Botanica Pacifica. A journal of plant science and conservation. 2025. 14(1):3–20
DOI: 10.17581/bp.2025.14112

REVIEW PAPER

Saposhnikovia divaricata (Apiaceae) – important species of Oriental Traditional Medicine: current research status, cultivation experience and biotechnological potential (a review)

Maksim V. Kazakov[1], Oleg A. Anenkhonov[2]*, Bayarma M. Zhigmittcyrenova[1], Tatiana V. Elisafenko[3], Tatiana V. Zheleznichenko[4], Faqi Zhang[5], Olga A. Altaeva[5], Belikto B. Tcybikov[5], Elena P. Dylenova[1,6], Vasilii V. Taraskin[1,6] & Zhargal A. Tykheev[1,6]

Maksim V. Kazakov [1]
e-mail: atamax89@yandex.ru

Oleg A. Anenkhonov [2]*
e-mail: anen@yandex.ru

Bayarma M. Zhigmittcyrenova [1]
e-mail: urbagarova.bayarma@mail.ru

Tatiana V. Elisafenko [3]
e-mail: tveli@list.ru

Tatiana V. Zheleznichenko [4]
e-mail: zhelez05@mail.ru

Faqi Zhang [5]
e-mail: fqzhang@nwipb.cas.cn

Olga A. Altaeva [6]
e-mail: altaeva_olga@mail.ru

Belikto B. Tcybikov [6]
e-mail: rector@bgsha.ru

Elena P. Dylenova [1,6]
e-mail: edylenova@mail.ru

Vasilii V. Taraskin [1,6]
e-mail: vvtaraskin@mail.ru

Zhargal A. Tykheev [1,6]
e-mail: gagarin199313@gmail.com

[1] Baikal Institute of Nature Management SB RAS, Ulan-Ude, Buryatia, Russia

[2] Institute of General and Experimental Biology SB RAS, Ulan-Ude, Buryatia, Russia

[3] Central Siberian Botanical Garden SB RAS, Novosibirsk, Russia

[4] Institute of Cytology and Genetics SB RAS, Novosibirsk, Russia

[5] Xining Botanical Garden & Northwest Institute of Plateau Biology, Chinese Academy of Sciences, Xining. Qinghai, China

[6] V.R. Filippov Buryat State Agricultural Academy, Ulan-Ude, Buryatia, Russia

* corresponding author

Manuscript received: 23.02.2025
Review completed: 15.03.2025
Accepted for publication: 19.03.2025
Published online: 21.03.2025

ABSTRACT

Saposhnikovia divaricata (Turcz. ex Ledeb.) Schischk. (Apiaceae) is a perennial monocarpic herbaceous plant, the only species of the Far Eastern, Daurian, and Mongolian genus *Saposhnikovia* Schischk. The roots of this plant are widely used in China, Korea, and Japan as an effective anti-inflammatory for arthralgia, rheumatism, generalized ache and headaches, strokes, fevers, colds and allergic rhinitis, as well as an analgesic, anti-Parkinsonian, and in multi-component herbal preparations. The high demand of *S. divaricata* products has raised the problem of sustainable use and conservation of the species due to the mass and unregulated harvesting of the roots of this plant. As an effective solution to this problem, *ex situ* and *in situ* methods of cultivation and clonal micropropagation can be developed. This would support the conservation of this species, and the recovery of its natural populations, and would also facilitate the production of valuable raw materials for pharmaceutical needs. Currently available data on this plant's successful cultivation and clonal propagation are fragmentary and not systematic. This review aims to summarize the latest data on *S. divaricata* in order to elucidate the main findings helpful for further progress in development of *ex situ* and *in vitro* cultivation of the species. A review of *in situ*, *ex situ*, and *in vitro* cultivation methods, as well as biotechnological aspects, including the engineering of metabolic pathways, is essential to ensure the conservation of the species and its sustainable use.

