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Medicinal plant diversity of Mangystau Region (Kazakhstan): Taxonomic structure, ecological characteristics and pharmacological potential

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ABSTRACT

Medicinal plants constitute an important component of biodiversity and represent a valuable source of biologically active compounds for pharmaceutical and medicinal applications. The Mangystau Region of Western Kazakhstan is characterized by unique desert ecosystems that support a diverse assemblage of medicinal plant species adapted to arid environmental conditions. This study aimed to assess the taxonomic composition, ecological structure, phytochemical characteristics, pharmacological potential, and utilization prospects of medicinal plants occurring in the flora of Mangystau. The analysis was based on floristic inventories, herbarium collections, ecological assessments, phytochemical data, pharmacological literature, and patent sources. A total of 302 medicinal plant species belonging to 174 genera and 58 families were examined. The results showed that medicinal plants constitute approximately 39.2% of the regional flora. Species diversity is concentrated within a limited number of dominant families, particularly Asteraceae, Amaranthaceae, Brassicaceae, Fabaceae, Polygonaceae, Lamiaceae, Rosaceae, Scrophulariaceae, Apiaceae, Boraginaceae, and Ranunculaceae, which collectively account for 65.5% of all recorded medicinal species. *Artemisia* was identified as the most species-rich genus. The ecological spectrum is dominated by perennial and annual herbs, as well as xerophytic, halophytic, and heliophytic species, reflecting long-term adaptation to water deficit, soil salinity, and intense solar radiation. Phytochemical analysis revealed a high prevalence of flavonoids (86.4% of species), phenolic compounds (43.7%), saponins (21.9%), and essential oils (17.9%). These compounds contribute to a broad range of pharmacological properties, including antioxidant, anti-inflammatory, antimicrobial, antiseptic, expectorant, and bronchodilatory activities. Several taxa, particularly representatives of *Artemisia*, *Ferula*, *Ephedra*, *Glycyrrhiza*, and *Astragalus*, demonstrate considerable potential as sources of medicinal raw materials and bioactive compounds. The findings highlight the significant biological and pharmacological values of the medicinal flora of Mangystau and provide a scientific basis for its conservation, sustainable utilization, cultivation, and further phytochemical and pharmacological investigation.

Keywords: Medicinal flora, Biodiversity, Arid ecosystems, Taxonomic diversity, Ecological groups, Bioactive compounds, Pharmacological potential, Sustainable utilization.
Article type: Research Article.

INTRODUCTION

Medicinal plants are an essential component of natural ecosystems and a valuable resource for medicine, pharmacy, and biodiversity conservation. They provide medicinal raw materials, bioactive compounds, and leads for the development of phytopharmaceuticals, while also supporting the preservation of traditional knowledge. Despite advances in chemical synthesis and biotechnology, plant-derived remedies remain important in primary healthcare in many countries, and numerous modern medicines are derived directly or indirectly from plant secondary metabolites (Rates 2001; Petrovska 2012; Sofowora *et al.* 2013; World Health Organization 2013). In

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the context of climate change and increasing anthropogenic pressures, regional assessments of medicinal plant diversity, ecological characteristics, and potential for sustainable use are increasingly important. Such studies help identify promising species, evaluate resource and conservation priorities, and develop evidence-based strategies for the sustainable management of plant resources (Schippmann *et al.* 2002; Hamilton 2004; Chen *et al.* 2016). The Mangystau Region is one of the most distinctive floristic regions of Kazakhstan. The territory is situated within the desert zone of the Turan Lowland. It includes the Mangyshlak Peninsula, the Ustyurt Plateau, the Buzachi and Tyubkaragan peninsulas, extensive sandy massifs, salt marshes, and the Karatau and Aktau Mountain systems. The region is characterized by an extremely arid continental climate, high solar radiation, low annual precipitation, and widespread saline soils (Safronova 1996). The combination of geographical position, geological and geomorphological heterogeneity, and extreme climatic conditions has produced a distinctive flora rich in xerophytic, halophytic, and psammophytic species. Regional inventories indicate that the Mangystau flora comprises approximately 770 vascular plant species, belonging to 333 genera and 73 families, of which more than 300 have been reported to possess medicinal properties. Many are sources of essential oils, alkaloids, flavonoids, saponins, tannins, and other bioactive compounds used in traditional and modern medicine (Imanbayeva *et al.* 2024a,b). Particularly valuable are representatives of the genera *Artemisia*, *Ephedra*, *Glycyrrhiza*, *Peganum*, *Crataegus*, *Ferula*, *Rheum*, *Mentha*, *Tribulus*, *Alhagi*, *Nitraria*, *Rhamnus*, and *Morus*. Many of these plants exhibit anti-inflammatory, antioxidant, antimicrobial, adaptogenic, and tonic properties. Several species are rare, endemic, or relict taxa, which considerably increases their conservation significance (Ekor 2014; Sagyndykova *et al.* 2022). Medicinal plants in the region occupy a broad range of habitats, including sandy deserts, salt marshes, stony plains, chalk outcrops, mountain gorges, and temporary watercourse valleys. This environmental heterogeneity contributes to a complex ecological structure and reflects extensive adaptation to arid conditions. Analysis of life forms, ecological groups, and habitat preferences is therefore essential for evaluating conservation priorities, resource potential, and prospects for introduction and cultivation (Baitenov 1999–2001; Tazhibayev & Bisenbayev 2018). Although Mangystau has been the subject of substantial floristic research, its medicinal flora has not previously been evaluated within a single integrated framework. Earlier studies have generally focused on individual taxa, floristic complexes, or economically important plant groups, whereas region-wide analyses combining taxonomy, ecology, phytochemistry, pharmacology, and utilization remain limited. At the same time, growing demand for plant-derived raw materials and increasing pressure on natural ecosystems require scientifically grounded approaches to conservation and sustainable use. Identifying promising species can support the development of the pharmaceutical raw-material base, the preservation of regional genetic resources, the conservation of rare and endemic taxa, and the rational management of plant resources in the arid landscapes of Western Kazakhstan. This study characterized Mangystau's medicinal flora, detailing its taxonomy, ecology, bioactive compounds, and pharmacological activities to assess its potential for medicine, pharmacology, introduction, conservation, and sustainable use. By integrating taxonomic, ecological, phytochemical, pharmacological, and utilization data, the study provides a comprehensive regional assessment of medicinal plant diversity in Mangystau.

MATERIALS AND METHODS

Study Area

The study was conducted in the Mangystau Region of Western Kazakhstan, within the desert zone of the Turan Lowland. The region covers approximately 165,600 km² and includes the Mangyshlak Peninsula, the Ustyurt Plateau, the Buzachi and Tyubkaragan peninsulas, extensive sandy massifs, saline depressions, and the Western and Eastern Karatau mountain systems. The climate is strongly continental and extremely arid. Mean annual precipitation generally ranges from 150 to 200 mm and may decline to approximately 50 mm in exceptionally dry years. The region is characterized by high solar radiation, intense evaporation, pronounced daily and seasonal temperature variation, strong winds, and widespread saline soils. Major soil types include brown and grey-brown desert soils, solonchaks, solonetzes, and sandy soils. Vegetation is dominated by wormwood–saltwort, shrub, psammophytic, halophytic, and ephemeral communities.

