучает стратегии растений в засушливых условиях.

**Ключевые слова:** *Arthrophytum*, аридные экосистемы, морфологическая адаптация, *Amaranthaceae*, биологически активные соединения, антиоксидантная активность, этнофармакология, С4 фотосинтез, флора Средней Азии, пустынные галофиты.

## Introduction

The genus *Arthrophytum* (commonly referred to as “saxaulchik”) comprises subshrubs from the family *Amaranthaceae* (formerly *Chenopodiaceae*), well-adapted to the harsh, arid climates of Eurasia and North Africa. These plants thrive in alkaline, gypsum-rich soils and are crucial to desert ecosystems, aiding soil stabilization and supporting biodiversity.

Scientific interest in *Arthrophytum* has grown substantially in recent years due to its ecological plasticity and emerging pharmacological relevance.

Particular species—including *A. scoparium*, *A. schmittianum*, and *A. lehmannianum*—are traditionally used in folk medicine and have demonstrated antioxidant, antidiabetic, and anti-melanogenic activities. Preliminary pharmacognostic studies prove the availability of phenolic compounds, flavonoids, and alkaloids with viable biological activity.

This review aims to consolidate current scientific knowledge on the taxonomy, morphological characteristics, ecological adaptations, and biogeographical distribution of *Arthrophytum* species. Special emphasis is placed on species with applied value, justifying further research and conservation efforts.

## Materials and methods

This work aims to provide a comprehensive overview of existing scientific data on the genus *Arthrophytum*, with a particular focus on its taxonomy, morphology, ecological adaptations, and pharmacological potential. To ensure completeness and reliability, a structured literature search was conducted using both modern scientific databases and traditional sources.

Materials were selected using keyword searches, including «*Arthrophytum*», «*Chenopodiaceae*», «*Amaranthaceae*», «desert halophytes», «biologically active compounds», and «phytochemistry». The search was conducted across several academic databases, such as SciFinder, Google Scholar, ISI Web of Knowledge, and ScienceDirect, which were selected for their extensive coverage of botanical, ecological, and pharmacological literature.

In addition to peer-reviewed scientific articles, information was gathered from local and international botanical monographs, floras, field guides, dissertations, and ethnobotanical reports, especially those addressing underexplored taxa of Central Asia. Traditional medical texts were also examined to trace the cultural and therapeutic use of *Arthrophytum* species by local populations.

Macroscopic investigations of *Arthrophytum longibracteatum* employed classical botanical methods. The analysis was based on herbarium specimens collected during an expedition in June 2024. Plant collection followed the methodology proposed by A.K. Skvortsov (1977). For specimen identification, key botanical references were consulted. (*Flora of Kazakhstan*, 1956–1966; *Illustrated Guide to the Plants of Kazakhstan*, 1969, 1972; *Key to the Plants of Central Asia*, 1968–1993). Nomenclature followed the standards established by S.K. Cherepanov (Cherepanov, 1995). Updated floristic zoning schemes were used to map species distribution in Kazakhstan (Aralbaev, 2002).

The criteria for source selection included:

- Descriptions or revisions of *Arthrophytum* taxonomy;
- Data on morphological features and anatomical adaptations;
- Information on ecological distribution, soil preferences, and plant community structures;
- Results of phytochemical or pharmacological studies;
- Records of ethnomedicinal use and conservation status assessments.

Sources lacking methodological transparency or based solely on unverified data were excluded to maintain scientific rigor. When necessary, Russian- and Kazakh-language publications were translated and evaluated using the same criteria, as a significant portion of the region's botanical knowledge remains unpublished in English. The literature review was written in four thematic areas: taxonomy, interspecific characteristics, morphological characteristics, ecology with adaptive features, and pharmacological potential.

The study of modern and traditional databases gave us a comprehensive and multifaceted picture of the genus *Arthrophytum* and revealed unexplored areas and promising directions for future scientific work.