Keywords: *Saposhnikovia divaricata*, Oriental Traditional Medicine, industrial uses, cultivation, *ex situ*, *in situ*, *in vitro*, biotechnology, agronomic practices

РЕЗЮМЕ

Казаков М.В., Аненхонов О.А., Жигмитцыренова Б.М., Елисафенко Т.В., Железниченко Т.В., Жанг Ф., Алтаева О.А., Цыбиков Б.Б., Дыленова Е.П., Тараскин В.В., Тыхеев Ж.А. *Saposhnikovia divaricata* (Apiaceae) – важный компонент Восточной традиционной медицины: современное состояние исследований, опыт культивирования и биотехнологический потенциал (обзор). *Saposhnikovia divaricata* (Turcz. ex Ledeb.) Schischk. (Apiaceae) – многолетнее монокарпическое травянистое растение, единственный вид дальневосточно-даурско-монгольского рода *Saposhnikovia* Schischk. Корни этого растения широко используются в Китае, Корее и Японии в качестве эффективного противовоспалительного средства для лечения артралгии, ревматизма, генерализованных и головных болей, при инсультах, лихорадке, простудных заболеваниях и аллергических ринитах, а также как анальгезирующее, противопаркинсоническое средство и в составе многокомпонентных сборах. Высокий спрос населения на фитопрепараты на основе *S. divaricata* привел к проблеме рационального использования и сохранения вследствие массовых нерегулируемых заготовок корней этого растения. Эффективным решением данной проблемы может быть разработка методов (*ex situ*, *in situ*) сохранения вида для восстановления природных популяций, способов плантационного культивирования и клонального микроразмножения с целью получения ценного сырья для фармацевтических нужд. Имеющиеся на сегодня сведения об успешном опыте возделывания растения, методиках клонального размножения фрагментарны, не систематизированы. Целью настоящего обзора является обобщение имеющихся сведений о таксономии и экологии, молекулярно-генетических и биотехнологических достижениях по *S. divaricata*. Обзор методов культивирования *in situ*, *ex situ* и *in vitro*, биотехнологических аспектов, включая инженерию метаболических путей, имеет большое значение для определения перспективных направлений и конкретных задач будущих исследований, которые необходимы для обеспечения сохранения вида и его устойчивого использования.

Ключевые слова: *Saposhnikovia divaricata*, Восточная традиционная медицина, промышленное использование, культивирование, *ex situ*, *in situ*, *in vitro*), биотехнология, агротехника

© The Author(s). 2025 **Open Access** (CC) BY-NC license: https://creativecommons.org/licenses/by-nc/4.0/

For over 2,000 years, the roots of *Saposhnikovia divaricata* (Turcz. ex Ledeb.) Schischk. have been an important component of Oriental Traditional Medicine. The first mention of their use is found in the oldest Chinese treatise on medicinal plants "Shen Nong Ben Cao Jing", according to which the dried roots of this plant are called "Fang Feng" in China (which means "dispelling wind") and belongs to the highest class of medicinal plant raw materials, due to its ability to use in treatment of pathogenic conditions "wind", "dampness" and "cold" (the concepts of Oriental Traditional Medicine) (Yang 1992). As phytochemical and pharmacological research methods have improved, the following properties of *S. divaricata* roots have been revealed: analgesic (Okuyama et al. 2001), anti-inflammatory (Khan & Kim 2013), antioxidant, antiproliferative (Tai & Cheung 2007), anticancer (Urbagarova et al. 2020), anti-allergic (Yu et al. 2015), antimicrobial (Kim et al. 2018), antifungal (Zhang et al. 2013), antipyretic (Yang et al. 2017). The above effects are due to the presence of secondary metabolites, especially chormones, the main ones being *prim-O*-glucosylcimifugin, cimifugin, and 4'-*O*-*β*-D-glucosyl-5-*O*-methylvisamminol, as well as coumarins and polyacetylene compounds (Kreiner et al. 2017). Given the pharmacological value of medical products made of *Saposhnikoviae divaricatae radices*, the producing plant *S. divaricata* was included in the pharmacopoeias of three countries – China (Chinese Pharmacopoeia 2015), Korea (Korean Pharmacopeia 2012), and Japan (Japanese Pharmacopeia 2011).