Research materials

The study focused on naturally occurring medicinal plant species of the Mangystau flora. The dataset combined field observations, herbarium collections of the Mangyshlak Experimental Botanical Garden (MEBG), published literature, and regional floristic inventories. Field surveys covered Mountain Mangyshlak, the Tyubkaragan Peninsula, the Ustyurt Plateau, and the Caspian coastal zone. During expeditions, herbarium specimens and reproductive organs were collected, and information on species occurrence and habitat conditions was recorded (Skvortsov 1977). Living collections and phenological observations were examined using standard protocols applied in botanical gardens (Methodology of Phenological Observations in Botanical Gardens of the USSR 1975; Takhtajan 1986). Species were identified using Flora of Kazakhstan (Vols. 1–9), modern botanical keys, and relevant taxonomic revisions. Nomenclature followed S.K. Cherepanov and internationally-recognized vascular-plant databases. Information on medicinal properties was compiled from specialized scientific literature, pharmacobotanical reference works, pharmacopoeial sources, and other authoritative publications. The final dataset comprised 302 medicinal plant species belonging to 175 genera and 58 families (Flora of Kazakhstan 1956–1966; Methodology of Phenological Observations in Botanical Gardens of the USSR 1975; Takhtajan 1986).

Taxonomic analysis

Taxonomic structure was characterized by determining the numbers of families, genera, and species and calculating their relative contributions to the medicinal flora. Leading families and genera were identified based on species richness, and the mean number of species per genus was calculated as an additional measure of taxonomic structure (Cherepanov 1995).

Ecological analysis

The ecological structure of the medicinal flora was evaluated by examining species distributions across habitat-related groups. Species were classified as xerophytes, xeromesophytes, mesophytes, halophytes, psammophytes, petrophytes, or hygrophytes/hydrophytes according to moisture requirements and habitat characteristics.
Life-form analysis was used to assess the adaptive structure of the flora. Species were assigned to annual herbs, biennial herbs, perennial herbs, semi-shrubs and dwarf shrubs, shrubs, or trees. The resulting life-form spectrum was interpreted in relation to adaptation to the arid environmental conditions of Mangystau (Bykov 1978).

Analysis of biologically active compounds, pharmacological activities, and uses of medicinal plants

Bioactive compounds, pharmacological activities, and practical applications were assessed through a literature-based review of scientific publications, pharmacopoeial sources, electronic databases, and patent documents. For each species, reported compound classes, pharmacological properties, and uses were compiled and standardized (Rabotnov 1987). Literature and patent searches were conducted in Scopus, Web of Science, Google Scholar, PubMed, Espacenet, and WIPO Patentscope. The retrieved information was organized by species and used to quantify the reported occurrence of major bioactive-compound classes and pharmacological activities within the medicinal flora of Mangystau (Krylova & Shreter 1986).

Statistical data analysis

Data for the 302 medicinal plant species were compiled in a structured database and analyzed using descriptive and multivariate statistical methods (Legendre & Legendre 2012; Hair *et al.* 2019). For each taxonomic group, life form, ecological category, class of bioactive compounds, and pharmacological activity, the absolute number of species (n) and its percentage of the total dataset were calculated. Since individual species could be assigned to more than one class of bioactive compounds or pharmacological activity, these categories were treated as non-mutually exclusive; consequently, their cumulative percentages could exceed 100%. Associations among ecological groups were evaluated using Pearson's correlation coefficients (Legendre & Legendre 2012; Hair *et al.* 2019). Hierarchical cluster analysis was performed on a correlation-based distance matrix ($d = 1 - r$) to identify groups with similar ecological profiles (Everitt *et al.* 2011; Jolliffe & Cadima 2016). Principal component analysis (PCA) was applied to standardized variables to reduce data dimensionality, visualize relationships among ecological groups, and identify the principal ecological gradients underlying their differentiation (Everitt *et al.* 2011; Legendre & Legendre 2012; Jolliffe & Cadima 2016). Results were presented as analytical tables, bar charts, correlation heatmaps, hierarchical-clustering dendrograms, and PCA ordination plots.

RESULTS

Taxonomic characteristics of the medicinal flora of Mangystau

The vascular flora of the Mangystau Region comprises approximately 770 species belonging to four divisions, 73 families, and 333 genera (Flora of Kazakhstan 1956–1966; Imanbayeva *et al.* 2024b). The medicinal component analyzed in this study included 302 species representing 175 genera and 58 families. Taxonomic analysis showed that species richness was strongly concentrated in the leading families (Table 1), each of which contained 9–54 medicinal species. Asteraceae, Amaranthaceae, Brassicaceae, Fabaceae, Polygonaceae, Lamiaceae, Rosaceae, Scrophulariaceae, Apiaceae, Boraginaceae, and Ranunculaceae together comprised 198 species, or 65.5% of the medicinal flora. Their high representation demonstrates the dominant role of a relatively small number of families in shaping the regional medicinal flora. By contrast, many families were represented by only one or a few species, indicating a markedly uneven distribution of species richness among families. The family Caryophyllaceae is represented by eight species including *Acanthophyllum borsczowii* Litv., *A. pungens* (Bunge) Boiss., *Gypsophila paniculata* L., *G. perfoliata* L., *Spergularia maritima* (All.) Chiov., *S. rubra* (L.) J. Presl & C. Presl, *S. segetalis* (L.) G. Don, and *Stellaria media* (L.) Vill. The families Rubiaceae (*Galium aparine* L., *G. humifusum* M. Bieb., *G. ruthenicum* Willd., *G. spurium* L., *G. uliginosum* L., and *G. verum* L.) and Euphorbiaceae (*Andrachne rotundifolia* C.A.Mey., *Chrozophora gracilis* Fisch. & C. A. Mey. ex Ledeb., *Euphorbia falcata* L., *E. humifusa* Willd., *E. seguieriana* Neck., and *E. turczaninowii* Kar. & Kir.) each comprise six species. The families Solanaceae, Papaveraceae, and Tamaricaceae are represented by five species each. In contrast, the family Ephedraceae includes four species (*Ephedra distachya* L., *E. equisetina* Bunge, *E. intermedia* Schrenk & C. A. Mey., and *E. lomatolepis* Schrenk). Moderate species richness is characteristic of the families Convolvulaceae, Plumbaginaceae, Zygophyllaceae, Asparagaceae, and Malvaceae, each represented by three species. Low species richness is characteristic of the families Elaeagnaceae, Frankeniaceae, Alliaceae, Ulmaceae, Salicaceae, Orobanchaceae, Plantaginaceae, Onagraceae, Nitrariaceae, Rutaceae, Iridaceae, Moraceae, Geraniaceae, and Fumariaceae, each represented by two species. The lowest species diversity is observed in the monotypic families including Biebersteiniaceae, Asclepiadaceae, Berberidaceae, Dryopteridaceae, Gentianaceae, Equisetaceae, Caprifoliaceae, Capparaceae, Ceratophyllaceae, Cuscutaceae, Cystopteridaceae, Ixioliriaceae, Poaceae, Hypecoaceae, Rhamnaceae, Portulacaceae, Primulaceae, Thymelaeaceae, Typhaceae, and Urticaceae. The dominance of the family Asteraceae is a characteristic feature of the floras of arid regions of Central Asia. It is associated with the high ecological plasticity and adaptive capacity of its species. Many representatives of the genera *Artemisia*, *Achillea, Centaurea, Jurinea*, and *Tanacetum* play an important role in the formation of vegetation cover in desert and steppe ecosystems. They are widely used in traditional and folk medicine (Gammerman *et al.* 1990; Mashkovsky 2012). The substantial representation of the family Amaranthaceae reflects the distinctive character of Mangystau's desert flora, where xerophytic and halophytic species adapted to water scarcity and high soil salinity are prominent. The families Fabaceae and Rosaceae include numerous economically valuable medicinal plants rich in biologically active compounds, widely used in both the pharmaceutical industry and traditional medicine (Fabricant & Farnsworth 2001; Duke 2002; Evans, 2009). Overall, the taxonomic structure of the medicinal flora was highly uneven: most species were concentrated in a few leading families, whereas many families contained only a few species. This pattern is characteristic of many arid floras and reflects pronounced taxonomic differentiation within the regional floristic complex. The prominence of families typical of the Irano-Turanian floristic region reflects the historical development of the regional flora and its long-term adaptation to the environmental constraints of the desert zone. Ancient Mediterranean and Irano-Turanian elements, therefore, make a substantial contribution to the contemporary medicinal flora of Mangystau.