## Results and discussion

### *Morphological characteristics of the genus Arthrophytum*

The morphological features of the genus *Arthrophytum* are characterised by opposite leaves that are sessile and fused at the base, with a surface covered with curly hairs. Plants of this genus often form loose, cushion-like semi-shrubs with short, twisted woody stems. Their knotty, lignified branches bear numerous annual herbaceous shoots, which may be simple or weakly branched, and almost entirely conceal the flowers.

The genus *Arthrophytum* Schrenk comprises approximately 20 species, eight of which are native to Kazakhstan. The taxonomic classification of the genus is as follows:

- Division: Magnoliophyta
- Class: Magnoliopsida
- Family: Chenopodiaceae

These are low-growing subshrubs or dwarf shrubs exhibiting a wide variety of morphological traits, particularly in the structure of their flowers, leaves, and stems.

The flowers are small and bisexual, located in the axils of bracts that resemble stem leaves. These bracts are longer than the flowers themselves and are accompanied by two smaller bracteoles. The perianth is nearly spherical, consisting of five free, almost rounded sepals. During fruit development, wing-like structures form at the apex of the pericarp, which in some species are replaced by callus-like thickenings. There are five stamens, which are united into a disk surrounding the ovary. The margin of the disk is thickened, glandular or fringed, often with semicircular or bilobed protrusions. The an-

thers bear small appendages on their upper side, and the ovary has two stigmas. The seeds are positioned horizontally and contain a spirally coiled embryo (Stepanova & Safronova, 2019).

### ***Morphological Characteristics of Arthrophytum longibracteatum***

*Arthrophytum longibracteatum* Eug. is a subshrub species that, in some cases, forms loose, cushion-like clumps. The central stem is shortened, thickened, often curved, and displays well-developed branching. The woody branches are knotty, with numerous annual herbaceous shoots developing at the nodes. These shoots are generally simple or weakly branched and are almost entirely covered with flowers.

The leaves at the lower part of the shoots are thickened, needle-shaped, cylindrical, sharp, and slightly curved, measuring 10–12 mm in length. The bracts are lanceolate with an ovate base and are approximately twice as long as the flowers. The flowers are grouped in six pairs per inflorescence; the perianth is nearly spherical, about 1.5 mm in diameter, with ovate, convex segments. The hypogynous disc is shallow, cup-shaped, and lobed. Stamens possess linear-subulate filaments and ovate anthers. There are two styles with dissected, lanceolate stigmas that broaden at the apex.

Flowering and fruiting occur from June to October. The species grows on takyrs (clay flats) and

stony plains of desert type, and is occasionally found on saline sandy areas. It is distributed in the Betpak-Dala region (lower reaches of the Sarysu River), the Balkhash-Alakol region (valleys of the Ili and Charyn rivers), as well as in Western China (Kuldja area).

**Figure 1**

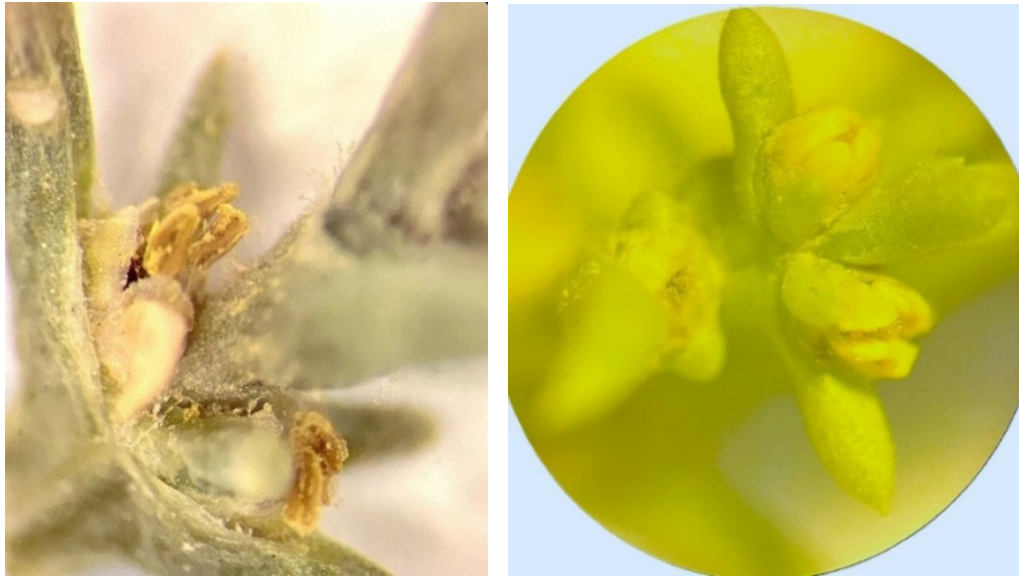
General view of *Arthrophytum longibracteatum*