In recent years also due to the pandemic of SARS-CoV-2 (Severe acute respiratory syndrome-related coronavirus 2) (COVID-19), there has been a worldwide increase in the demand for herbal remedies due to their poly-targeting, relatively mild properties, and low toxicity. Increasing demand has also been noted for the roots of *S. divaricata* as an anti-inflammatory. This led to sufficient decreasing the population of *S. divaricata* in Buryatia and Transbaikalia due to the mass and unregulated harvesting of roots by local people (Korsun 2018). As a first step toward the conservation of this plant in Russia, *S. divaricata* was included in Red Lists of Trans-Baikal Territory (with a category "4 – Uncertain Status") (Geltman 2024) and Republic of Buryatia ("2 – Vulnerable") (Anenkhonov et al. 2023). The same situation is observed in Mongolia due to overharvesting, export of plant raw materials abroad, degradation of pastures, and steppe fires (Urgamal 2015). In order to reach the balance between the demand and supply in situation when the natural populations of *S. divaricata* must be preserved the cultivation should be intensified. This strengthens attention to development and application of new techniques for *S. divaricata* cultivation *ex situ* and *in vitro*.

To restore these natural populations and obtain valuable biotechnological raw materials for pharmaceutical needs, the cultivation and clonal micropropagation techniques can be effective for this species. By this reason, there are some papers (64) considering the *S. divaricata* cultivation *ex situ*. From the other side, 2 papers were devoted to *in situ* cultivation. The first fact strongly supports the significance of the problem of *S. divaricata* conservation, cultivation, and manufacturing the secondary metabolites for pharmacological purposes. Meanwhile, a very small number of publications on *in situ* cultivation this fact reflects the complexity, the presence of environmental issues, as well as the limited possibilities of this method of cultivation.

The available modern data on this plant's successful cultivation and clonal propagation are fragmentary and not systematic; some studies are not available in English. The most of reviews are devoted to the phytochemical composition and pharmacological values of *S. divaricata* while assessments of cultivation experience are lacked; the habitat confinement and geographical distribution are also briefly considered (Kreiner et al. 2017, Yang et al. 2020). This review aims to summarize the wide scope of data on *S. divaricata* in order to elucidate the main findings helpful for further progress in development of *ex situ* and *in vitro* cultivation of the species. A review of *in situ*, *ex situ*, and *in vitro* cultivation methods, and biotechnological aspects including the engineering of metabolic pathways is essential to ensure the conservation of the species and its sustainable use.

PUBLICATION ANALYSIS

For this review, five international (Web of Science, ScienceDirect, Scopus, ResearchGate, Google Scholar) and two Russian (e-library, CyberLeninka) databases were used as information sources. The following keywords and their combinations were used as search criteria: '*Saposhnikovia divaricata*', 'microclonal propagation' / 'micropropagation, 'callus culture', 'cell culture', 'cell-rich fluid', 'hairy root culture', 'somatic embryogenesis', 'introduction', 'agricultural technology', 'cultivation'. As a result, 1122 papers were analyzed, of which 588 were devoted to the study of the chemical composition and pharmacological activity of extracts, herbal preparation, and individual substances; 377 papers concerned the botanical and taxonomic studies, biology, and ecology of the species; 20 papers did not consider *S. divaricata*. 137 publications were devoted to *ex situ*, *in situ* (113), and *in vitro* cultivation (24) (Fig. 1), of which 41 papers were reviewed, because abstracts or full text of the others were not available.