Table 1. Taxonomic composition of the medicinal flora of the Mangystau Region.

Family	**Species**	**Species, n (%)**
ASTERACEAE DUMORT.	*Acantholepis orientalis, Achillea micrantha, A. nobilis, Acroptilon australe, A. repens, Amberboa nana, Artemisia absinthium, A. arenaria, A. austriaca, A. diffusa, A. dracunculus, A. gurganica, A. kelleri, A. lercheana, A. lessingiana, A. marschalliana, A. santolina, A. scoparia, A. sieberi, A. sieversiana, A. songarica, A. terrae-albae, A. tomentella, A. tournefortiana, A. tschernieviana, Carduus crispus, Carthamus lanatus, Centaurea adpressa, C. scabiosa, C. squarrosa, Chondrilla juncea, Cichorium intybus, Cirsium vulgare, Cousinia astracanica, Crepis tectorum, Echinops albicaulis, E. meyeri, E. ritro, Erigeron canadensis, Hyalea pulchella, Inula britannica, Jurinea cyanoides, Koelpinia linearis, Lactuca serriola, Microcephala lamellata, Onopordum acanthium, Pulicaria prostrata, Senecio subdentatus, Sonchus oleraceus, Tanacetum vulgare, Taraxacum officinale, Tripolium vulgare, Xanthium spinosum, X. strumarium*	54 (17.88)
AMARANTH	*Agriophyllum latifolium, Amaranthus blitoides, A. cruentus, A. retroflexus, Anabasis aphylla, A. brachiata, A. eriopoda, A. salsa, Atriplex cana, A. littoralis, A. patens, A. sagittata, A. tatarica, Bassia hyssopifolia, Bienertia*	34 (11

ACEAE JUSS.	*cycloptera, Camphorosma lessingii, Chenopodium urbicum, C. album, C. botrys, C. hybridum, C. rubrum, Ceratocarpus arenarius, C. utriculosus, Kochia prostrata, K. scoparia, Halothamnus subaphyllus, Nanophyton erinaceum, Salicornia europaea, Salsola gemmascens, S. richteri, Suaeda acuminata, S. altissima, S. confusa, S. physophora*	.26)
BRASSICACEAE BURNETT	*Barbarea arcuata, Cakile maritima, Camelina microcarpa, C. sylvestris, Cardaria draba, Descurainia sophia, Erysimum versicolor, Lepidium aucheri, L. crassifolium, L. latifolium, L. perfoliatum, L. pinnatifidum, L. ruderale, Sinapis arvensis, Sisymbrium altissimum, S. loeselii, S. polymorphum, Syrenia siliculosa*	18 (5.96)
FABACEAE LINDL.	*Alhagi persarum, A. pseudalhagi, Astragalus filicaulis, A. flexus, A. onobrychis, A. tribuloides, Eremosparton aphyllum, Glycyrrhiza aspera, G. glabra, G. korshinskyi, Halimodendron halodendron, Medicago sativa, Melilotus albus, M. officinalis, Meristotropis triphylla, Onobrychis arenaria, Sophora alopecuroides, Trifolium fragiferum*	18 (5.96)
POLYGONACEAE JUSS.	*Atraphaxis replicata, Calligonum leucocladum, Polygonum acerosum, P. acetosum, P. aviculare, P. convolvulus, P. minus, P. patulum, Rheum tataricum, Rumex crispus, R. marschallianus, R. chalepensis, R. ucranicus*	13 (4.3)
LAMIACEAE LINDL.	*Lallemantia royleana, Lamium amplexicaule, Lycopus europaeus, Marrubium vulgare, Mentha longifolia, Nepeta cataria, N. saturejoides, Ocimum basilicum, Salvia deserta, Teucrium polium, Thymus kirgisorum, Ziziphora tenuior*	12 (3.97)
ROSACEAE JUSS.	*Agrimonia asiatica, Armeniaca vulgaris, Crataegus ambigua, C. altaica, Malus sieversii, Potentilla supina, Prunus spinosa, Rosa canina, R. iliensis, R. laxa, Rubus caesius, Spiraea hypericifolia*	12 (3.97)
SCROPHULARIACEAE JUSS.	*Dodartia orientalis, Verbascum blattaria, V. lychnitis, V. phoeniceum, V. songaricum, V. thapsus, Veronica anagallis-aquatica, V. chamaedrys, V. persica, V. teucrium*	10 (3.31)
APIACEAE LINDL.	*Eryngium planum, Falcaria vulgaris, Ferula caspica, F. foetida, F. karelinii, F. lehmannii, Prangos odontalgica, Scandix stellata, Sium sisaroideum*	9 (2.98)
BORAGINACEAE JUSS.	*Argusia sibirica, Arnebia decumbens, Asperugo procumbens, Buglossoides arvensis, Cynoglossum officinale, Heliotropium arguzioides, H. ellipticum, Lappula squarrosa, Rindera tetraspis*	9 (2.98)
RANUNCULACEAE JUSS.	*Adonis aestivalis, A. parviflora, Ceratocephala falcata, C. testiculata, Clematis orientalis, Consolida camptocarpa, C. divaricata, Ranunculus sceleratus, Thalictrum isopyroides*	9 (2.98)