**Figure 2**

Structure of the aerial shoot of *Arthrophytum longibracteatum*



**Figure 3***Flower structure of Arthrophytum longibracteatum*

This species is closely related to *A. subulifolium* Schrenk but differs by having awl-shaped, spiny bracts and leaves, as well as a generally shorter overall height. It is considered a critical taxon and is likely to represent an eastern race of *A. lehmannianum* Bge. ex Litw.

#### **Taxonomic Clarification Through Integrative Evidence**

This study presents a comprehensive comparative analysis of three desert-adapted species—*Arthrophytum longibracteatum*, *Arthrophytum balchaschense*, and *Haloxylon aphyllum*—combining morphological, anatomical, and molecular genetic data to resolve longstanding taxonomic uncertainties. Of particular focus is the ambiguous placement of *A. balchaschense*, whose classification within *Arthrophytum* has historically been based on superficial morphological traits rather than rigorous phylogenetic evidence.

The results are decisive: *A. balchaschense* shows a consistent pattern of alignment with the genus *Haloxylon* across all data streams. Morphologically, its young shoots and fruit structures resemble those of *H. aphyllum* far more than those of *A. longibracteatum*. Anatomically, cross-sections of stem tissue reveal nearly identical features between *A. balchaschense* and *H. aphyllum*, particularly in epidermal thickness and tissue layering. Most conclusively, molecular analyses of nrITS and *rps16* intron sequences place *A. balchaschense* firmly within the

*Haloxylon* clade, prompting its formal reclassification as *Haloxylon balchaschense* (Iljin) Osmonali, Veselova & Kudab.

An intriguing outlier, specimen B62 (*Arthrophytum* sp.), exhibited genetic signatures of both genera, raising the possibility of a hybrid origin. This finding hints at historical gene flow between *Arthrophytum* and *Haloxylon*, warranting further investigation.

*H. balchaschense* is a narrow endemic, restricted to Kazakhstan's central-eastern North Turanian deserts, where it inhabits solonchak and rubbly desert soils—an ecological preference consistent with other *Haloxylon* species. This refined classification not only clarifies phylogenetic relationships within the Amaranthaceae but also contributes to more accurate biodiversity assessment and conservation planning in Central Asia's arid zones (Osmonali et al., 2025).

#### **Ecological Adaptations and Geographic Distribution**

In Kazakhstan, eight species of the genus *Arthrophytum* Schrenk (commonly known as “seksewilche”) are found, five of which are endemic, meaning they occur exclusively within the country. This genus is considered part of the Turanian mesophyte group. One of its most remarkable representatives is the endemic and relict species *Arthrophytum pulvinatum* Litv., a cushion-forming plant first described by botanist D.I. Litvinov in 1913 (Polyakov, 1960; Lavrenko, 1962; Gureeva & Balashova, 2013).

The species *A. iliense*, *A. betpakdalense*, *A. kovinii*, and *A. pulvinatum* are primarily distributed in the Betpak-Dala and Balkhash-Alakol regions. In contrast, *A. lehmannianum* exhibits the broadest distribution range, occurring in seven floristic regions, including the Emba, Mangyshlak, and Aral Sea areas (Vintergoller, 1970). *A. lehmannianum* is a steppe desert halophyte with a fragmented range. Currently, its distribution extends from 52°30' to 83°E longitude, although until recently its northern boundary did not exceed 50°N latitude. This discovery broadens our understanding of the ecological tolerance and distribution potential of *Arthrophytum* species, contributing to general knowledge on plant adaptation to arid environments (Usen et al., 2024).