A large body of the articles was published in Chinese, Korean, and Japanese rather than in English, so we were able to review them thanks to the kind help of our colleague, Dr. Innokenty G. Aktamov, a Head of Oriental Languages Translations Center (Institute for Mongolian, Buddhist and Tibetan Studies SB RAS).

For the first time, the range of *S. divaricata* was mapped by transferring observation points of the species from iNaturalist (https://www.inaturalist.org), Global Biodiversity Information Facility (https://www.gbif.org) databases, and the scientific article "Distribution pattern and change prediction of *Saposhnikovia divaricata* suitable area in China under climate change" to Google Maps.

TAXONOMY, MORPHOLOGY, AND ECOLOGY

Saposhnikovia divaricata belongs to the family Apiaceae, subfamily Apioideae (Drude) Thorne ex Royen, tribe Selineae (Downie et al. 2010). *Saposhnikovia* Schischk. is a monotypic genus and includes a single species (Fig. 2).

According to The World Checklist of Vascular Plants (https://wcvp.science.kew.org) *Saposhnikovia divaricata* has a number of synonyms such as: *Trinia dahurica* Turcz. ex Besser, *T. seselioides* (Hoffm.) Ledeb., *Rumia seseloides* Hoffm., *Cachrys seseloides* (Hoffm.) M. Bieb., *Ledebouriella divaricata* (Turcz. ex Ledeb.) M. Hiroe, *L. seseloides* (Hoffm.) H. Wolff, *Johrenia seseloides* (Hoffm.) Koso-Pol., *J. sieversii* Koso-Pol., *Siler divaricatum* (Turcz. ex Ledeb.) Benth. & Hook. f. ex Franch. & Sav., *Apinella seseliodes* Kuntze, *Stenocoelium divaricatum* Turcz. ex Ledeb., *Saposhnikovia seseloides* Kitag., *Laser divaricatum* (Turcz. ex Ledeb.) Thell. The name *Saposhnikovia* was suggested in 1951 by B.K. Shishkin (Shishkin 1951) in honor of the famous Russian botanist V.V. Sapozhnikov. In 2022, a phylogenetic analysis using 47 sequences of chloroplast DNA of Apioideae members confirmed the validity of separating *Saposhnikovia* from *Ledebouriella* and subsequently the renaming *Ledebouriella seseloides* to *Saposhnikovia divaricata* at the genomic level (Yi et al. 2022). Phylogenomic relationships of the Apiaceae plastome based on the method of maximum likelihood showed the genetic proximity of *S. divaricata* to such species as *Peucedanum japonicum* Thunberg in Murray, *P. praeruptorum* Dunn, and *Pimpinella rhomboidea* var. *tenuiloba* R.H. Shan & F.T. Pu (a synonym of *Melanosciadium bipinnatum* (R.H. Shan & F.T. Pu) Pimenov & Kljuykov) (Li et al. 2020).

Saposhnikovia divaricata is a perennial monocarpic plant, 40–80 cm tall, with an unbranched caudex and with tap roots branching only at depth. The stem is solitary, erect, 4–13 mm in diameter, and branched from the base, forming a 'tumbleweed'. The radical leaves have numerous petioles up to 25 cm long, twice or thrice dissected, with wedge-shaped segments 2–4 cm long. Cauline leaves are pinnate, without petioles, not stem-forming; leaf sheaths are glabrous, not swollen. Umbels are numerous, corymbose, 2–6 cm in diameter, usually without spathes, with 5–8 glabrous, ribbed rays. Umbels up to 1.5 cm in diameter, with 4–9 glabrous rays. Petals are white, glabrous, broadly oval, whole at the tip, and curved inside. Stylodium bent toward mericarp dorsally. Fruits are ovate, 5–7 mm long, and 3–3.5 mm wide. Mericarps are slightly compressed dorsally, elliptic, ovoid, and glabrous. Karyotype: $2n = 16$ (Pimenov & Ostroumova 2012). According to Serebryakov (1962), it is a taproot perennial herbaceous monocarpic with a single-headed caudex.