Generic analysis likewise showed an uneven distribution of species richness (Fig. 1). *Artemisia* was the most species-rich genus, with 18 species (approximately 6.0% of all medicinal plants recorded). Its dominance is consistent with the arid character of Central Asian floras and reflects the ecological plasticity, drought tolerance, and salinity tolerance of many wormwood species. Within Amaranthaceae, *Anabasis*, *Atriplex*, *Chenopodium*, and *Salsola* were among the most species-rich genera. These taxa are important components of desert and halophytic vegetation and include species well adapted to water deficit and saline substrates. Together, these genera contribute substantially to wormwood–saltwort and other desert plant communities in the region. *Lepidium*, *Polygonum*, and *Galium* were each represented by six species, demonstrating the contribution of taxa occupying a range of ecological niches and habitats in Mangystau. *Atriplex*, *Verbascum*, and *Tamarix* were represented by five species each, whereas *Anabasis*, *Astragalus*, *Chenopodium*, *Ephedra*, *Euphorbia*, *Ferula*, *Rumex*, *Suaeda*, and *Veronica* each comprised four species. Most of these genera are characteristic of the Irano-Turanian region and are well represented in the desert and semi-desert ecosystems of Western Kazakhstan. From a practical perspective, *Artemisia*, *Ferula*, *Astragalus*, *Ephedra*, *Glycyrrhiza*, *Crataegus*, *Rosa*, and *Verbascum* are especially important because they are widely used in traditional medicine. These genera contain alkaloids, flavonoids, saponins, tannins, essential oils, phenolic compounds, and other constituents of pharmacological interest (Bruneton 1999; World Health Organization 1999–2009; Evans 2009; State Pharmacopoeia of the

Republic of Kazakhstan 2015–2020; Van Wyk & Wink 2017; State Pharmacopoeia of the Russian Federation 2018).

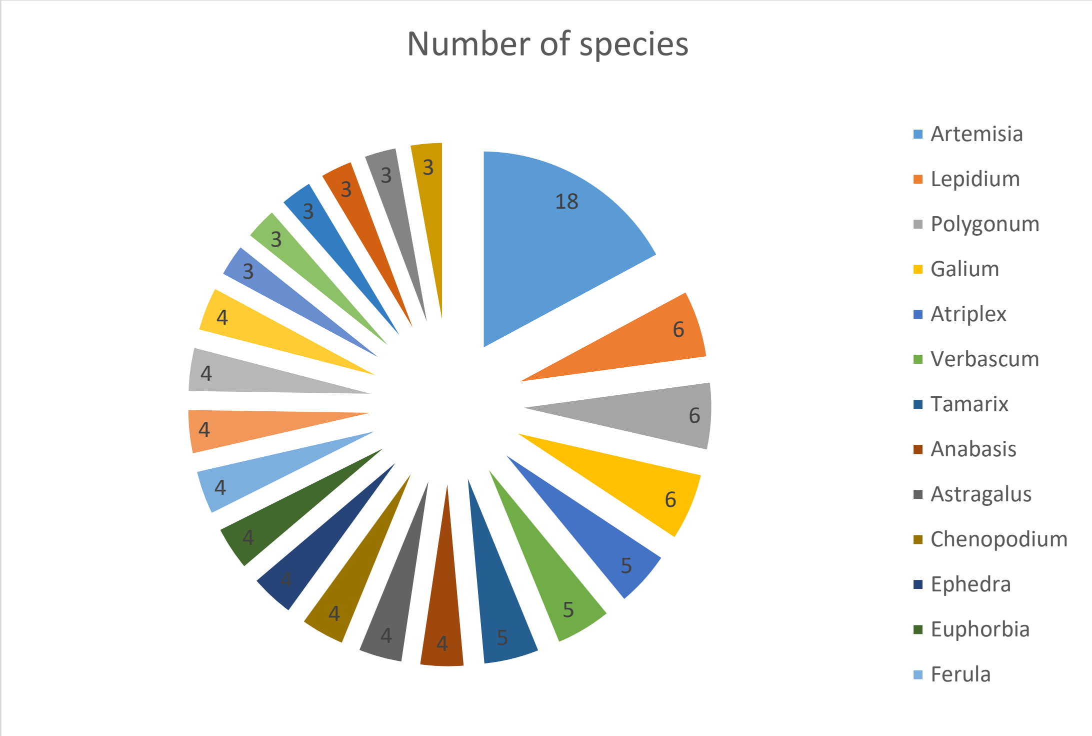

Fig. 1. Distribution of medicinal plant species among the leading genera of the Mangystau flora.

The mean genus richness was 1.73 species per genus (302 species in 175 genera). This low average indicates that only one or two species represented most genera. In contrast, a comparatively small number of species-rich genera accounted for a substantial share of the total diversity. Such a structure is typical of arid Irano-Turanian floras and reflects long-term ecological differentiation under desert conditions. Overall, the generic spectrum confirms the strong Irano-Turanian character of the medicinal flora and the prominence of xerophytic and halophytic elements. Several medicinal species, including *Rheum tataricum*, *Ferula foetida*, *Anabasis aphylla*, *Peganum harmala*, *Ephedra distachya*, *Alhagi pseudalhagi*, *Meristotropis triphylla*, *Nepeta cataria*, *Mentha longifolia*, and *Anabasis salsa*, have been reported to possess notable resource potential. However, any expansion of harvesting should be preceded by population-level resource assessments and the establishment of sustainable collection limits (Faustino-Rocha *et al.* 2023; Takubessi *et al.* 2025; Swastini, *et al.* 2025; Alotaibi *et al.* 2025; Sharma *et al.* 2025; Panda 2025).

Ecological analysis of medicinal plants of the mangystau flora

The medicinal flora of Mangystau has developed under extremely arid conditions characterised by high solar radiation, limited precipitation, soil salinity, and pronounced temperature fluctuations.

Life-form analysis showed a clear predominance of herbaceous plants, a pattern typical of arid floras (Table 2).

Table 2. Distribution of medicinal plant species of the Mangystau flora by life form.

Life form	Number of species	Percentage (%)	Representative species
Perennial herbs	122	40.4	*Glycyrrhiza glabra, Achillea nobilis, Plantago major, Ferula foetida, Mentha longifolia, Teucrium polium*
Annual herbs	106	35.1	*Peganum harmala, Portulaca oleracea, Chenopodium album, Polygonum aviculare, Fumaria parviflora*
Shrubs	28	9.3	*Rosa canina, Rosa laxa, Nitraria schoberi, Lycium ruthenicum, Tamarix ramosissima*

Semi-shrubs and dwarf shrubs	21	7.0	*Artemisia lercheana, Artemisia terrae-albae, Anabasis aphylla, Kochia prostrata*
Biennial herbs	15	5.0	*Verbascum thapsus, Verbascum songaricum, Melilotus officinalis*
Trees	10	3.3	*Crataegus ambigua, Crataegus altaica, Morus alba, Elaeagnus angustifolia, Salix alba*
Total	302	100.0	—

