Ethnobotany, phytochemistry, taxonomy, propagation of the genus *Rheum* L.: a comprehensive review with emphasis on Central Asia

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Review

Abstract

Background: Species of the genus *Rheum* L. are widely distributed in desert and mountainous regions of China and Central Asia, where they exhibit distinct morphological variations under diverse ecological conditions. Many species of this genus are medicinal plants, whose rhizomes are extensively used in traditional medicine and pharmacology. In Central Asia and some other countries, the leaf petioles are consumed in spring as vegetables rich in vitamins and biologically active compounds. Consequently, numerous studies have been conducted on species of this genus. The present study provides an extensive overview of previously published research on species of the genus *Rheum* L.

Methods: An extensive online literature search was conducted using major scientific databases, including PubMed, DOAJ, Scopus, and Google Scholar. The following keywords were used, often in combination: *Rheum* L., *Rheum*, Latin names of species, rhubarb, traditional medicine, pharmacology, biochemical composition, taxonomy of *Rheum* L., in vitro, and plantation. In addition, locally published sources on traditional medicine in Uzbekistan, as well as major floristic works, were also consulted.

Results: The results indicate that in China, the rhizomes of *Rheum palmatum* L., *Rheum tanguticum* (Maxim. ex Regel) Balf., *Rheum officinale* Baill., and *Rheum rhabarbarum* L. have long been valued for their medicinal properties. In Central Asia and some other regions, species such as *Rheum maximowiczii* Losinsk., *Rheum macrocarpum* Losinsk., *Rheum khorasanicum* Baradaran & Jafari, and *Rheum ribes* L. are consumed in spring by local populations, particularly their leaf petioles growing under stones or in open habitats. Therefore, many biochemical investigations have been conducted on different species of this genus, demonstrating that anthraquinones and related compounds present in the rhizomes represent the major bioactive constituents. Furthermore, extensive research has been conducted on taxonomy, morphology, molecular genetics, in vitro propagation, and plantation establishment. However, several gaps remain in the existing studies, particularly the need for additional taxonomic, morphological, and molecular-genetic investigations. Moreover, studies on chromosomal characteristics, seed germination, and especially the ontogenetic age structure and demographic parameters of populations are insufficient or limited.

Conclusions: In general, representatives of this genus are of significant economic importance due to their medicinal properties. Therefore, further research in the identified priority areas will contribute to a deeper understanding of their biological characteristics and facilitate the conservation of populations by identifying and mitigating potential threats.

Keywords: *Rheum* L., ethnobotany, medicinal plants, phytochemistry, taxonomy, chloroplast genome, micropropagation, cultivation

Background

Rhubarb is a thick-rooted, erect plant with loose stems and small white-green or red-brown flowers arranged in inflorescences at the top of the stem. Rhubarb is one of the oldest and most important medicinal plants. It is also known as “Rhei” or “Dahuang” in China, “Ревень” in Russia, “Chukuruk” in Kyrgyzstan, “Chukri” or “Revoch” in Tajikistan and Uzbekistan and “Işkın” in Turkey (Lee *et al.* 2017; Batsatsashvili *et al*. 2020 a, b ; Xiang *et al.* 2020; Gecibesler *et al.* 2021; Kosimov *et al.* 2023;).The genus *Rheum* L. comprises approximately 60 species in the family Polygonaceae (Cao *et al*. 2017). *Rheum* was first described by Carl Linnaeus in 1753 in the first volume of his book Species Plantarum, as *“Rheum*, with smooth, thin leaves and equal petioles, pubescent on the petioles” (Linnaeus 1753). The etymology of the term “Rhubarb” is uncertain and is largely obscured in historical records. According to Barney and Hummer (2012), in their book “The Treasury of Botany”, the genus name *Rheum* is derived from Old French. The rhizome of rhubarb has historically been recognized in China as one of the major medicinal plants, and its earliest documented use dates back to approximately 270 BC in “Shen Nong Ben Cao Jing” (Tsai *et al.* 2013; Khaja *et al.* 2025). China is recognized as the primary center of origin of rhubarb, where 38 species are found, the majority of which are distributed in northwestern and southwestern China (Bao & Grabovskaya-Borodina 2003; Tan *et al.* 2016). The introduction of Chinese medicine to the Western world during the Islamic Golden Age (8th-13th centuries CE) stimulated significant commercial and scientific exchange between the Chinese and the Muslim world through the trade of herbal medicinal products. Chinese herbal medicines were described by medieval Muslim medical scholars such as Avicenna (1037 CE) and Jurjani (1137 CE). In “The Canon of Medicine”, Avicenna (1037 CE) used the Arabic terms “rivand - rhubarb” and “al-siniy - from China” 46 times to refer to herbal medicines imported from China. Among these references, rhubarb—“rivand al-sini”—was one of the most frequently mentioned expressions (Heyadri *et al.* 2015).

Numerous studies on species of this genus have been conducted in various directions (Chin & Youngken 1947; Shikishima *et al.* 2001; Komakine *et al.* 2005; Liu *et al.* 2010; Mun & Mun 2016; Tabin *et al.* 2016; Clapa et al. 2020; Zhang *et al.* 2024; Aitzhan *et al.* 2024; Aldaif *et al.* 2025). However, in recent years, a comprehensive analysis of the literature on species of this genus has not been carried out. The present review summarizes scientific studies on selected medicinal species of *Rheum L*., with particular attention to their traditional medicinal applications, biochemical constituents, taxonomic position, molecular-genetic studies, cytological studies, micropropagation methods and plantation establishment

Materials and Methods

The literature search was conducted in the PubMed, DOAJ, Scopus, Google Scholar databases, the eLIBRARY.RU scientific electronic library (eLIBRARY.RU 2026), and Fundamental Electronic Library "Flora and Fauna" (Shipunov 2026), covering from 1753 to 2026. During the search process, the following keywords were commonly used, often in combination: *Rheum* L., *Rheum*, Latin names of species, rhubarb, traditional or folk medicine, pharmacology, biochemical composition, taxonomy of *Rheum* L., seed germination, micropropagation, cultivation, and plantation establishment. Additionally, some locally published books on traditional medicine, issued in limited numbers and not available for purchase in online PDF format, were accessed directly through practitioners or obtained from the publishing houses, and relevant sources from these

materials were used for the present study. All authors independently conducted the literature search. This article utilized books on traditional medicine published in Uzbekistan concerning the genus, particularly floristic works dedicated to Central Asia, as well as local and international articles on various topics. Furthermore, the use of the species in folk medicine was documented photographically during field studies. Among the articles and books identified through the above-mentioned keywords and literature searches, 119 sources addressing taxonomic, ethnobotanical, biochemical, molecular phylogenetic and genomic characterization, cytogenetic, cultivation and propagation, and in vitro propagation studies of the genus *Rheum* L. were ultimately included in the analysis. All photo illustrations were processed using Adobe Photoshop 2025 software solely for non-diagnostic technical adjustments; no content or scientifically relevant features of the images were altered. Tables and diagrams were created using Microsoft Excel. The accepted nomenclature presented in the Plants of the World Online (POWO) platform was used to standardize all species names of the genus *Rheum* L. (Table 1. Plants of the World Online 2026).