Saposhnikovia is an Asian endemic genus occurring in southeastern regions of Russia; several Chinese provinces (especially the northern ones: Inner Mongolia, Xinjiang, Gansu, Ningxia, Shaanxi, Shanxi, Hebei, Shandong, Heilongjiang, Jilin, Liaoning, Henan, Hubei); Kazakhstan (the specimen was collected on June 26, 1991 in Dzhezkazgan region, eastward of Atasu, Aktau Mountain, by M.G. Pimenov and E.V. Klyuikov), Mongolia (Khentii, Khangai, Mongolian Daguur, Central Khalkha, Eastern Mongolia) (https://powo.science.kew.org/taxon/847902-1, https://www.catalogueoflife.org/data/taxon/79KXR) (Fig. 3). Although this plant has been known on the Korean Peninsula for quite a long time, it has been determined as an adventitious plant, introduced to the local flora (Chang et al. 2014). It should also be noted that the specimen collected in Kazakhstan (as judged by the scans of the herbarium specimen) differs from the plants of *S. divaricata*. Several differences were observed, such as the structure of the umbels, the shape of the leaf lobules, the branching of the caudex, and the general habitus. Therefore, additional research is required to determine whether this specimen belongs to another species. In Russia, *S. divaricata* is distributed in the southern parts of Eastern Siberia and the Far East – in Republic of Buryatia, Amur Region, Trans-Baikal Territory, Khabarovsk Territory, and Primorye Territory. The plant belongs to the East Asian chorological and mountain-steppe belt-zonal groups (Malyshev & Peshkova 1984).

A recent study showed the distribution pattern for *S. divaricata* and also predicted the changes in its geographical range in China under climate change. It was revealed that the total area suitable for the growth of the species tends to increase. The underlying factors of the potential area increasing are predicted temperature rising and drought enhancing according to the climatic model BCC-CSM2-MR developed by the Beijing Climatic Center. The so-called geometric center of the area suitable for plant cultivation in China is now in Chifeng (Inner Mongolia), but under various climatic scenarios, it can move 32–200 km to the northeast or northwest. In general, possible changes in the suitable growing area of *S. divaricata* with "North expansion" and "South contraction" have been established with a high probability (Chen et al. 2022).

Saposhnikovia divaricata grows mainly in meadow stony and sandy steppes, dry rock streams, slopes of hills, steppe shrubs, forest edges in the forest-steppe landscape, in fallow and even arable lands (Pimenov & Ostroumova 2012). The plant is a hemixerophyte growing in moderately dry places, having a very long root system reaching the groundwater and therefore characterized by intensive transpiration, helping to avoid tissue overheating (Prokop'ev 2001).

CULTIVATION ON PLANTATIONS AND INTRODUCTION (*EX SITU*, *IN SITU*)

Considering the medicinal value of *S. divaricata* and its limited natural resources, cultivation of this species is underway in China (Wan et al. 1999, Sun et al. 2013, Cui 2014, Jia et al. 2019), Japan (Ishizuka et al. 1998, Nishihara et al. 2018, Fuchino et al. 2021, Nishidono et al. 2021), Korea (Kim et al. 2010, Ahn et al. 2012), Germany (Heuberger et al. 2008a, b), and Russia (Shishmaryov et al. 2018). The most extensive plantations where the plant is grown are in Heilongjiang, Jilin, Liaoning, Anhui, Shanxi, Shaanxi, Gansu, Hebei, Ningxia, Shandong (Sun et al. 2013, Jia et al. 2019), and Inner Mongolia (Cui 2014) provinces of China. The sort named "Guangfangfeng 1" was developed in Heilongjiang province, where the most extensive plantations are located and the best raw material is grown (Wan et al. 1999, Young-Hua et al. 2016). In the Republic of Korea plantations of *S. divaricata* are rather restricted covering totally about 10 ha however constant work is underway to improve the methods of its cultivation (Oh et al. 2018). As a result, the highest productivity of *S. divaricata* has been achieved in the central plain areas (Sung et al. 2008). Similar works in Russia just began in Buryatia (Shishmaryov et al.