Among the 302 species, perennial herbs were the largest group, with 122 species (40.4%). Their dominance reflects their capacity to persist through prolonged periods of water deficit. Annual herbs were also abundant (106 species; 35.1%) and completed their life cycles during short periods of favourable moisture availability, particularly in spring. Shrubs comprised 28 species (9.3%), semi-shrubs and dwarf shrubs 21 species (7.0%), biennial herbs 15 species (5.0%), and trees 10 species (3.3%). The low representation of woody life forms is consistent with severe aridity and the limited availability of persistently moist habitats. Overall, the prevalence of perennial and annual herbs illustrates complementary strategies for persistence in desert environments. Xerophytes formed the largest ecological group, with 106 species (35.1%). Their predominance reflects low precipitation, high temperatures, and intense solar radiation. This group included numerous representatives of *Artemisia, Atriplex, Ferula, Anabasis, Kochia, Ephedra, Astragalus, Echinops*, and *Cousinia*. Common xerophytic adaptations include extensive root systems, leaf pubescence, reduced leaf area, and water-storage capacity (Table 3). Xeromesophytes were the second-largest group, comprising 68 species (22.5%). They occurred mainly in relatively mesic microsites, including Karatau gorges, temporary watercourse valleys, and topographic depressions. Representative species included *Achillea nobilis, Inula britannica, Mentha longifolia*, and *Nepeta cataria*.

Table 3. Ecological structure of medicinal plants of the Mangystau flora.

Ecological group	n	%	Representative species	Ecological significance
Xerophytes	106	35.1	*Artemisia lercheana, Ferula caspica, Anabasis aphylla*	The dominant group determines the arid character of the flora
Xeromesophytes	68	22.5	*Achillea nobilis, Ferula foetida, Asparagus pallasii*	Widely distributed under moderately moist conditions
Halophytes	39	12.9	*Salicornia europaea, Atriplex cana, Suaeda physophora*	Associated with saline habitats and salt marshes
Psammophytes	41	13.6	*Agriophyllum latifolium, Artemisia kelleri, Calligonum leucocladum*	Confined to sandy massifs and dune habitats
Petrophytes	25	8.3	*Nanophyton erinaceum, Biebersteinia multifida, Capparis herbacea*	Characteristics of rocky slopes and rock outcrops
Mesophytes	15	5.1	*Eryngium planum, Sium sisaroideum, Artemisia dracunculus, Mentha longifolia,*	Confined to relatively moist habitats
Hygrophytes and Hydrophytes	8	2.5	*Mentha piperita, Veronica anagallis-aquatica, Typha angustifolia, Ceratophyllum demersum, Lycopus europaeus*	Associated with water bodies, springs, and temporary watercourses
Total	302	100.0		

Halophytes comprised 39 species (12.9%) and were associated primarily with saline soils, salt marshes, and Caspian coastal habitats. Representative genera included *Suaeda, Salicornia, Atriplex, Limonium, Halothamnus*, and *Tamarix*. Psammophytes and petrophytes formed distinct groups associated with sandy and rocky substrates, respectively. Psammophytes comprised 41 species (13.6%) and occurred mainly in the Tuyesu, Sam, Bostankum, and Senek sandy massifs. Petrophytes included 25 species (8.3%) and were concentrated on rocky slopes and outcrops of the Western and Eastern Karatau. Mesophytes comprised 15 species (5.1%) and were largely restricted to temporary watercourses, spring-fed sites, and sheltered Karatau gorges. Hygrophytes and hydrophytes were the least represented group (8 species; 2.5%) and occurred mainly near springs, floodplains, and temporarily wet habitats. In a separate classification based on salinity tolerance, salt-tolerant species predominated (167 species; 55.3%) (Table 4), reflecting the widespread occurrence of solonetzic and saline soils and the influence of Caspian coastal ecosystems. Strict halophytes comprised 48 species (15.9%), moderately salt-tolerant species 59 (19.5%), and salt-sensitive species only 28 (9.3%). With respect to light requirements, heliophytes dominated (236 species; 78.1%), consistent with the open character of desert and semi-desert landscapes and the scarcity of closed woody vegetation. Semi-heliophytes accounted for 52 species (17.2%), whereas sciophytes comprised only 14 species (4.7%). Thus, the ecological structure of the medicinal flora was dominated by herbaceous, xerophytic, salt-tolerant, and light-demanding species. This composition reflects strong adaptation to aridity, high irradiance, and soil salinity and is consistent with the desert ecosystems of the Irano-Turanian floristic region (Fabricant & Farnsworth 2001; Hamilton 2004; Schippmann *et al.* 2020; World Health Organization 2025).

Table 4. Distribution of medicinal plants according to soil-salinity tolerance and light requirements.

Ecological group	Number of species	Percentage (%)	Ecological characteristics
According to soil-salinity tolerance			
Salt-tolerant species	167	55.3	Tolerate moderate to high soil salinity
Halophytes	48	15.9	Specialised for growth on saline soils
Moderately salt-tolerant species	59	19.5	Prefer slightly saline habitats
Salt-sensitive species	28	9.3	Confined to non-saline soils
According to light requirements			
Heliophytes	236	78.1	Light-demanding plants of open habitats
Semi-heliophytes	52	17.2	Plants of moderately illuminated habitats
Sciophytes	14	4.7	Shade-tolerant species
Total	302	100.0	

Correlation, cluster, and ordination analyses of ecological groups of medicinal plants

Pearson correlation analysis, hierarchical clustering, and principal component analysis (PCA) were used to characterize ecological differentiation within the medicinal flora and to identify the main environmental gradients associated with species distributions under arid conditions. Pearson correlation analysis revealed clear associations among the ecological groups. Positive correlations among xerophytes, halophytes, and, to a lesser extent, petrophytes suggest partly shared adaptation to water deficit, high solar radiation, soil salinity, and substrate stress. By contrast, mesophytic, hygrophytic, and hydrophytic groups were negatively associated with the xerophytic complex, reflecting differences in moisture requirements and habitat preferences. The correlation heatmap (Fig. 2) visualizes the direction and strength of these relationships. The strongest positive associations occurred among groups linked to arid and saline habitats, supporting the interpretation that water availability and soil salinity are major ecological filters shaping the medicinal flora of Mangystau. Hierarchical cluster analysis (Fig. 3) separated the ecological categories into five subgroups, which could be interpreted as two broad ecological complexes. The first was dominated by xerophytic, halophytic, psammophytic, and petrophytic categories associated with drought, high temperatures, intense solar radiation, salinity, and specialized substrates. The second broad complex comprised mesophytic, hygrophytic, and hydrophytic categories associated with comparatively moist habitats, such as spring-fed sites, temporary watercourses, valleys, and sheltered Karatau gorges. This separation emphasizes the central role of moisture availability in the ecological differentiation of the regional flora. PCA (Fig. 4) provided an ordination of the ecological categories and highlighted the principal gradients underlying their distribution. The first principal component (PC1) primarily represented an aridity–moisture gradient, whereas the second component (PC2) differentiated categories associated with saline, sandy, rocky, and other specialized habitats. Together, the multivariate analyses indicate that climatic aridity, soil salinity, moisture availability, and habitat heterogeneity are the principal factors structuring the medicinal flora of Mangystau. These patterns are relevant to assessments of ecological resilience, potential responses to climate change, and the development of conservation and sustainable-use strategies.