In the works of Usen S. and co-authors, herbarium data from the period 1935–1960 are cited, during which more than 60% of specimens were collected by expeditions led by prominent Soviet botanists. A significant contribution was made by Z.V. Kubanskaya, who is credited with approximately 20% of the collected specimens.

Herbarium data reveal the highest concentration of *Arthrophytum* species in the Betpak-Dala region (6 species, 27 specimens), followed by the Balkhash-Alakol region (4 species, 48 specimens) and the Dzhungarian Alatau (4 species, 6 specimens) (Vintergoller, 1970).

Ecological studies of *Arthrophytum iliense* have revealed significant adaptations to various types of arid soils and landscapes. This species demonstrates high ecological plasticity, thriving in a wide range of environmental conditions.

Typically, *A. iliense* forms communities on light gypsiferous loamy soils of arid-denudation plateaus. Interestingly, it is also found in association with *Nanophyton erinaceum* on weakly gypsiferous soils. In desert environments, *A. iliense* often dominates monodominant plant communities on gypsiferous soils, growing alongside perennial halophytes such as *Salsola orientalis* and *S. arbusculiformis*. Field observations show the species is well adapted to eroded, gravelly-gypsum loamy soils. *A. iliense* frequently forms mixed thickets with *Arthrophytum longibracteatum* on extremely dry stony plains. These communities are often adjacent to shrub associations (*Caragana balchashensis*, *Atraphaxis replicata*, etc.) that grow on meadow-brown soils along ephemeral watercourses. Such a distribution highlights the remarkable ecological flexibility of *A. iliense*, which is capable of establishing on poorly developed slope soils in canyon systems (Sultanova et al., 2020).

Our study also revealed an important biogeographic anomaly of the Chenopodiaceae family in Central Asia. The localized distribution of three *Arthrophytum* species (*A. balchashense*, *A. iliense*, *A. longibracteatum*) in the Junggar-Turan desert zone west of northern Kashgar suggests a relict distribution pattern. A shared evolutionary background is hypothesized with genera such as *Nanophyton*, *Petrosimonia*, *Londesia*, *Camphorosma*, and *Ceratocarpus*. These findings underscore the importance of continued interdisciplinary research in the region (Grubov, 2000).

#### ***Arthrophytum schmittianum*: A Promising Source of Antioxidant and Antimitotic Activity.**

Among the species of pharmacological interest, *Arthrophytum schmittianum* (family Chenopodiaceae) stands out as a regional endemic of El Bayadh, Algeria, traditionally used in folk medicine. Recent investigations have focused on the methanolic and tannin-rich extracts from various plant parts. These studies assessed total phenolic content, antioxidant activity using the DPPH method, and antimitotic effects on *Allium cepa* L. root tips (Dif et al., 2022). Phytochemical screening revealed considerable variation in phenolic concentrations across plant tissues. The ethyl acetate fraction of the bark demonstrated the highest antioxidant potential ( $IC_{50} = 0.16$  mg/mL). Meanwhile, the methanolic extract from twigs showed significant antimitotic activity, inhibiting root growth by 47%. Importantly, hemolytic assays indicated low toxicity for *A. schmittianum* extracts in concentrations ranging from 50–250 µg/mL ( $p > 0.05$ ). Only at 500 µg/mL was a minor increase in hemolysis (1.42%) observed. These results suggest that *A. schmittianum* is a promising candidate for further study as a natural source of bioactive compounds. In-depth research on its essential oil composition and broader pharmacological spectrum is warranted (Zohra & Fawzia, 2014).