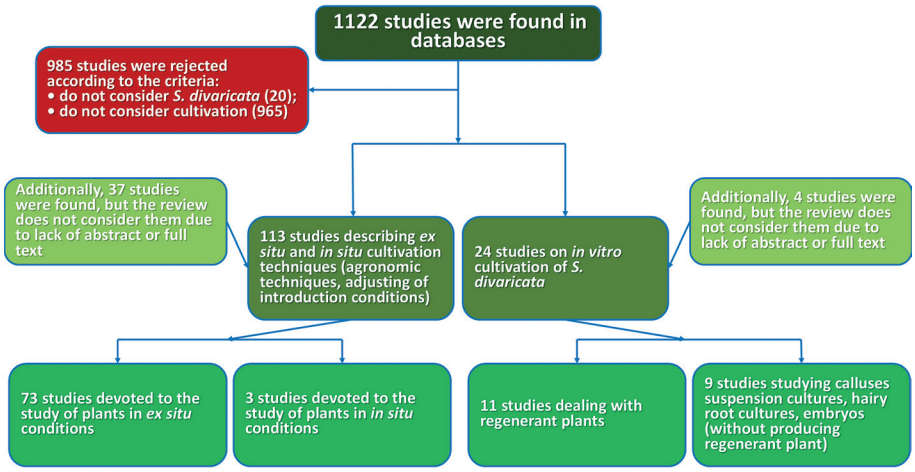

Figure 1 Distribution of papers on the cultivation of *Saposhnikovia divaricata* (Turcz. ex Ledeb.) Schischk. by the research area

Figure 2 A general view of *Saposhnikovia divaricata* (Turcz. ex Ledeb.) Schischk. Russia, Republic of Buryatia, Ivolginski district

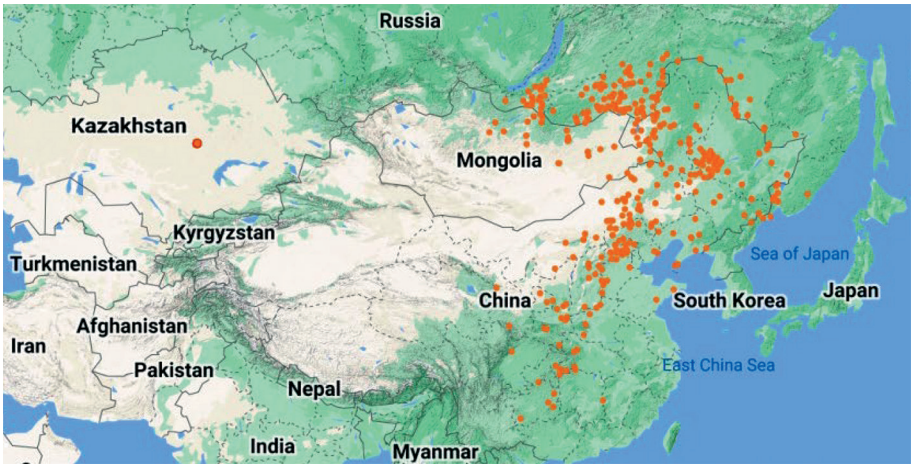

Figure 3 A map of the range of *Saposhnikovia divaricata* (Turcz. ex Ledeb.) Schischk., compiled using the databases of iNaturalist, Global Biodiversity Information Facility (GBIF 2022), and the scientific article "Distribution pattern and change prediction of *Saposhnikovia divaricata* suitable area in China under climate change" (Chen et al. 2022)

2018), Altai Territory (Zubova 2020), Irkutsk (Polovinkina 2022), Moscow (Tsitsilin 2022), Novosibirsk and Belgorod (Kulishova et al. 2022) Regions, where laboratory studies have shown the success of growing in the ground in greenhouses (Elisafenko et al. 2021). Although the cultivation of medicinal plants is a time-consuming process, the quality of the resulting raw material (namely, the composition and content of metabolites) may depend on several factors. Table 1 summarizes the published studies on the chemical composition of *S. divaricata* plants both from natural flora and introduced ones from different habitats, as well as the plants bred using different agricultural techniques.