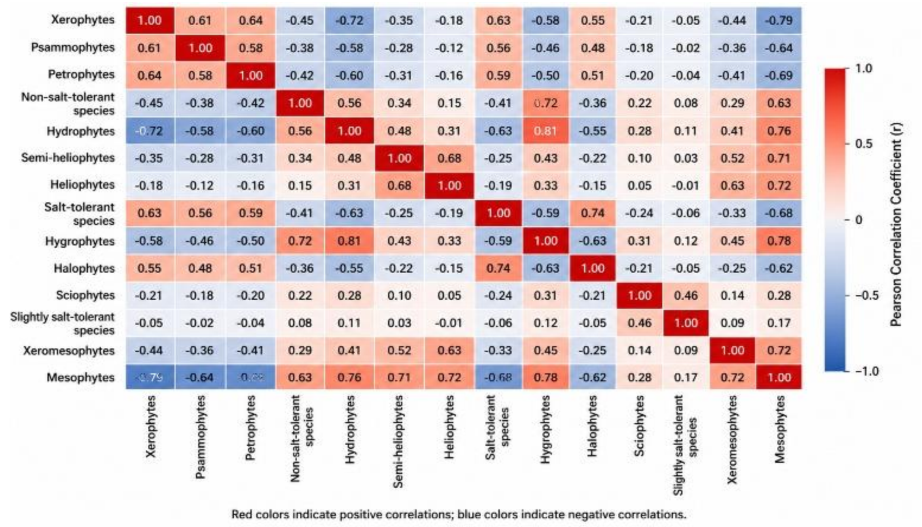

Fig. 2. Pearson correlation heatmap showing relationships among ecological groups of medicinal plants in the Mangystau flora.

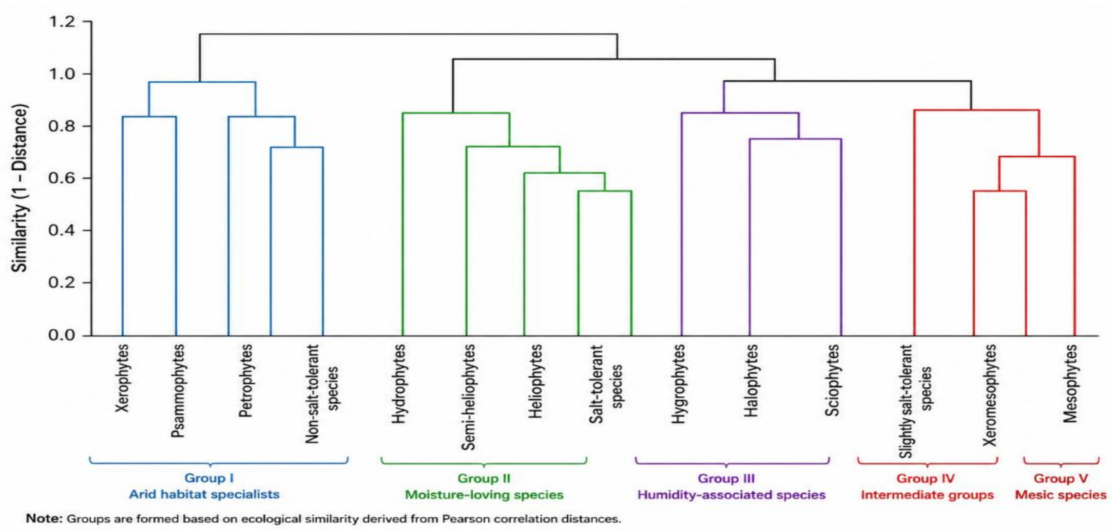

Fig. 3. Hierarchical clustering dendrogram showing ecological relationships among medicinal plant groups in the Mangystau flora.

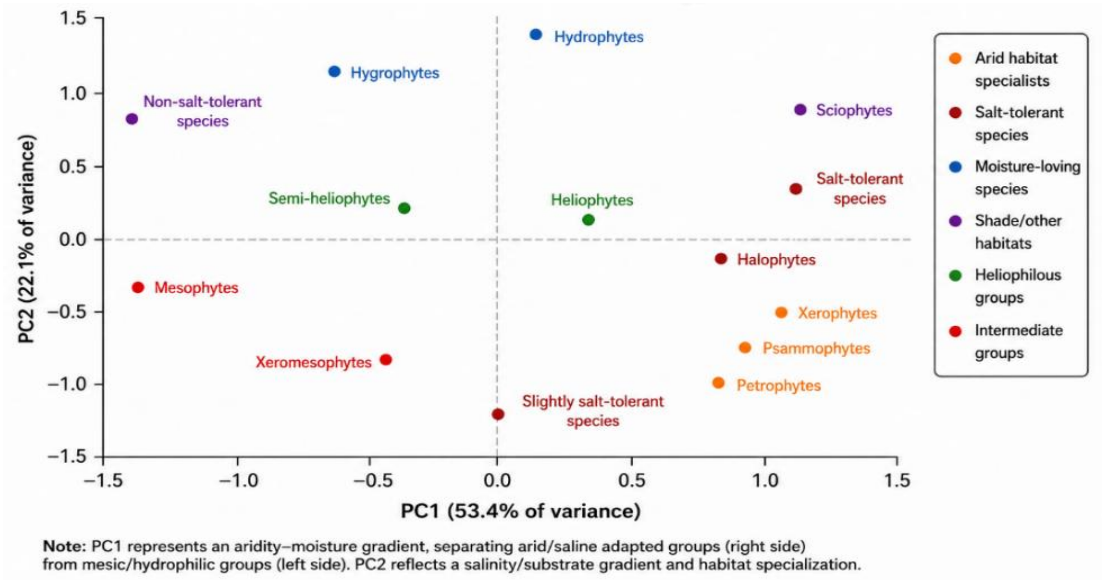

Fig. 4. Principal component analysis (PCA) ordination of ecological groups of medicinal plants in the Mangystau flora.