Table 1. Description of certain species of the genus *Rheum* L. reported in the literature

№	Species	Bibliographic source	№	Species	Bibliographic source
1	*Rheum coreanum* Nakai	Mun S.Ch. & Mun G.S., 2016	23	*Rheum orientale* Losinsk.	Lozina-Lozinskaya 1936; Komarov 1970
2	*Rheum palmatum* L.	Yoo *et al.* 2012; Zhou *et al.* 2015; Zhang *et al.* 2024	24	*Rheum rupestre* Litv. ex Losinsk.	Lozina-Lozinskaya 1936; Komarov 1970
3	*Rheum tanguticum* (Maxim. ex Regel) Balf.	Zhou *et al.* 2015; Zhang *et al.* 2024; Wang *et al.* 2026	25	*Rheum korshinskyi* V.S.Titov ex Losinsk.	Lozina-Lozinskaya 1936; Komarov 1970
4	*Rheum officinale* Baill.	Cai *et al.* 2004; Zhou *et al.* 2015; Zhang *et al.* 2024	26	*Rheum lucidum* Losinsk.	Li & Tojibaev 2024
5	*Rheum ribes* L.	Öztürk *et al.* 2007; Aldaif *et al.* 2025	27	*Rheum darvasicum* V.S.Titov ex Losinsk.	Korovin & Vvedenskiy 1953; Li & Tojibaev 2024
6	*Rheum khorasanicum* Baradaran & Jafari	Jafari *et al.* 2012; Darrudi *et al.* 2015	28	*Rheum spiciforme* Royle	Vvedenskiy 1971; Khan *et al.* 2022; Li & Tojibaev 2024
7	*Rheum cordatum* Losinsk.	Zhumashova *et al.* 2019; He *et al.* 2024; Amangeldinova *et al.* 2025	29	*Rheum rhizostachyum* Schrenk	Lozina-Lozinskaya 1936; Komarov 1970; Li & Tojibaev 2024
8	*Rheum maximowiczii* Losinsk.	Shikishima *et al.* 2001; Kogure *et al.* 2004; Batsatsashvili *et al.* 2020 a; Rakhmataliev *et al.* 2025; Wang *et al.* 2026	30	*Rheum reticulatum* Losinsk.	Lozina-Lozinskaya 1936; Komarov 1970
9	*Rheum macrocarpum* Losinsk.	He *et al.* 2024	31	*Rheum nanum* Siev.	Lozina-Lozinskaya 1936; Komarov 1970; Vvedenskiy 1971; Li & Tojibaev 2024
10	*Rheum lobatum* Litv. ex Losinsk.	Lozina-Lozinskaya 1936; Komarov 1970	32	*Rheum fedtschenkoi* Maxim. ex Regel	Korovin & Vvedenskiy 1953; Li & Tojibaev 2024
11	*Rheum plicatum* Losinsk.	Lozina-Lozinskaya 1936; Komarov 1970	33	*Rheum hissaricum* Losinsk.	Korovin & Vvedenskiy 1953; Komarov 1970; Li & Tojibaev 2024
12	*Rheum rhaponticum* L.	Paneitz & Westendorf, 1999; Liudvytska *et al.* 2023	34	*Rheum alexandrae* Batalin	Chin & Youngken 1947; Liu *et al.* 2010; Wan *et al.* 2014

13	*Rheum undulatum* Pall.	Paneitz & Westendorf, 1999	35	*Rheum nobile* Hook.f. & Thomson	Chin & Youngken 1947; Liu *et al.* 2010; Wan *et al.* 2014
14	*Rheum rhabarbarum* L.	Will & Dietrich 2013; Clapa *et al.* 2020	36	*Rheum rhomboideum* Losinsk.	Chin & Youngken 1947; Liu *et al.* 2010; Wan *et al.* 2014
15	*Rheum sanguineum* Meisn.	Chin & Youngken 1947; Liu *et al.* 2010; Wan *et al.* 2014	37	*Rheum likiangense* Sam.	Chin & Youngken 1947; Liu *et al.* 2010; Wan *et al.* 2014
16	*Rheum franzenbachii* Münter	Liu *et al.* 2010; Wang *et al.* 2011; Wan *et al.* 2014;	38	*Rheum × collinianum* Baill.	Chin & Youngken 1947; Liu *et al.* 2010; Wan *et al.* 2014
17	*Rheum turkestanicum* Janisch.	Dehghan *et al.* 2018; Ghorbani *et al.* 2019; Yazdi *et al.* 2019	39	*Rheum emodi* Wall.	Tabin *et al.* 2018; Singh & Chaturvedi 2022
18	*Rheum tataricum* L.f.	Amangeldinova *et al.* 2024; Turgunbayeva *et al.* 2025	40	*Rheum webbianum* Royle	Rashid *et al.* 2014; Wan *et al.* 2014
19	*Rheum uzengukuushi* Lazkov & H.J.Choi	Lazkov *et al.* 2020	41	*Rheum australe* D.Don	Chin & Youngken 1947; Liu *et al.* 2010; Wan *et al.* 2014
20	*Rheum compactum* L.	Lozina-Lozinskaya 1936; Komarov 1970	42	*Rheum crassinervium* Fisch. ex Lindl.	Chin & Youngken 1947; Liu *et al.* 2010; Wan *et al.* 2014
21	*Rheum altaicum* Losinsk.	Aitzhan *et al.* 2024	43	*Rheum pumilum* Maxim.	Chin & Youngken 1947; Liu *et al.* 2010; Wan *et al.* 2014
22	*Rheum wittrockii* C.E.Lundstr.	Li & Tojibaev 2024			

Results

Taxonomic classification of the genus *Rheum* L.: an overview of species and sections.

Among the genera of the family Polygonaceae widely distributed in Central Asia, species of the genus *Rheum* L. are considered plants of significant economic importance, being used as forage, food, and medicinal plants (Wani *et al.* 2022; Aitzhan *et al.* 2024). The genus *Rheum* L. belongs to the subfamily Polygonoideae is included in the tribe Rumiceae. This genus is mainly distributed in the Qinghai-Tibet Plateau, the Himalayan region and Central Asia, and exhibits high morphological and ecological diversity (Sanchez *et al.* 2011; Kunwar et al. 2021). In traditional taxonomy, the genus *Rheum* L. was initially classified into sections based on general morphological characteristics: Lozina-Lozinskaya (1936) divided it into nine sections, Kao and Cheng (1975) into seven sections, and Li (1998) into eight sections (Wang *et al.* 2005). In the work "Flora of the U.S.S.R." (Flora of the Union of Soviet Socialist Republics) by Lozina-Lozinskaya (1936), the taxonomic status of the genus *Rheum* L. was described, and 22 species belonging to six sections were recorded within the flora of the USSR. Later, Komarov (1970) translated the "Flora of the U.S.S.R." from Russian into English. In the work "Key to the Identification of Plants of Central Asia" by Vvedenskiy (1971), the taxonomic descriptions of 12 species belonging to the genus *Rheum* L. were provided, and their main morphological characteristics were presented using identification keys. In the work "Flora of China", 38 species of the genus *Rheum* L., along with their distribution, ecology, and morphological characteristics, were documented (Bao & Grabovskaya-Borodina 2003). In the book "Checklist of Central Asian Plants", taxonomic descriptions of 16 species were provided, and some synonymous species were also noted (Li & Tojibaev 2024). In addition, species of the genus *Rheum* L. are widely covered in major floristic sources of Central Asian countries. A total of 10 species were reported in the flora of Tajikistan (Ovchinnikov 1968), 2 in the flora of Turkmenistan (Fedchenko 1937), 7 in the flora of Kyrgyzstan (Vvedenskiy 1953), 9 in the flora of Uzbekistan (Korovin & Vvedenskiy 1953) and 10 in the flora of Kazakhstan (Pavlov 1960; Aitzhan *et al.* 2024) (Fig. 1). In these floristic sources, the vegetation characteristics and ecological-geographical descriptions of the species were provided, and their main morphological traits were described using identification and diagnostic keys (Lazkov *et al.* 2020).

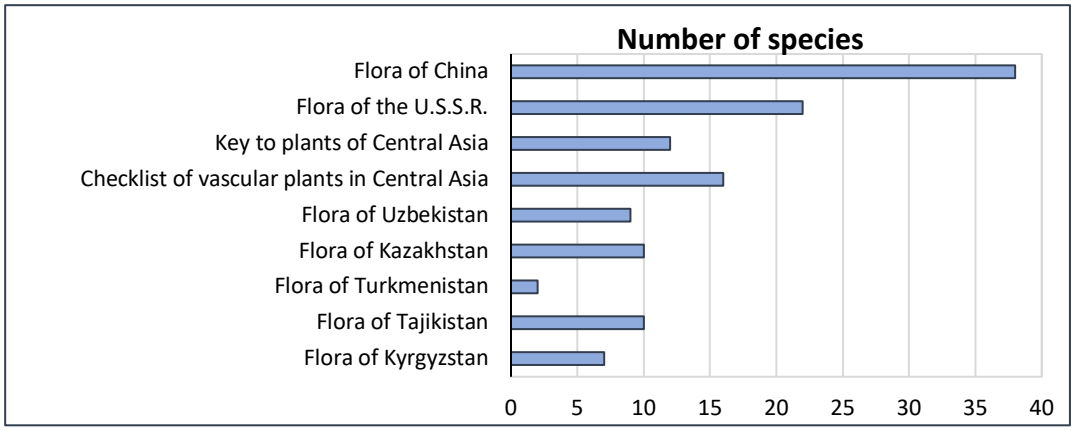


Figure 1. The number of recorded species of the genus *Rheum* L. in the flora of China and Central Asian countries.