It is shown that anatomical and morphological differences between the roots of wild and cultivated specimens of *S. divaricata* are insignificant (Zhi & Ming-yan 1997). However, in Mongolia, anatomical differences between the roots of wild and cultivated specimens were elicited, as well as between species living in biomes with increased and decreased anthropogenic load. At the same time, species with a clearly dissected root head grew in the favorable environments (Gombo et al. 2022). But there is a fairly large difference between them in the content of secondary metabolites. The content of *prim-O*-glucosylcimifugin and cimifugin was found to be low in plants cultivated for 6 years (Nishihara et al. 2018); although it is suggested that a long period of cultivation may result in a chromone content approaching that of wild-type plants (Fuchino et al. 2021). However, the typical cultivation period for *S. divaricata* in crop farms in China is 2–3 years (Ji 2014).

Environmental conditions have a significant impact on the quality of plant raw materials. Therefore, many studies include

Table 1. Summary of studies on cultivation of *Saposhnikovia. divaricata* (*ex situ, in situ*)

Field of Study	Sub-Field	References
Studying or comparing specimens grown under different conditions	Cultivation in different geographic areas	Heuberger et al. 2008a,b, 2010
	Influence of certain environmental factors and development phases	Wan et al. 1999, Sun et al. 2013, Guan et al. 2008a,b, Sun & Meng 2008, Han et al. 2009, 2011, Men et al. 2018, Xu 2016, Han et al. 2017, Jiang et al. 2018, Guo et al. 2020, Noh et al. 2002, Cao et al. 2022, Zhang et al. 2023, Liu et al. 2022 (Preprint), Gombo et al. 2022.
	Wild and cultivated specimens	Nishihara et al. 2018, Fuchino et al. 2021, Zhi & Ming-yuan 1997, Meng et al. 2012, Urbagarova et al. 2021, Lyu et al. 2022
Introduction	Choice of conditions for introduction and cultivation	Shishmaryov et al. 2018, Zubova 2020, Elisafenko et al. 2021, Zhi & Ming-yuan 1997, Heuberger et al. 2010, Du & Yan 2002, Polovinkina 2022, Tsitsilin 2022, Kulishova et al. 2022
Selective breeding	Production of crops with high-quality plant raw material	Xu et al. 2016, Sung et al. 2008, Guan et al. 2008a,b
Agricultural techniques	Summary information	Cui 2014, Jia et al. 2019, Oh et al. 2018
	Harmful (parasitism, allelopathy) and beneficial (mutualism) organisms	Nishidono et al. 2021, Yao et al. 2000, Guan et al. 2010, Hao et al. 2015, Ma et al. 2015, Wang et al. 2015, Liang et al. 2016, Li et al. 2017, Morino et al. 2018, Yang et al. 2018, Zheng 2019; Han et al. 2021, Lee & Kwak 2014; Kim et al. 2020, Wu 1963, Lee et al. 2001, Kang et al. 2012, Sato et al. 1992, Sun et al. 2023, Han et al. 2022.
	Use of agrochemicals, biofertilizers, growth regulators, and other substances	Guan et al. 2010, Liu et al. 2010, Yuan et al. 2011, Meng et al. 2008, Hao et al. 2022, Kim & Chun 1992
	Timing of planting and harvesting	Ishizuka et al. 1998, Ji 2014, Liu 2007, Cao 2003
	Mechanization and planting care techniques	Wang et al. 2013; Otani et al. 2020; Nam et al. 2018
	Methods of propagation	Kim et al. 2010, Ahn et al. 2012, Jiang et al. 2018, Meng et al. 2012, Heuberger et al. 2010, Zhou 2009, Zhou et al. 2009, Dou et al. 2010, Stupina & Chernetsova 2018; Park et al. 2011, Chao & Xueli 2015, Choi & Chon 2000, Yoon et al. 1999, Tsybikova et al. 2022
	Hydroponic cultivation	Heo et al. 2018, Heo et al. 2013