Bioactive compounds, pharmacological activities, and applications of medicinal plants of the Mangystau flora

The literature-based synthesis revealed a broad diversity of reported bioactive compounds among medicinal plants of the Mangystau flora (Table 5). Flavonoids were the most frequently reported class, occurring in 261 species (86.4%). They were common in *Artemisia, Achillea, Glycyrrhiza, Crataegus, Rosa, Mentha,* and other genera, indicating substantial antioxidant and anti-inflammatory potential (Plants [Basel] 2024; Frontiers in Plant Science 2024; Elsevier 2024–2025; Pharmaceutical Biology 2023–2025). Phenolic compounds ranked second, being reported in 132 species (43.7%). These compounds exhibit antioxidant, antimicrobial, and anti-inflammatory activities and may also contribute to plant protection against the oxidative stress characteristic of arid environments (Biodiversity and Conservation 2023). Saponins were reported in 66 species (21.9%) and were especially characteristic of Fabaceae, Caryophyllaceae, and Asparagaceae. Their documented activities include expectorant, immunomodulatory, and anti-inflammatory effects. Essential oils were reported in 54 species (17.9%), particularly within Asteraceae, Lamiaceae, and Apiaceae. They exhibit antiseptic, antimicrobial, and antispasmodic activities. *Artemisia austriaca, Mentha longifolia, Thymus kirgisorum*, and *Ocimum basilicum* were among the principal essential-oil-bearing species (Economic Botany 2024). Alkaloids were reported in 39 species (12.9%), with notable representation in *Ephedra, Peganum, Sophora, Glaucium,* and *Anabasis*. Because of their high biological activity, these compounds exhibit bronchodilatory, neurotropic, cardiotonic, and antimicrobial effects. *Ephedra distachya, E. strobilacea, Peganum harmala, Sophora alopecuroides, Anabasis aphylla,* and *Glaucium corniculatum* are therefore of particular pharmacological interest (Journal of Herbal Medicine 2023). Tannins were reported in 38 species (12.6%), especially among Rosaceae, Plantaginaceae, and Polygonaceae. Their recognized properties include astringent, anti-inflammatory, and wound-healing effects.

Other compound classes were reported less frequently, including vitamins (19 species; 6.3%), polysaccharides (12 species; 4.0%), coumarins (12 species; 4.0%), glycosides (9 species; 3.0%), anthraquinones, iridoids, and naphthoquinones. Despite their lower frequency, these compounds may determine important species-specific therapeutic properties.

Table 5. Major classes of bioactive compounds reported in medicinal plants of the Mangystau flora.

Class of bioactive compounds	Representative species	Number of species (n)	Percentage (%)
Flavonoids	*Artemisia terrae-albae, Achillea nobilis, Glycyrrhiza glabra, Crataegus ambigua, Rosa canina, Plantago lanceolata, Teucrium polium, Mentha longifolia*	261	86.4
Phenolic compounds	*Atriplex cana, Chenopodium album, Galium verum, Polygonum aviculare, Rumex crispus, Salix alba*	132	43.7
Saponins	*Astragalus onobrychis, Glycyrrhiza glabra, Gypsophila paniculata, Acanthophyllum pungens, Asparagus officinalis, Rosa laxa*	66	21.9
Essential oils	*Artemisia austriaca, Mentha arvensis, Mentha longifolia, Ocimum basilicum, Nepeta cataria, Thymus kirgisorum, Achillea nobilis, Ferula foetida*	54	17.9
Alkaloids	*Ephedra distachya, Ephedra strobilacea, Peganum harmala, Sophora alopecuroides, Glaucium corniculatum, Anabasis aphylla, Echinops ritro*	39	12.9
Tannins	*Plantago major, Limonium gmelinii, Rumex crispus, Agrimonia asiatica, Salix alba, Elaeagnus angustifolia*	38	12.6
Coumarins	*Ferula caspica, Ferula foetida, Prangos odontalgica, Melilotus officinalis, Melilotus albus*	12	4.0
Polysaccharides	*Plantago major, Cistanche salsa, Astragalus filicaulis, Glycyrrhiza glabra, Asparagus officinalis*	12	4.0
Glycosides	*Adonis aestivalis, Adonis parviflora, Erysimum versicolor, Cynanchum acutum* subsp. *sibiricum, Plantago lanceolata*	9	3.0

Anthraquinones	*Rheum tataricum*, *Rumex crispus*, *Rumex marschallianus*, *Rumex ucranicus*	8	2.6
Iridoids	*Plantago lanceolata*, *Veronica anagallis-aquatica*, *Lonicera tatarica*, *Lamium amplexicaule*	6	2.0
Naphthoquinones	*Arnebia decumbens*, *Rindera tetraspis*	2	0.7

Table 6. Major reported pharmacological activities, therapeutic applications, and representative medicinal plants of the Mangystau flora.

Pharmacological activity	**Therapeutic application**	**Representative species**
Antioxidant	Prevention of oxidative stress; tonic and restorative remedies	*Artemisia terrae-albae*, *Rosa canina*, *Ribes aureum*, *Elaeagnus angustifolia*, *Portulaca oleracea*
Anti-inflammatory	Diseases of the respiratory, gastrointestinal, and urinary systems	*Achillea nobilis*, *Plantago major*, *Teucrium polium*, *Mentha longifolia*, *Verbascum thapsus*
Antimicrobial and Antiseptic	Respiratory infections, colds, and infectious diseases	*Allium caspium*, *Peganum harmala*, *Ocimum basilicum*, *Thymus kirgisorum*, *Artemisia austriaca*
Expectorant and Bronchodilatory	Respiratory diseases	*Ephedra distachya*, *Glycyrrhiza glabra*, *Plantago lanceolata*, *Marrubium vulgare*, *Verbascum songaricum*
Antispasmodic	Disorders of the gastrointestinal and respiratory systems	*Mentha longifolia*, *Ferula foetida*, *Glaucium corniculatum*, *Ocimum basilicum*
Cardiotonic	Cardiovascular diseases	*Crataegus ambigua*, *Crataegus altaica*, *Adonis aestivalis*, *Adonis parviflora*, *Erysimum versicolor*
Diuretic	Diseases of the urinary system	*Asparagus officinalis*, *Alhagi pseudalhagi*, *Equisetum ramosissimum*, *Galium aparine*, *Polygonum aviculare*
Hypoglycemic	Prevention and adjunctive therapy of diabetes mellitus	*Morus alba*, *Portulaca oleracea*, *Teucrium polium*
Hepatoprotective and Choleretic	Liver and biliary tract diseases	*Cichorium intybus*, *Artemisia scoparia*, *Ferula foetida*, *Fumaria parviflora*
Wound-healing	Skin diseases, wounds, and burns	*Plantago major*, *Arnebia decumbens*, *Stellaria media*
Tonic and Vitamin-rich	Vitamin deficiencies and immune system support	*Rosa canina*, *Ribes aureum*, *Morus alba*, *Armeniaca vulgaris*