Table 2. Records of the genus *Rheum* L. in Central Asia in major published floristic sources.

Species	Source		
	Flora of the U.S.S.R.	Key to plants of Central Asia	Checklist of vascular plants in Central Asia
Rheum undulatum Pall.	+	–	–
Rheum compactum L.	+	–	+
Rheum altaicum Losinsk.	+	+	+
Rheum wittrockii C.E.Lundstr.	+	+	+
Rheum orientale Losinsk.	+	–	–
Rheum tataricum L.f.	+	+	+
Rheum turkestanicum Janisch.	+	+	+
Rheum rupestre Litv. ex Losinsk.	+	–	–
Rheum korshinskyi V.S.Titov ex Losinsk.	+	–	–
Rheum lucidum Losinsk.	+	+	+
Rheum darvasicum V.S.Titov ex Losinsk.	+	+	+
Rheum spiciforme Royle	–	+	+
Rheum rhizostachyum Schrenk	+	–	+
Rheum reticulatum Losinsk.	+	–	–
Rheum nanum Siev.	+	+	+
Rheum uzengukuushi Lazkov & H.J.Choi	–	–	+
Rheum fedtschenkoi Maxim. ex Regel	+	+	+
Rheum ribes L.	+	–	–
Rheum maximowiczii Losinsk.	+	+	+
Rheum cordatum Losinsk.	+	+	+
Rheum hissaricum Losinsk.	+	–	+
Rheum plicatum Losinsk.	+	–	–
Rheum macrocarpum Losinsk.	+	+	+
Rheum lobatum Litv. ex Losinsk.	+	–	–

Note: listed as a species in the respective source (+); not listed as a species in the respective source.In that source (–).

Ethnobotanical uses and significance of *Rheum* L. species.

Many species of the genus *Rheum* L. are valued as medicinal herbs and as food. *Rheum coreanum* in Korea (Mun & Mun 2016), *Rheum palmatum*, *Rheum tanguticum*, and *Rheum officinale* in China (Zhou *et al.* 2015; Zhang *et al.* 2023, 2024), *Rheum ribes* in Turkey (Batsatsashvili *et al.* 2020 b; Aldaif *et al.* 2025), *Rheum khorasanicum* in Iran (Darrudi *et al.* 2015; Batsatsashvili *et al.* 2020 b) and *Rheum maximowiczii*, *Rheum macrocarpum* and *Rheum cordatum* in Central Asia (Zhumashova *et al.* 2019; Batsatsashvili *et al.* 2020 a; He *et al.* 2024) are considered medicinal plant species, and their roots and petioles are consumed (excluding the species found in China). However, rhubarb leaves are not suitable for consumption, as the oxalic acids present in the leaves are considered toxic (Schrader 2000; Marr & Carey, 2001; Parsons *et al.* 2003). In China, rhubarb has long been regarded as having effects such as “clearing and reducing heat,” “cooling the blood,” “dispersing blood stasis,” “removing vascular obstructions,” detoxification, and laxative properties. It has been used to treat constipation, diabetic nephropathy, hepatitis, chronic renal failure, acute pancreatitis, gastrointestinal bleeding, hypertension, detoxification, the common cold, respiratory tract inflammation, and various other diseases (Cao *et al.* 2017; Batsatsashvili *et al.* 2020 a).

Rhubarb was described by Abu Ali ibn Sina (Avicenna, 1037) as a medicinal plant beneficial for the management of uterine bleeding, asthma, intestinal inflammation, and disorders related to the kidneys and bladder (Mukhtorov & Najmiddinov 2009). In the 19th century, during the period of former Soviet rule in Central Asia, the traditional healer Alikhontura Soguniy also reported in his work "Shifo ul-ilal" that rhubarb, in combination with other plants, possesses medicinal properties and is used in the treatment of kidney and bladder diseases (Soguniy 2023). Traditional practitioners in Central Asia prepare rhubarb rhizomes by removing the outer layer, cutting them into fragments and infusing them in milk. This preparation is consumed to treat numerous internal ailments and is believed to improve digestive and cardiac activity while also reducing bleeding (Umarov et al. 2010). Rhubarb is also described as having a cold and dry temperament and is considered a beneficial plant for improving vision, treating diarrhea, and jaundice (Umarov *et al.* 2010; Shahobiy *et al.* 2016). The dried rhizomes are ground and taken at a dose of 0.2-0.5 g three times a day as an anti-diarrheal agent. As a laxative, it is taken at a dose of 1-2 g three times a day (Karimov & Shomakhmudov 1993; Usmonkhodjaev *et al.* 2018). In Central Asia, *Rheum maximowiczii* and *Rheum macrocarpum* are the most widely consumed and medicinally used species (Fig. 2, Kosimov *et al.* 2023; He *et al.* 2024; Rakhmataliev *et al.* 2026 a,c; Wang *et al.* 2026). Therefore, due to its economic, nutritional and pharmaceutical properties, this species is of significant importance in Central Asia (Batsatsashvili *et al.* 2020 a; Rakhmataliev *et al.* 2025; Rakhmataliev *et al.* 2026a).



Figure 2. Use of rhubarb as a food and medicinal resource: A, B, E - processes of drying rhubarb petioles; C - seeds; D - its dried rhizomes; F - specially processed petioles.

Phytochemical composition of *Rheum* L. species.

As a consequence of scientific development during the 20th century, researchers showed an increasing interest in medicinal plants, particularly in various species of rhubarb. During this period, scientists began to study not only the morphological characteristics of these plants but also their chemical composition in depth. In particular, the biologically active compounds present in rhubarb, along with their therapeutic properties and significance in medicine, started to be systematically analyzed from a scientific perspective (Jiao & Du 2000; Barney & Hummer 2012). In the genus *Rheum* L., the most common bioactive compounds include anthraquinones—emodin, rhein, chrysophanol, physcion; phenolics—gallic, caffeic, chlorogenic acids; flavonoids—rutin, catechin, apigenin and anthocyanins. These biologically active compounds are recognized for their diverse therapeutic properties, particularly antioxidant, anticancer, antimicrobial, antidiarrheal, antidiabetic, anti-inflammatory, diuretic, and hepatoprotective activities (Tripathi *et al.* 2014; Pham *et al.* 2017; Shen *et al.*

2017; Clapa *et al.* 2020; Batsatsashvili *et al*. 2020 a, b; Aldaif *et al.* 2025; Wang *et al.* 2026). Plants belonging to the genus *Rheum* L. have been domesticated as medicinal plants, as the existence of anthraquinone compounds such as emodin and rhein has been identified in their rhizomes and petioles (Zargar *et al.* 2011; Tabin *et al.* 2014). Emodin and aloe-emodin have been shown to inhibit proliferation and induce apoptosis (programmed cell death) in various cancer cell lines, including breast and liver cancer cells, thereby suppressing their growth (Rajkumar *et al.* 2011; Khaja et al. 2025). These compounds exhibit a wide range of pharmacological effects, including the regulation of gastrointestinal function, anticancer activity, antimicrobial effects, hepatoprotective properties, anti-inflammatory action, as well as protective effects on the cardiovascular and cerebrovascular systems (Cao *et al.* 2017). Numerous species of the genus *Rheum* L., distributed across Europe, China and adjacent regions, as well as in Central Asian countries, have been investigated for their bioactive compounds (Shikishima *et al.* 2001; Komakine *et al.* 2005).

Bioactive compounds in *Rheum undulatum*, the "Baillon" cultivar of *Rheum officinale* and *Rheum rhaponticum* were investigated by Paneitz and Westendorf (1999). In this study, rhizomes of Baillon and *Rheum rhaponticum*, as well as leaves, petioles and rhizomes of *Rheum undulatum*, were used as plant materials. The results showed that anthraquinone derivatives, particularly emodin, chrysophanol and physcion, were present in high concentrations in compounds isolated from the leaves of *Rheum undulatum*. Furthermore, *Salmonella*/microsome (Ames) tests were conducted using extracts from Baillon, *Rheum rhaponticum* rhizomes and *Rheum undulatum* leaf blades. The findings demonstrated that these extracts exhibited mutagenic activity. Notably, the extract of *Rh. officinale* showed mutagenic effects independent of metabolic activation, whereas *Rh. rhaponticum* and *Rh. undulatum* exhibited mutagenicity only in the presence of the S9 metabolic activation system (Paneitz & Westendorf 1999).