#### ***Arthrophytum scoparium*: A Valuable Target for Phytochemical and Pharmacological Research.**

*Arthrophytum scoparium* – a halophytic species native to the deserts of North Africa, has attracted attention for its remarkable ability to survive in extreme environmental conditions—such as water scarcity and intense solar radiation. As a result, it synthesizes an array of bioactive molecules widely utilized in traditional medicine to treat ailments, including headaches, migraines, and neurological disorders.

Modern studies have identified several biological activities of *A. scoparium* extracts, including antioxidant effects, neuroprotective action, melanogenesis inhibition, and antidiabetic potential. The present review summarizes key findings related to the plant's therapeutic applications. According to the IUCN (2005), traditional preparations combine powdered fruits and stems with fatty bases to produce poultices effective against fungal skin infections, indicating the plant's potential for antifungal therapy (Othman et al., 2021).

High-performance liquid chromatography (HPLC) analysis of *A. scoparium* extracts identified the following main bioactive constituents: p-Coumaric acid, cinnamic acid, chrysoeriol, catechol. In addition, the plant contains cyanidin and caffeoylquinic acid, expanding its pharmacological potential.

Of special interest is the plant's rich alkaloid profile, which includes salsolinol, isosalsolinol, N-Methylisosalsolinol, salsolidine. These compounds suggest possible neuroprotective and psychotropic activities, opening avenues for drug development. *A. scoparium* is, therefore, a compelling candidate for continued phytochemical and pharmacological investigations to develop new pharmaceuticals and nutraceuticals (Belabdelli et al., 2023).

Among its many features, *A. scoparium* is particularly noted for its antioxidant capacity. Studies evaluating various extracts from the aerial parts of the plant identified high levels of phenolics, flavonoids, and tannins. The hydro-methanolic (ASE) and ethyl acetate (EAE) extracts exhibited the most pronounced antioxidant effects. ASE showed intense activity in both DPPH and ABTS assays ( $IC_{50} = 0.045$  and  $0.0017$  mg/mL, respectively), while EAE demonstrated 83.29% inhibition in the  $\beta$ -carotene/linoleic acid leaching test. In vivo results supported these findings: daily administration of ASE reduced lipid peroxidation and increased hepatic glutathione (GSH) levels. These results validate the traditional use of the plant in treating inflammation and oxidative stress-related conditions (Kaddour et al., 2019).

Research by Smach M.A. et al. demonstrated the neuroprotective effects of *A. scoparium* aqueous extract (ASAE) against galactose-induced neurotoxicity in a mouse model. Chronic galactose exposure led to cognitive impairment, increased malondialdehyde (MDA) levels, and elevated acetylcholinesterase (AChE) activity—indicative of oxidative stress. In contrast, administration of ASAE (300 mg/kg) reduced these markers, improved memory performance, and decreased AChE activity. These results

highlight the plant's potential in managing neurodegenerative disorders (Smach et al., 2020).

In a study by Chao H.C. et al. (2013), ethanolic extracts of *A. scoparium* (ASEE) inhibited melanin synthesis in B16 murine melanoma cells by downregulating tyrosinase and other melanogenic genes (Tyr, Trp-1, Mitf, and Mc1R). The active compounds—p-coumaric acid, catechol, and caffeoylquinic acid—support the plant's potential use in cosmeceuticals targeting hyperpigmentation (Chao et al., 2013).

Extracts of *A. scoparium* have shown vigorous inhibitory activity against  $\alpha$ -glucosidase, a key enzyme in carbohydrate metabolism. Boubrima Y. et al. (2018) reported that its phenolic extracts had the lowest  $IC_{50}$  ( $5.02 \mu\text{M}$ ) among the tested Saharan plants, indicating promising applications in the development of antidiabetic agents aimed at managing postprandial blood sugar levels (Boubrima et al., 2018).

The results of this review underscore the ecological, morphological, and pharmacological uniqueness of the genus *Arthrophytum*, particularly in the context of arid and semi-arid ecosystems of Central Asia and North Africa. The adaptive strategies observed across several species—including cushion-forming growth forms, gypsophily, and reduced leaf morphology—highlight a clear evolutionary response to extreme abiotic stressors such as salinity, drought, and high solar radiation. These adaptations are consistent with broader patterns found in desert halophytes of the family Chenopodiaceae.