The diversity of reported compound classes was reflected in a broad spectrum of pharmacological activities (Table 6). Antioxidant activity was widely reported, including for *Artemisia terrae-albae, Rosa canina, Ribes aureum, Elaeagnus angustifolia*, and *Portulaca oleracea*. Anti-inflammatory activity was also common, notably in *Achillea nobilis, Plantago major, P. lanceolata, Glycyrrhiza glabra, Mentha longifolia, Teucrium polium*, and *Verbascum thapsus*. Antimicrobial and antiseptic activities were reported for a substantial number of species, including *Peganum harmala, Ocimum basilicum, Thymus kirgisorum, Artemisia austriaca*, and representatives of *Allium, Sophora, and Glaucium*. Plants with expectorant and bronchodilatory uses included *Ephedra distachya, E. strobilacea, Glycyrrhiza glabra, Plantago lanceolata, Marrubium vulgare,* and *Verbascum songaricum*. Species with reported cardiotonic activity included Crataegus ambigua, C. altaica, Adonis aestivalis, and *A. parviflora*; those with diuretic activity included *Asparagus officinalis, Alhagi pseudalhagi, Polygonum aviculare*, and *Galium aparine*. *Morus alba, Portulaca oleracea,* and *Teucrium polium* were associated with hypoglycaemic effects. At the same time, *Cichorium intybus, Ferula foetida, Arnebia decumbens*, and *Plantago major* were notable for hepatoprotective, choleretic, or wound-healing applications. The synthesis of reported uses showed that medicinal plants of Mangystau are most frequently used for respiratory, gastrointestinal, cardiovascular, and urinary disorders. Many are also used as tonic, vitamin-rich, anti-inflammatory, or antioxidant remedies (Industrial Crops and Products 2024; South African Journal of Botany 2024). Alkaloid-containing species of *Ephedra, Peganum, Sophora, Anabasis*, and *Glaucium* are especially important as sources of pharmacologically active raw materials. Overall, the medicinal flora of Mangystau contains a broad spectrum of reported bioactive compounds and pharmacological activities. The prevalence of species with antioxidant, anti-inflammatory, antimicrobial, and adaptogenic effects highlights the region's potential for further studies of phytochemicals, pharmacology, cultivation, and sustainable resources (Plant Diversity 2025).

DISCUSSION

This study demonstrates that the medicinal flora of Mangystau has high taxonomic and ecological diversity and substantial reported phytochemical and utilization potential. Its structure reflects the region's extreme aridity and the broader characteristics of Irano-Turanian desert ecosystems, including the prominence of xerophytic and halophytic species and the concentration of species richness within a limited number of leading families and genera. The dominance of Asteraceae, Amaranthaceae, Brassicaceae, and Fabaceae is consistent with the composition of many Central Asian and Western Kazakh floras, in which these families play a major role in desert and semi-desert vegetation. *Artemisia*, represented by 18 species, was the leading genus. Its prominence reflects the capacity of many wormwoods to tolerate water deficit, intense solar radiation, and saline soils. Life-form analysis confirmed the leading role of herbaceous plants, which accounted for more than 75% of the medicinal flora. Perennial herbs provide persistence under prolonged drought, whereas annuals exploit short periods of favourable spring moisture. The limited representation of woody species reflects the scarcity of habitats with reliable water availability. The predominance of xerophytes, salt-tolerant species, and heliophytes further demonstrates the importance of aridity, high irradiance, and soil salinity. The substantial representation of halophytes highlights the contribution of saline and coastal habitats. At the same time, psammophytes, petrophytes, mesophytes, and hygrophytes reflect the ecological heterogeneity of sandy massifs, rocky substrates, temporary watercourses, springs, and sheltered gorges. Correlation, clustering, and ordination analyses revealed close associations among ecological categories adapted to arid, saline, and rocky habitats, whereas moisture-dependent categories were more distinct from the xerophytic complex. These patterns demonstrate that water availability, salinity, and substrate type jointly organize the ecological structure of the regional medicinal flora. The cluster analysis broadly separated arid–halophytic categories from mesic and hydrophilic categories, emphasizing the central role of moisture availability. PCA further indicated that the primary gradients were related to aridity–moisture conditions and specialization to saline, sandy, and rocky substrates. These multivariate patterns should be interpreted as an exploratory synthesis of ecological classifications rather than as direct measurements of physiological tolerance. Nevertheless, they provide a useful framework for prioritising habitat-specific conservation and monitoring. The observed ecological structure indicates a high degree of adaptation to desert conditions and provides a basis for evaluating vulnerability to climate change, habitat disturbance, and unsustainable harvesting. The literature-based phytochemical synthesis showed that flavonoids, phenolic compounds, saponins, and essential oils were the most frequently reported compound classes. The high prevalence—not necessarily the concentration—of flavonoids and phenolics may partly reflect their protective roles under intense radiation and oxidative stress. Since the present study compiled occurrence data from published sources, species-specific concentrations and pharmacological efficacy require direct experimental verification. The compiled evidence nevertheless indicates considerable pharmacological potential. Antioxidant, anti-inflammatory, antimicrobial, and adaptogenic activities were especially common, and alkaloid-containing species of *Ephedra, Peganum, Sophora, Anabasis*, and *Glaucium* merit particular attention. The broad use of regional plants for respiratory, gastrointestinal, cardiovascular, and urinary disorders further underscores their ethnopharmacological and economic importance. Overall, the study expands current knowledge of the taxonomic structure, ecological organization, and reported bioactive potential of Mangystau's medicinal flora. Future research should combine population-resource assessments, voucher-based taxonomic verification, quantitative phytochemical profiling, pharmacological testing, and conservation-status evaluation to support safe and sustainable utilization.

CONCLUSION

The medicinal flora assessed in this study comprised 302 vascular plant species belonging to 175 genera and 58 families, representing approximately 39.2% of the regional vascular flora. Eleven leading families accounted for 198 species (65.5%), demonstrating a pronounced concentration of diversity within a limited number of taxonomic groups. *Artemisia* was the most species-rich genus, with 18 species. *Anabasis, Atriplex, Chenopodium, Salsola, Ferula, Astragalus, Ephedra, Glycyrrhiza, Crataegus*, and *Rosa* also contributed substantially to the ecological or medicinal significance of the flora. Herbaceous life forms dominated, particularly perennial herbs (40.4%) and annual herbs (35.1%). Xerophytes (35.1%) and xeromesophytes (22.5%) were the leading ecological groups, illustrating complementary strategies for persistence under chronic aridity and seasonal moisture availability. The high representation of salt-tolerant species (55.3%), strict halophytes (15.9%), and heliophytes (78.1%) reflects adaptation to saline soils, intense solar radiation, and open desert landscapes. Psammophytes, petrophytes, mesophytes, and hygrophytes demonstrate the additional importance of sandy, rocky, spring-fed, and temporary-watercourse habitats. Correlation, clustering, and ordination analyses identified climatic aridity, moisture availability, soil salinity, and substrate heterogeneity as the principal ecological gradients structuring the medicinal flora. The literature synthesis revealed broad phytochemical diversity. Flavonoids (86.4% of species), phenolic compounds (43.7%), saponins (21.9%), and essential oils (17.9%) were the most frequently reported compound classes. These compounds underpin substantial reported antioxidant, anti-inflammatory, antimicrobial, antiseptic, expectorant, and bronchodilatory potential. However, quantitative chemical analyses and controlled pharmacological studies are required to confirm species-specific efficacy and safety. Regional medicinal plants are most commonly used for respiratory, gastrointestinal, cardiovascular, and urinary disorders, as well as for tonic or vitamin-rich remedies. *Artemisia*, *Ferula*, *Astragalus*, *Ephedra*, *Glycyrrhiza*, *Crataegus*, and *Rosa* are especially promising for further investigation. The results provide a regional baseline for conservation, cultivation, phytochemical research, and sustainable use. Future work should prioritize field-based resource assessment, monitoring of vulnerable populations, quantitative chemical profiling, and validation of pharmacological activities.

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Conflicts of Interest

The authors declare no conflicts of interest.

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