In China, Cai *et al.* (2004) evaluated the antioxidant activity of phenolic compounds in the roots of *Rheum officinale* and *Rubia cordifolia*. The results indicated that the principal antioxidant phenolic constituents in the roots of *Rubia cordifolia* were hydroxyanthraquinones, whereas tannins and gallic acid were identified as the main antioxidant compounds in the rhizomes of *Rheum officinale*.

In Germany, Will and Dietrich (2013) conducted a study aimed at optimizing the juice production process from the Sutton cultivar of rhubarb (*Rheum rhabarbarum*) and evaluating its chemical composition. The preparation of rhubarb juice involved washing the petioles, grinding them using a perforated disc mill and subsequently extracting the juice immediately.
According to the chemical analysis, the juice was characterized by low sugar content and high total acidity. Malic acid was identified as the predominant organic acid, followed by oxalic and citric acids. The total polyphenol content and antioxidant activity were relatively low. In addition, the levels of anthocyanins, including cyanidin-3-rutinoside, cyanidin-3-glucoside and delphinidin-3-rutinoside, were also found to be low. However, the rhubarb juice was rich in mineral elements such as potassium and magnesium, as well as nitrate.

The phenolic composition of the rhizomes, petioles and leaves of *Rheum rhabarbarum* cultivated under field and in vitro conditions was investigated. The results revealed the presence of various phenolic compounds, including gallic acid, protocatechuic acid, *p*-hydroxybenzoic acid, vanillic acid, chlorogenic acid, caffeic acid, syringic acid, *p*-coumaric acid, ferulic acid, rosmarinic acid and its two derivatives (in the rhizomes), as well as catechin and vitexin. In the leaves, compounds such as rutin, resveratrol, isoquercitrin, quercitrin, apigenin and galangin were identified (Clapa *et al.* 2020).

In the experimental fields of the Federal Scientific Vegetable Center located in the Moscow region of Russia, four rhubarb cultivars—Malakhit, Krupnochereshkovy, Upryamets and Zaryanka—developed by the same center were cultivated. Kharchenko *et al.* (2023) conducted comparative studies on the leaves, stalks (juice and press residues) and roots of these cultivars to assess their biochemical differences. According to laboratory analyses, 98% of the total organic acids consisted of citric, oxalic and succinic acids. The juice of the Upryamets cultivar was found to contain high levels of sorbic and benzoic acids, making it suitable for juice production. The press residues were identified as a rich source of pectin and dietary fiber. Furthermore, the total antioxidant activity was found to be predominantly associated with the root tissues (Kharchenko *et al.* 2023).

Liudvytska *et al.* (2023) investigated the biological activity of extracts obtained from the petioles and roots of *Rheum rhaponticum* and *Rheum rhabarbarum*, as well as the effects of typical stilbenes present in these plants—rhapontigenin and rhaponticin—on blood physiology and cardiovascular health. Considering the interplay between inflammation and oxidative stress in cardiovascular diseases, antioxidant properties were also evaluated. The study employed peripheral blood mononuclear cells (PBMCs), which reflect the human immune response, as well as THP1-ASC-GFP human monocyte-derived

cells expressing green fluorescent protein, enabling visualization under fluorescence microscopy. The results demonstrated that extracts derived from rhubarb petioles were slightly more effective in reducing inflammatory responses in PBMCs, whereas rhizome-derived extracts exhibited stronger antioxidant and anti-inflammatory effects in THP1-ASC-GFP cells. Furthermore, the tested compounds significantly reduced the oxidative effects of the highly reactive molecule peroxynitrite ($ONOO^-$) on human blood plasma proteins, including fibrinogen, tryptophan and tyrosine, thereby demonstrating notable antioxidant and protective properties.

In Turkey, Öztürk *et al.* (2007) evaluated the antioxidant activity of chloroform and methanol extracts obtained from the rhizomes and petioles of *Rheum ribes* using six different assay methods. The results demonstrated that both chloroform and methanol extracts of the rhizomes exhibited high antioxidant activity. Moreover, methanol extracts showed stronger DPPH (1,1-diphenyl-2-picrylhydrazyl) radical scavenging activity compared to the corresponding chloroform extracts. The methanol extract of the petioles was found to be more effective than the synthetic antioxidant BHT (butylated hydroxytoluene). In addition, both rhizome extracts exhibited stronger superoxide anion radical scavenging activity than BHT and showed activity comparable to L-ascorbic acid, a well-known natural antioxidant with protective effects in biological systems.

The chemical composition of *Rheum maximowiczii*, a species native to Central Asia, has been investigated, revealing the presence of phenylbutanoids and stilbene dimers in its rhizomes, while an indole alkaloid was isolated from its seeds (Shikishima *et al.* 2001; Komakine *et al.* 2005). In Uzbekistan, several plant species, including *Ferula pallida* Korovin, *Ferula penninervis* Regel & Schmalh., *Inula macrophylla* Kar. & Kir. (*Inula grandis* Schrenk ex Fisch. & C.A.Mey.- POWO, 2026), *Prangos pabularia* Lindl., *Prangos tschimganica* O.Fedtsch. and *Rheum maximowiczii* Losinsk., are traditionally used as medicinal plants. Kogure *et al.* (2004) investigated the antioxidant activity of chemical compounds isolated from the seeds of these plants using a model system based on egg yolk lipids incorporated into an artificial membrane. Lipid peroxidation was induced by ADP/Fe^{2+}, while the scavenging activity against DPPH radicals was also evaluated. The ADP (adenosine diphosphate) + Fe^{2+} system is known to generate highly reactive free radicals that promote lipid oxidation (Nakano *et al.* 1984; Valenzuela & Guerra 1986; Kawano *et al.* 1991). DPPH (1,1-diphenyl-2-picrylhydrazyl) is a stable synthetic free radical commonly used to assess antioxidant activity, where a reduction in its characteristic purple color to yellow or pink indicates radical scavenging activity (Dehghan *et al.* 2018; Kumar *et al.* 2024). The results demonstrated that among the tested plant-derived compounds, the strongest antioxidant activity was observed in *Rheum maximowiczii*. According to the authors, this species may represent a promising source for the development of effective antioxidant agents for pharmaceutical applications (Kogure *et al.* 2004). According to the most recent scientific studies, *Rheum maximowiczii* has attracted considerable interest as a medicinal plant for cultivation as an industrial crop in Central Asia (Rakhmataliev *et al.* 2025). Therefore, a comprehensive comparative analysis was conducted with the widely cultivated *Rheum tanguticum*. The results showed that *Rheum maximowiczii* contains lower levels of anthraquinones but is rich in phenolic acids, including catechin and gallic acid. Furthermore, despite its low anthraquinone content, the acute toxicity of *Rheum maximowiczii* was found to be more than three times lower than that of *Rheum tanguticum*. These findings indicate the safety of the traditional medicinal and food uses of this species for human health in Central Asia (Wang *et al.* 2026).

Dehghan *et al.* (2018) conducted a study aimed at isolating bioactive phytochemical compounds from the rhizomes of *Rheum turkestanicum* using a bioassay-guided fractionation and purification (BGFP) approach. Among the various extracts tested, the ethyl acetate extract was identified as the most effective and was therefore selected for further analysis. This extract was fractionated using column chromatography, and all fractions were evaluated through α-amylase and α-glucosidase inhibition assays, DPPH radical scavenging activity, and total phenolic content determination. The results led to the isolation of several active compounds, including chrysophanol, physcion, emodin, daucosterol and rhododendrin (betuloside). According to the authors, the rhizomes of *Rheum turkestanicum* represent a promising source of bioactive phytochemicals for the development of novel therapeutic agents.

Yazdi *et al.* (2020) evaluated the toxicity of the hydroalcoholic extract of *Rheum turkestanicum* rhizomes using acute and subacute oral administration in Swiss albino male and female mice, as well as Wistar male rats, over a 14-day period. In the acute toxicity study, a single high dose was administered. No mortality or signs of toxicity were observed at a dose of 300 mg/kg in both male and female mice, whereas at 3000 mg/kg, one male and one female mouse died. In the subacute study, the extract was orally administered to male rats at doses of 100 and 400 mg/kg daily for four weeks. No mortality, changes in body weight, general behavior, hematological parameters, serum biochemical markers (related to liver and kidney function), or histopathological alterations in the heart, liver, kidneys and brain tissues were observed. The authors concluded that *Rheum turkestanicum* rhizome extract is non-toxic at doses up to 400 mg/kg. Additionally, a review of the ethnobotanical and pharmacological properties of *Rheum turkestanicum* was also conducted (Ghorbani *et al.* 2019).