The endemic status of five *Arthrophytum* species in Kazakhstan and their confinement to specific floristic regions such as Betpak-Dala and Balkhash-Alakol further support the genus as a key indicator of regional biodiversity and environmental stability. The relict nature of species such as *A. pulvinatum* and the fragmented distribution of *A. lehmannianum* reflect a complex evolutionary and biogeographical history shaped by climatic shifts and edaphic specialization. Herbarium records from the Soviet era, validated by recent field data, confirm consistent species distributions and offer a valuable baseline for future monitoring.

The taxonomic clarification of *A. balchaschense* as *Haloxylon balchaschense*, supported by morphological, anatomical, and molecular evidence, marks a significant step in resolving long-standing systematic ambiguities within the Amaranthaceae s.l. This integrative approach underscores the importance of combining classical taxonomy with molecular phylogenetics, particularly for underexplored desert taxa.

Species of the genus *Arthrophytum* belong to halophytes, i.e. plants adapted to growing in high salinity conditions. It is known that in response to stress factors such plants are able to accumulate significant amounts of primary and secondary metabolites. These compounds are of medical interest because of their diverse bioactive properties, including antioxidant, antimicrobial, anti-inflammatory and anti-tumour activity (Custódio et al., 2022; Ksouri et al., 2012).

According to thorough scientific studies, halophytes are considered as promising sources of phenolic compounds with significant potential for medical and pharmacological applications (Lopes et al., 2023).

From a pharmacological perspective, species such as *A. schmittianum* and *A. scoparium* demonstrate substantial therapeutic promise. Documented antioxidant, antimutagenic, neuroprotective, and antidiabetic activities—correlated with high levels of phenolics, flavonoids, and specific alkaloids—make these species compelling candidates for the development of novel phytotherapeutics. The bioactivity of ethyl acetate and methanolic fractions, as shown in multiple assays (e.g., DPPH, AChE inhibition, melanogenesis suppression), suggests a chemically diverse metabolome adapted for survival under oxidative stress, which may also be pharmacologically exploitable.

Importantly, the presence of both traditional medicinal uses and scientifically validated bioactivity in these species illustrates the value of ethnobotanical knowledge as a foundation for modern pharmacognostic research. However, the lack of standardized extraction methods, limited in vivo testing, and insufficient toxicity profiling remain obstacles to clinical translation.

According to ecological data, *A. iliense* stands out as an adaptive plant that grows on a wide range of soil types and in various plant communities. Its ability to grow in poorly developed soils and saline environments and to adapt to arid ecosystems demonstrates its ecological significance.

The review data show that the genus *Arthrophytum* is the subject of in-depth interdisciplinary research. Its ecological role, systematics, and pharmacological potential are directing researchers' efforts towards preserving genomic, metabolomic, ecological, and pharmacognostic data for better understanding and practical application.

## Conclusion

The genus *Arthrophytum* is a group of semi-shrubby plants with a high degree of adaptation to

extreme environmental conditions. Their unique morphological and anatomical features demonstrate their adaptation to salty, poorly developed soils and highlight their ecological significance and evolutionary activity. Species with endemic characteristics and relict distributions require special attention, and measures should be taken to preserve them.

A multifaceted analysis of the genus, including herbarium, morphological, anatomical, and molecular data, clarified systematic ambiguities in the case of *A. Balchaschense*, resulting in its phylogenetic reclassification from *Arthrophytum* to the genus *Haloxylon*. This once again proves the need for an integrative approach in taxonomic studies.

In addition, species of the genus *Arthrophytum* are promising subjects for pharmacognostic research. The presence of antioxidant, antimutagenic, neuroprotective, and antidiabetic activity and high content of biologically active substances makes it a potential natural source for medicines. Particularly promising are *A. schmittianum* and *A. scoparium*, whose bioactive compounds may serve as a foundation for the development of novel phytopharmaceuticals and nutraceuticals.

Thus, *Arthrophytum* should be regarded not only as a vital component of Central Asian and North African desert biodiversity but also as a valuable source of natural compounds with significant applied potential. Future research should focus on in-depth phytochemical profiling, pharmacological characterization, and elucidation of adaptive mechanisms, alongside the development of strategies for the conservation and sustainable utilization of these plants.

## Conflict of interest – not declared

This material has not been previously submitted for publication in other publications and is not under consideration by other publishers. There has been no funding from outside organisations or medical representations in the conduct of this work.

## Author contributions:

*A.E. Nurmanbek: Investigation, Data curation, Writing – original draft. T.S. Ibragimov: Conceptualization, Methodology, Supervision, Writing – review & editing. L.N. Kiekbayeva: Formal analysis, Validation, Writing – review & editing. N.Z. Akh-taeva: Conceptualization, Supervision, Project administration, Writing – review & editing.*

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**Information about the authors:**

A.E. Nurmanbek – doctoral student of the 2nd year of study of the Department of Biodiversity and Bioresources of Al-Farabi Kazakh National University, (Almaty, Kazakhstan, e-mail: aydyn.nurmanbek@gmail.com).

N.Z. Akhtaeva – professor of the Department of Biodiversity and Bioresources of Al-Farabi Kazakh National University (Almaty, Kazakhstan, e-mail: akhtaeva@mail.ru).

L.N. Kiyekbayeva – associate professor of the Department of Pharmaceutical Technology, School of Pharmacy, Asfendiyarov Kazakh National Medical University (Almaty, Kazakhstan, e-mail: lashynk@mail.ru).

T.S. Ibragimov – associate Professor of the Department of Biodiversity and Bioresources, Al-Farabi Kazakh National University (Almaty, Kazakhstan; e-mail: ecopastbish@mail.ru).

**Авторлар туралы мәлімет:**

А.Е. Нұрманбек – әл-Фараби атындағы Қазақ ұлттық университетінің биоәртүрлілік және биоресурстар кафедрасының 2-курс докторанты (Алматы, Қазақстан, e-mail: aurdun.nurmanbek@gmail.com).

Н.З. Ахтаева – әл-Фараби атындағы Қазақ ұлттық университетінің биоәртүрлілік және биоресурстар кафедрасының профессоры (Алматы, Қазақстан, e-mail: akhtaeva@mail.ru).

Л.Н. Киекбаева – С.Д. Асфендияров атындағы Қазақ ұлттық медицина университеті Фармация мектебінің фармацевтикалық технология кафедрасының қауымдастырылған профессоры (Алматы, Қазақстан, e-mail: lashynk@mail.ru).

Т.С. Ибрагимов – әл-Фараби атындағы Қазақ ұлттық университетінің биоәртүрлілік және биоресурстар кафедрасының қауымдастырылған профессоры (Алматы, Қазақстан, e-mail: ecorastbish@mail.ru).

**Сведения об авторах:**

А.Е. Нұрманбек – докторант 2 курса обучения кафедры биоразнообразия и биоресурсов КазНУ им. аль-Фараби (Алматы, Казахстан, e-mail: aurdun.nurmanbek@gmail.com).

Н.З. Ахтаева – профессор кафедры биоразнообразия и биоресурсов КазНУ им. аль-Фараби (Алматы, Казахстан, e-mail: akhtaeva@mail.ru).

Л.Н. Киекбаева – ассоциированный профессор кафедры фармацевтической технологии школы фармации, Казахский национальный медицинский университет им. С.Д. Асфендиярова (Алматы, Казахстан, e-mail: lashynk@mail.ru).

Т.С. Ибрагимов – ассоциированный профессор кафедры биоразнообразия и биоресурсов КазНУ им. аль-Фараби (Алматы, Казахстан, e-mail: ecorastbish@mail.ru).

Поступила 13 июля 2025 года

Принята 25 марта 2026 года