In Kazakhstan, the phytochemical composition of roots and leaves from two species, *Rheum tataricum* and *Rheum cordatum*, was investigated to evaluate their antioxidant and antimicrobial activities (Amangeldinova *et al.* 2024; Amangeldinova *et al.* 2025). In this study, three extraction methods—supercritical CO_2 extraction ($ScCO_2$), subcritical ethanol extraction (Sc) and ultrasound-assisted extraction (UAE)—were applied. A total of 53 phytochemical compounds were identified in the extracts, and their chemical composition was correlated with biological activity. The results indicated that extracts of *Rheum tataricum* contained high levels of catechin, epicatechin, cyranoside and chlorogenic acid. Among the extraction techniques, UAE demonstrated superior efficiency compared to the other methods. Furthermore, extracts obtained using Sc-400 atm and Sbc-EtOH-E 140-60 and 140-80 extraction conditions exhibited strong antimicrobial activity against the Gram-positive bacterium *Enterococcus faecalis* (Amangeldinova *et al.* 2024).

The extracts of *Rheum cordatum* were found to contain high levels of gallic acid (UAE-EtOH-4h), rutin ($ScCO_2$-150) and hesperidin ($ScCO_2$-150). Extracts obtained using the $ScCO_2$-150 method exhibited antimicrobial activity against Gram-positive bacteria, including *Bacillus subtilis* and *Staphylococcus aureus*, as well as the Gram-negative bacterium *Pseudomonas aeruginosa* (Amangeldinova *et al.* 2025).

Turgunbayeva *et al.* (2025) prepared an ethanol extract from the rhizomes of *Rheum tataricum*, which was subsequently fractionated using tert-butyl methyl ether (TBME) and ethyl acetate (EtOAc). The obtained fractions were further subjected to chromatographic separation on silica gel to isolate individual compounds. As a result, a total of 12 individual compounds were identified: rhododendrin (2-O-β-D-glucopyranoside of R-(4-hydroxyphenyl)-2-butanol) (1), gallic acid (2), epi-rhododendrin (3), their aglycones—(-)-(2R)-rhododendrol (4) and (+)-(2S)-rhododendrol (5), the gallotannin β-glucogallin (6), chlorogenic acids (7 and 8), 4-(4-hydroxyphenyl)-2-butanone (9), and three stilbenes—rhaponticin (10), deoxyrhaponticin (11) and resveratroloside (12). According to in vitro biological assays (MTT test), the ethanol extract of *Rheum tataricum* exhibited no toxicity toward normal epithelial VERO cells. However, compounds 1, 4, 11 and 12 demonstrated cytotoxic activity at low micromolar concentrations against cervical cancer (CaSki), breast adenocarcinoma (MCF7) and glioblastoma (SNB-19) cell lines. Polyhydroxystilbenes—compounds 11 and 12—showed the strongest effects against adenocarcinoma cells. These findings suggest that the identified secondary metabolites may serve as promising candidates for the development of novel anticancer agents (Turgunbayeva *et al.* 2025).

Molecular phylogeny and genomic characterization of *Rheum* L. species.

According to chloroplast genome studies by Zhao *et al.* (2020), the chloroplast genomes of *Rheum* L. range in size from 159,051 bp to 161,707 bp and possess a similar typical quadripartite and circular structure. The ITS regions of 30 species belonging to the genus *Rheum* L. were cloned and sequenced, and compared with cpDNA phylogeny, revealing relatively recent hybridization events (Wan *et al.* 2014).

In a study conducted by Li and Wang (2020), molecular phylogenetic analyses were performed based on cpDNA trnS-G sequences using 27 samples representing 21 species (covering 7 of the 8 taxonomic sections) of the genus. To determine the monophyletic origin of this genus and to assess its infrageneric relationships, the trnL - F region of chloroplast DNA was studied and phylogenetic relationships were analyzed based on 29 samples representing 26 species of the genus *Rheum* L. belonging to 7 sections (Wang *et al.* 2005). According to the authors, despite the high morphological diversity, genetic variation in the examined DNA fragment was relatively low. Based on the divergence of trnL - F sequences, it was suggested that the genus *Rheum* L. underwent extensive diversification (speciation) within approximately 7 million years. The studies suggest that geological and ecological complexity resulting from the late Tertiary uplift of the Qinghai-Tibet Plateau, together with Quaternary climatic changes, contributed to fast speciation in small isolated populations and the fixation of uncommon morphological traits. Additionally, rapid radiation and reticulate evolution accompanied by introgressive hybridization may have caused the transfer of chloroplast DNA haplotypes between morphologically distinct species (Wang *et al.* 2005).

Cytogenetic studies of *Rheum* L. species.

In plants, polyploidy—the condition of having additional complete sets of chromosomes—plays a crucial role in evolutionary development and diversification (Heslop-Harrison *et al.* 2023). The main advantage of such chromosome multiplication is the increase in gene copy number within the plant. As a result, certain traits may be enhanced, new phenotypes may arise and tolerance to stress conditions may increase. In polyploid plants, cells are often enlarged, leaves and tissues become thicker, and water retention is improved; numerous studies have linked polyploidy with tolerance to drought and heat stress (Tossi *et al.* 2022). Rhubarb cultivated for food is typically tetraploid (2n = 4x = 44). However, under natural conditions, different levels of polyploidy occur in rhubarb, including diploid (2n = 2x = 22) and hexaploid (2n = 6x = 66) forms (Kuhl & De Boer 2008; Barney & Hummer 2012). The chromosome number is 2n = 22 in *R. maximowiczii*, *R. nobile, R. alexandrae, R.*

palmatum, R. tanguticum, R. rhomboideum, R. reticulatum, R. nanum, R. likiangense, R. collinianum, R. spiciforme, R. emodi, R. franzenbachii, and *R. undulatum*; 2n = 44 in *R. turkestanicum*, *R. altaicum, R. australe, R. compactum, R. crassinervium, R. ribes, R. sanguineum, R. tataricum, R. wittrockii, R. rhaponticum, R. pumilum,* and *R. officinale*; and 2n = 22 or 44 in *R. undulatum* and *R. webbianum* (Jaretzky 1928; Edman 1929; Chin & Youngken 1947; Hu & Xie 2007; Liu *et al.* 2010; Wan *et al.* 2014; Rakhmataliev *et al.* 2026d).

Genome analysis of *Rheum officinale*, identified as an autotetraploid, has shown that tetraploidization, changes in gene copy number, and gene regulation are associated with genes involved in metabolite biosynthesis, stress tolerance, root development, and increased anthraquinone content. Thus, the 44-chromosome condition may have contributed to greater accumulation of medicinal compounds and improved environmental adaptability in certain species (Zhang *et al.* 2024). The chromosomes of species of the genus *Rheum* L. were studied by Darlington and Janaki-Ammal (1932-1945), who classified the species into two groups with 2n = 22 and 2n = 44 chromosomes (Chin & Youngken 1947).

Cultivation and Propagation of *Rheum* L. Species and Cultivars.

Due to the high value of the genus as both a medicinal and food product, the cultivation of rhubarb varieties began first in Russia, later in England around the 1600s, and in Alaska in the 1700s (Morse & Fiske 1901; Hedrick 1919; Parsons *et al.* 2003; Barney & Hummer 2012; Kowenstrot *et al.* 2025). In the United Kingdom, rhubarb cultivation expanded to more than 8,000 hectares by the late 1930s. This area later declined to approximately 170 hectares, with an average yield of 23 tons per hectare. By the 1920s-1930s, the production and consumption of rhubarb reached their peak in North America (Foust & Marshall 1991). In North America, rhubarb cultivation is mainly concentrated in the states of Washington, Oregon, and Michigan, with a total area of approximately 486 hectares. Of this, approximately 71 hectares were cultivated under greenhouse conditions in the states of Washington and Michigan (Morse & Fiske 1901; Schrader 2000). According to the USDA Agricultural Marketing Service (2010), about 1,100 tons of rhubarb were produced in Oregon and Washington from April to August 2009, while approximately 1 ton was produced in greenhouses in Washington during February-March and supplied across the country (Barney & Hummer 2012).

Various rhubarb cultivars, including Poncho, Canada Red, McDonald, Valentine, Cherry, Victoria, Raspberry, Red Champagne, and many others, have been cultivated for consumption purposes (Marr & Carey 2001; Parsons *et al.* 2003; Barney & Hummer 2012; Wojtania *et al.* 2023). In Wasilla, Alaska, 22 rhubarb cultivars were grown by a local plant enthusiast, Erika Wolters (Kowenstrot *et al.* 2025). Among the listed cultivars, the Red Champagne cultivar showed the highest yield (45.58 t/ha) and the greatest juice extraction potential (85%) (Mezeyova *et al.* 2021).

Rhubarb can be propagated from seeds. For this purpose, seeds are sown at a depth of 1-2 cm in peat containers, and the emerging seedlings should be protected from strong sunlight. In a study conducted in Florida, rhubarb seeds were sown in August, and harvesting was carried out from March to May (Schrader 2000). However, seed propagation is not recommended for rhubarb cultivated for food, as the offspring do not remain genetically uniform (Parsons *et al.* 2003). According to Kuhl & De Boer (2008), seeds obtained through self-pollination may be more similar to the parent plant, whereas seeds resulting from cross-pollination between different genotypes exhibit higher genetic variability. Due to the lack of genetic stability in seed-propagated plants, rhubarb is mainly propagated vegetatively in practice—using rhizomes from plants older than three years during the dormant period (at 4.4°C or lower) or in early spring at the onset of growth (Rumpunen & Henriksen 1999; Schrader 2000; Marr & Carey 2001).

When temperatures exceed 7.2-10.0°C, rhizome buds begin to develop. In spring, temperatures below 32.2°C, with an average daytime temperature of 23.9°C and nighttime temperatures of 10-13°C, are considered optimal for rapid vegetative growth of rhubarb. When the average summer temperature exceeds 32.2°C, the growth of the aerial parts slows, and the plants re-enter dormancy. Rhizome segments are planted in early spring, from February to April. In southern regions, rhubarb can be grown as an annual crop; but, it often either fails to survive or produces pale, thin, and elongated petioles (Schrader 2000).

The best results in rhubarb cultivation from rhizomes are obtained in deep, well-drained, fertile soils with a pH of 5.5-7.0, under full sunlight conditions. To achieve high yields, it is recommended to apply 56-78 tons of manure per hectare in autumn or early spring before planting, and during cultivation to supply 78-90 kg ha^{-1} nitrogen (N), 78-90 kg ha^{-1} phosphorus (P_2O_5), and 157-179 kg ha^{-1} potassium (K_2O). In subsequent years, the application of 157-179 kg ha^{-1} N, 56-78 kg ha^{-1} P_2O_5, and 157-179 kg ha^{-1} K_2O is recommended (Schrader 2000; Marr & Carey 2001; Barney & Hummer 2012).

Rhizome segments with one or two well-developed buds are typically used for the propagation of new plants. The rhizomes are planted at a depth of 7.5-15 cm, with the growth buds covered by 1-2.5 cm of soil, maintaining a spacing of 60-90 cm within rows and 120-150 cm between rows. Rhubarb productivity generally declines after 5-10 years; therefore, rhizomes are dug up and replanted in early spring (Marr & Carey 2001; Parsons *et al.* 2003; Barney & Hummer 2012). To control weeds, cultivation should be carried out shallowly to avoid damage to the roots. Harvesting should not be performed in the first year after planting (Marr & Carey 2001), as the leaves play an important role in accumulating nutrients in the rhizomes for the following year's growth. However, if the plants are well developed, a small harvest may be taken in the first year (Schrader 2000).

While the cultivation and consumption of rhubarb cultivars are widely practiced in the USA, in European countries, in Iran and Central Asian countries, harvesting from natural populations of *Rheum khorasanicum, Rheum maximowiczii, Rheum macrocarpum* and other species by local communities during spring, as well as the sale of these products, have been observed (Barney & Hummer 2012; Darrudi *et al.* 2015; Rakhmataliev *et al.* 2025; Kowenstrot *et al.* 2025). In addition, several studies have been conducted to conserve certain species or cultivars from abiotic, biotic, and anthropogenic threats, including the use of in vitro and ex vitro methods for reintroducing young rhubarb plantlets into natural habitats or for establishing plantations (Darrudi *et al.* 2015; Mun & Mun 2016; Tabin *et al.* 2018; Clapa *et al.* 2020; Khan *et al.* 2022; Wojtania *et al.* 2023; Rakhmataliev *et al.* 2025; Aldaif *et al.* 2025).

In vitro propagation enables the large-scale production of disease-free planting material (Binsy *et al.* 2026). In North Korea, *Rheum coreanum* was propagated in vitro from rhizomes, and the young plantlets were transplanted into natural mountain habitats, where successful acclimatization was observed (Mun & Mun 2016).

Rheum emodi has also been successfully rooted under in vitro conditions. The young plantlets were transferred to plastic containers filled with a mixture of sand, soil, and peat (1:2:1). After being maintained under controlled conditions for a certain period, the plants were transplanted into nursery soil. The plants showed good growth performance, with a survival rate of 35% recorded within four months (Tabin *et al.* 2018).

In a study conducted by Clapa *et al.* (2020), *Rheum rhabarbarum* was propagated under in vitro conditions, and the acclimatization process was investigated. Rooted plantlets were initially transferred to containers filled with peat and maintained under greenhouse conditions (21 ± 4 °C). In the later stages of the study, after six months, rhizomes measuring 2-3 cm in length were formed.

In a greenhouse of the National Institute of Horticultural Research in Poland, ex vitro studies were conducted on the "Raspberry" cultivar of *Rheum rhaponticum*. Initially, the Raspberry cultivar was propagated in vitro. For acclimatization, rooted plantlets with shoot diameters of approximately 30 mm were used. The acclimatization process was carried out under phytotron conditions at 25 ± 2 °C. The plantlets were transferred to containers with a substrate composed of sphagnum peat and perlite under high humidity conditions. They were grown under different LED light variants. The authors recommended the use of white LED lighting during the early ex vitro growth stage of micropropagated rhubarb plantlets to achieve an optimal balance between plant growth and anthocyanin biosynthesis (Wojtania *et al.* 2023).

Plants of *Rheum ribes* that formed roots under in vitro conditions were transferred to small containers filled with a 1:1 mixture of peat and soil and gradually acclimatized to external conditions. The acclimatized plants were then transplanted into larger containers containing garden soil and subsequently maintained under greenhouse conditions (Aldaif *et al.* 2025).

Species or cultivars of the genus *Rheum* L. may sometimes be affected by pests. For example, Japanese beetle (*Popillia japonica*), potato flea beetle (*Epitrix cucumeris*), stalk borer (*Papaipema nebris*), European corn borer (*Pyrausta nubilalis*), potato leafhopper (*Empoasca fabae*), cutworms (various species), garden symphylan (*Scutigerella immaculata*), and gray garden slug (*Agriolimax reticulatum*) have been reported (Schrader 2000; Marr & Carey 2001). In addition, root rot may occur in poorly drained or over-irrigated soils, caused by fungi belonging to the genera *Phytophthora, Pythium, Rhizoctonia,* and *Botrytis*. Leaf spot disease caused by *Ramularia* may also result in the formation of angular lesions on leaves (Schrader 2000).

In vitro propagation of species of the genus *Rheum* L.

Several species of the genus *Rheum* L. have been propagated using *in vitro* methods and their seed germination has been studied. For example, studies have been conducted on *Rheum franzenbachii* and *Rheum rhabarbarum* in China (Wang *et al.* 2011; Clapa *et al.* 2020), the endemic medicinal plant *Rheum ribes* (Aldaif *et al.* 2025), the medicinal plants *Rheum*

webbianum, Rheum spiciforme, and *Rheum emodi* (Rashid *et al.* 2014; Tabin *et al.* 2018; Khan *et al.* 2022; Singh & Chaturvedi 2022); *Rheum coreanum* in North Korea (Mun & Mun 2016) and *Rheum khorasanicum* growing in the Neyshabour mountains of Khorasan Razavi Province, Iran (Darrudi *et al.* 2015).

Lateral buds of rhizomes of *Rheum rhabarbarum* and plant growth regulators such as 6-benzyladenine (BA), kinetin (Kin), 2-isopentenyladenine (2-iP), and meta-topolin (mT) have been used for *in vitro* propagation. During propagation, a high proliferation rate was observed in nutrient media supplemented with BA and mT. However, petiole growth was limited. In contrast, the opposite effect was observed in media supplemented with Kin and 2-iP. At the multiplication stage, the highest number of roots and shoot clusters was obtained in the Murashige and Skoog medium (MS) supplemented with 4 mg L^{-1} Kin. During acclimatization, placing 10 shoots per container resulted in a higher rate of root formation, whereas placing 20 shoots led to a lower percentage. In this process, rhubarb plantlets did not produce new roots under *ex vitro* conditions. However, root formation was observed in MS + 4 mg L^{-1} Kin (90%) and MS+ 4 mg L^{-1} 2-iP (80%). The transplanted plants showed a 98% survival rate and formed rhizomes 2-3 cm in size after 6 months (Clapa *et al.* 2020).

Seeds of *Rheum ribes* (54.4%, 7.5 days) and their embryos (69.4%, 10.2 days) were propagated using *in vitro* methods and a significant difference was observed in both germination rate and time, with embryos showing higher germination. For *in vitro* propagation of *Rheum ribes*, plant growth regulators were used, and the nutrient media included ½ MS, 30 g/L sucrose, 1.95 mg/L 2-(N-morpholino) ethanesulfonic acid - MES hydrate, 7 g/L agar, gibberellic acid (GA_3), 0.7 mg/L polyvinylpyrrolidone (PVP), and indole-3-butyric acid (IBA). In the study, somatic embryogenesis and organogenesis mainly occurred in green and light green calli. Yellow, white, and watery calli had a loose and soft structure, while red-colored calli were non-viable. The highest callus formation was observed in MS medium containing 0.5 mg/L 6-benzylaminopurine (BAP), 0.5 mg/L Kin, and 1.0 mg/L 2,4-dichlorophenoxyacetic acid (2,4-D) under dark conditions. The highest rate of direct organogenesis was recorded in the embryonic axis (12.6%), followed by the hypocotyl (8.8%) and cotyledon (8.2%). The highest rate of direct somatic embryogenesis was observed in the hypocotyl (40.0%), followed by the cotyledon (39.4%) and embryonic axis (34.0%). the most optimal germination was observed in ½ MS medium supplemented with 1.75 mg/L GA_3 and 1.0 mg/L IBA (Aldaif *et al.* 2025).

Seed germination of *Rheum khorasanicum* was evaluated using seeds aged 2 and 10 months. According to the results, the best germination was observed in seeds stratified at 2°C for 30 days and then incubated at 5°C. In addition, the application of GA_3 improved seed germination. An 81% germination percentage was recorded in 2-month-old seeds after soaking in a 500 ppm GA_3 solution for 48 hours followed by 30 days of stratification at 2 °C. Moreover, longer storage periods led to reduced germination rates (Darrudi *et al.* 2015).

Seeds of *Rheum emodi* and plant growth regulators, including cytokinins—BAP, Kin, and thidiazuron (TDZ)—as well as auxins—IBA, naphthaleneacetic acid (NAA), indole-3-acetic acid (IAA) (), 2,4-D, PVP and MS supplemented with 0.7% agar were used for *in vitro* propagation. In the study, the highest formation of light green callus was observed within 16 days from primary veins on MS medium supplemented with Kin, 2,4-D, and TDZ. In leaf explants, callus formation was observed on media supplemented with BAP, NAA, and 2,4-D. Shoot regeneration from callus was recorded within 19 days on media containing BAP, NAA, and IAA, whereas in leaf explants, it was observed within 14 days on media supplemented with BAP and IBA. The highest root formation was recorded within 23 days on MS medium supplemented with IBA, NAA, and BAP (Singh & Chaturvedi 2022).

Stem tips, young leaves, rhizomes and root tips of *Rheum coreanum* have been used for in vitro propagation. Auxins (2,4-D, NAA, IBA) and cytokinins (BAP and kinetin) were applied for callus induction. Among the cytokinin-auxin combinations, BAP and 2,4-D produced the best results, yielding whitish and friable callus. Shoot regeneration from callus was highest in media containing BAP and NAA, while root formation was observed in media supplemented with NAA and IBA. The survival rate of regenerated plantlets reached 95% when transplanted into mountainous environments (Mun & Mun 2016).

Leaves of *Rheum franzenbachii* collected from Lingshan mountain in the Beijing region of China were used for in vitro propagation. The maximum callus formation from leaf explants was achieved on medium supplemented with 2.0 mg L^{-1} BAP and 0.5 mg L^{-1} NAA, whereas a lower response was observed with BAP combined with 1 mg L^{-1} NAA. The highest fresh and dry weight of callus was obtained on MS medium supplemented with 0.5 mg L^{-1} TDZ and 0.2 mg L^{-1} NAA (Wang *et al.* 2011).

The germination of mature seeds of *Rheum spiciforme* was evaluated on MSm medium supplemented with 30 g L^{-1} sucrose and 0.8% agar. For callus induction, shoot, leaf, root, and seed embryo explants were used. The highest germination rate

(92.6%) was achieved on MSm medium supplemented with 0.005 mM GA_3, 1 mM $CaCl_2$, and 1 mM KNO_3. In contrast, germination was very low when seeds were sown in garden soil (13.6%) and coco peat (58.5%). Callus formation from shoot (81.7%), leaf (87.4%), and root (79.8%) explants was observed on media supplemented with 2,4-D and BA. In seed embryos, TDZ increased both the response rate and the speed of callogenesis, whereas the opposite effect was observed in shoot, leaf, and root explants. Callus derived from leaf explants produced shoots when transferred to MSm medium supplemented with equal concentrations of BA and kinetin (Kin). Somatic embryogenesis (91%) was observed in leaf explants when treated with a combination of 25 µM BA, 1.0 µM NAA, 2.0 µM GA_3, 50 µM glutamine (GTM), and adenine sulfate (ADS). The highest regeneration rate (96.3%) was recorded in callus derived from shoot segments on medium supplemented with 8.0 µM BA and Kin, along with 4.0 µM GA_3. Increasing concentrations of BA and Kin also promoted root formation from callus (Khan *et al.* 2022).

In vitro propagation of *Rheum webbianum* using rhizome explants showed that 0.5 mg L^{-1} 2,4-D induced callus formation. The combination of 5 mg L^{-1} BAP and 2 mg L^{-1} IAA in MS medium resulted in the highest shoot regeneration (Rashid *et al.* 2014).

A germination experiment was conducted using seeds of *Rheum palmatum*. The results showed that the highest germination rate (64.2%) was observed at 25°C, whereas almost no germination occurred at 5°C and 40°C (Yoo *et al.* 2012).

Discussion

Analysis of the differences between ethnobotanical sources, classical and modern taxonomic approaches in the genus *Rheum* L.

Rhubarb is consumed by local populations in China, Iran, Turkey and Central Asian countries, where its seeds, rhizomes and petioles are used in folk medicine and applied as remedies for certain diseases (, Zhou *et al.* 2015; Darrudi *et al.* 2015; Batsatsashvili *et al.* 2020 a, b; Zhang *et al.* 2023; Aldaif *et al.* 2025; Bussmann *et al.* 2025; Rakhmataliev *et al.* 2026 a). In Central Asia, local populations generally do not recognize that rhubarb represents a genus - *Rheum* L. or that it comprises multiple species, nor are they able to distinguish among them (Rakhmataliev *et al.* 2026 a,c). Moreover, many traditional healers value the medicinal properties of rhubarb and use it as a key component in their remedies; however, they are often unaware of its scientific name, *Rheum maximowiczii* (Usmonkhodjaev *et al.* 2018; Rakhmataliev *et al.* 2025). This can be explained as follows. In works such as “The Canon of Medicine” by Avicenna (1037), “Shifo ul-ilal” by Alikhontura Soguniy and “Qonuni Bositiy” by Basitkhan healer, the phrase “*Rheum palmatum rivand al-siniy* - Chinese rhubarb” is mentioned and its medicinal properties in traditional medicine are described (Shoshiy 2018; Soguniy 2023). However, at present, local healers do not use Chinese rhubarb but instead utilize the rhizomes and petioles of the Central Asian endemic species *Rheum maximowiczii* (Komarov 1970; Rakhmataliev *et al.* 2025). As an example of such cases, the ethnobotanical study conducted by Niyozov *et al.* (2025) in Gelon village, Kashkadarya, Uzbekistan, can be mentioned. According to the authors, the leaves of chukri (rhubarb) were reported to be used as a medicinal plant. However, *Rheum officinale* does not occur in the flora of Uzbekistan. In an ethnobotanical study conducted by Sezik et al. (2004) in the Tashkent, Jizzakh, and Samarkand provinces, the leaves of *Rheum tataricum* L. were reported to be used against diarrhea. However, in our field studies, we confirmed the occurrence of *Rheum tataricum* in the Nukus area of the Republic of Karakalpakstan, Uzbekistan (Rakhmataliev *et al.* 2026b).

In addition, many books on traditional medicine in Uzbekistan have been published by local publishers. However, they are not available for sale in electronic format on online platforms (Fig. 3). To access these materials, it is necessary to purchase printed copies. Some of the publishing houses that produced these books are no longer in operation, resulting in their limited availability in printed form. Investigations in Central Asia suggest that medicinal plant knowledge and usage are predominantly observed in communities located in mountain and foothill areas. Such factors have contributed to the limited ethnobotanical knowledge among local populations in Central Asia (Sharipov *et al.* 2025, Rakhmataliev *et al.* 2026 a,c).

There are also inconsistencies in the taxonomic classification (both at the sectional and species levels) of the genus *Rheum* (Wan *et al.* 2014). The genus Rheum includes approximately 60species distributed worldwide (Li *et al.* 2003 Plants of the World Online 2026). Among these, China represents the primary center of diversity, with around 38 species occurring in this region. This distribution highlights the ecological and evolutionary significance of the genus, particularly in East Asia, especially in China, where many species exhibit considerable morphological and genetic diversity (Wang *et al.* 2005; Wan *et al.* 2014).



Figure 3. Popular folk medicine books in Central Asia: (A) Shifo ul-ilal; (B) Qonuni Bositiy; (C) Traditional medicine; (D) Evidence-based methods of traditional medicine; (E) Fundamentals of medicine - hijama; (F) Etymological modern encyclopedia of medicinal plants growing in Uzbekistan.

In general, the genus *Rheum* L. requires further taxonomic investigation, as its species were initially classified in traditional taxonomy based on general morphological characteristics. In Central Asia, according to the work "Flora of the U.S.S.R." by Lozina-Lozinskaya (1936), the genus was divided into nine sections, while Kao and Cheng (1975) recognized seven sections, and Li (1998) classified it into eight sections (Libert & Englund 1989; Li & Wang 2020). However, the work "Flora of the U.S.S.R." by Lozina-Lozinskaya (1936) and Komarov (1970) was examined, in which 24 species were reported and classified into seven sections as follows:

Sect. *Rhapontica - Rheum undulatum, Rheum compactum, Rheum altaicum, Rheum wittrockii, Rheum orientale;*
Sect. *Deserticola - Rheum tataricum, Rheum turkestanicum, Rheum rupestre;*
Sect. *Glabrifolia - Rheum korshinskyi, Rheum lucidum, Rheum darvasicum;*
Sect. *Spiciformia - Rheum rhizostachyum, Rheum reticulatum;*
Sect. *Acaulia - Rheum nanum;*
Sect. *Ribesiformia - Rheum fedtschenkoi, Rheum ribes, Rheum maximowiczii, Rheum cordatum, Rheum hissaricum, Rheum plicatum, R. macrocarpum, R. lobatum;*
Sect. *Palmata - Rheum palmatum, Rheum rhaponticum* (Lozina-Lozinskaya 1936; Komarov 1970).

Kao and Cheng (1975) classified 60 species of *Rheum* L. into eight sections (*Orbicularia, Ribesiiformia, Palmata, Acuminata* (new), *Deserticola, Spiciformia, Globulosa* (new), *Nobilia*) and proposed grouping *Rheum webbianum* Royle*, Rheum emodi* Wall.*,* and *Rheum moorcroftianum* Royle into a separate taxonomic unit (Li 1998). In other studies, an additional section, *Rheum*, has also been reported alongside the above sections (*Rheum, Acuminata, Deserticola, Globulosa, Nobilia, Orbicularis,*

Palmata, Spiciformis) but this section has not been included in major floristic works published in Central Asia (Komarov 1970; Liu *et al.* 2010; Barney & Hummer 2012; Wan *et al.* 2014; Li & Wang 2020; Aitzhan *et al.* 2024). In floristic literature, some species of the genus are currently treated as synonyms of other species, which may also contribute to taxonomic inconsistencies at both the sectional and species levels (Table 3).

Table 3. Accepted species and species treated as synonyms in the genus *Rheum* L.

Species considered synonyms	Accepted species	Bibliographic source
Rheum lobatum Litv. ex Losinsk. *Rheum plicatum* Losinsk. *Rheum vvedenskyi* Sumnev.	*Rheum macrocarpum* Losinsk.	Plants of the World Online, 2026; Li & Tojibaev, 2024
Rheum undulatum Pall.	*Rheum rhaponticum* L.	Plants of the World Online, 2026
Rheum franzenbachii Münter *Rheum sanguineum* Meisn.	*Rheum rhabarbarum* L.	Plants of the World Online, 2026
Rheum megalophyllum Sumnev. *Rheum renifolium* Sumnev. *Rheum rupestre* Litv. ex Losinsk.	*Rheum turkestanicum* Janisch.	Plants of the World Online, 2026; Li & Tojibaev, 2024
Rheum altaicum Losinsk. *Rheum orientale* Losinsk.	*Rheum compactum* L.	Plants of the World Online, 2026
Rheum korshinskyi V.S.Titov ex Losinsk.	*Rheum lucidum* Losinsk.	Plants of the World Online, 2026
Rheum reticulatum Losinsk. *Rheum rhizostachyum* Schrenk *Rheum crassinervium* Fisch. ex Lindl.	*Rheum spiciforme* Royle	Plants of the World Online, 2026
Rheum × collinianum Baill.	*Rheum × hybridum* Murray	Plants of the World Online, 2026
Rheum emodi Wall.	*Rheum webbianum* Royle	Plants of the World Online, 2026

In recent years, molecular phylogenetic studies have also revealed inconsistencies between classical taxonomy and the sectional classification of species. Currently, it has been proposed to revise the taxonomy of this genus based on both molecular data and morphological characteristics of plants (Wan *et al.* 2014; Li & Wang 2020).

Conclusion

In general, species of the genus *Rheum* L. are widely distributed in desert and mountainous regions and are ecologically adapted to diverse environmental conditions. Many species of this genus are of great importance as food plants rich in vitamins and biologically active compounds, as well as medicinal plants. Therefore, extensive studies have been conducted on the genus, including pharmacological, taxonomic, morphological, and molecular-genetic research, as well as investigations on in vitro propagation and plantation establishment.

However, in recent years, studies on the taxonomic status, molecular genetics and cytogenetic characteristics, seed germination, and particularly the ontogenetic age structure and demographic characteristics of populations have been insufficient, or the available information remains limited. This highlights the need for more detailed investigations of natural populations of the genus.

In this article, scientific studies on the genus *Rheum* L. across various research directions have been comprehensively analyzed. The presented data contribute to a deeper understanding of the biological, ecological, and practical significance of the genus and may serve as an important theoretical and practical basis for future research.

Declarations

List of abbreviations: The full names of the biochemical compounds, together with their abbreviations, were provided when they were first mentioned in the manuscript. Thereafter, only the abbreviations were used throughout the text. POWO - Plants of the World Online; ITS - Internal Transcribed Spacer; PBMCs - Peripheral Blood Mononuclear Cells; THP1-ASC-GFP - THP-1 - human monocytic leukemia cell line, ASC - apoptosis-associated speck-like protein containing a CARD domain, also known as PYCARD, GFP- Green Fluorescent Protein; ADP - Adenosine diphosphate; BGFP - Bioassay-guided Fractionation and Purification; UAE - Ultrasound-assisted extraction; USSR - Union of Soviet Socialist Republics; USDA - the United States Department of Agriculture.

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