a comparative analysis of the content of the active substances depending on soil composition, precipitation, and light levels of different growing areas (within the natural range, and for introduced crops). For example, *S. divaricata* plants grown in Bavaria, Germany, have a high content of chromones and coumarins, comparable with those in samples of plants grown in China (Heuberger et al. 2008a,b). In our previous work, it was shown that the total content of chromones in the samples of *S. divaricata* cultivated in Buryatia is 4.45 mg/g, which is twice as high as their content in the samples of plants grown in Novosibirsk Region (2.03 mg/g) (Urbagarova et al. 2021). These results indicate the need for appropriate conditions for cultivation (soil, moisture supply, number of light hours, etc.) as close to natural as possible.

It was noted in studies (Shishmaryov 2018, Han et al. 2017, Cao et al. 2022), that the increased content of chromones in *S. divaricata* is promoted by the cultivation of the plant in soil with low humidity, due to the increased activity of leaf protective enzymes and the number of osmoregulatory substances. Other data also indicate the effect of moisture on the growth and quality of *S. divaricata*: an unfavorable effect on plants was noted in the average annual rainfall of 200 mm (insufficient) and 450 mm (excessive), while values of 300 and 400 mm during the growing season promoted shoot and root growth, increased yields and improved quality of the plant raw material. The content of *prim*-*O*-glucosylcimifugin and 4'-*O*-*β*-D-glucosyl-5-*O*-methylvisamminol increased with the decrease in moisture that the plants received (Han et al. 2009, 2011). The content of substances such as malonic dialdehyde, hydrogen peroxide, and ascorbic acid in roots and leaves also gradually increased as drought stress continued, and decreased after irrigation. At the same time, the glutathione content in the roots increased while the moisture deficit persisted until irrigation (Men et al. 2018). In other words, moderate water stress has been found to increase the activity of key enzymes it is higher for the underground part of the plant compared to the above-ground part. However, as the duration of stress increased, the enzyme activity and chromone content variously decreased (Xu 2016). In the Irkutsk Region (Russia), the excessive precipitation in 2021 caused growth retardation of the root system due to soil excessive moisturizing and compaction. On the second year of life, most of the individuals remained there in vegetative phase, only about 5–6 % entered the generative phase, which may also be due to the soil excessive moisturizing (Polovinkina 2022).

The content of secondary metabolites in plant raw material is also influenced by the physicochemical properties of the soil. The study (Guo et al. 2020) established a negative correlation of the total chromone content in *S. divaricata* with the electrical conductivity of the soil, the content of available phosphorus and available calcium; and from the other side a positive correlation with the content of available manganese has been revealed. The authors (Sun et al. 2013) revealed a correlation between the content of essential oils in roots and soil composition: a negative one – with the content of total nitrogen in the rhizospheric horizon; a positive one – with the content of hydrolyzable nitrogen, mobile phosphorus, mobile potassium, and organic matter. Such studies are important for the selection of mineral fertilizers and the species cultivation. It is worth noting that the soil composition of natural habitats is usually optimal. One more potential application of *S. divaricata* is the ability to absorb nitrates harmful to the human body from the soil. And the methanol fraction has manifested the ability to ab-

sorb much stronger than aquatic one reaching 95.3 % under pH 1.2 (Noh et al. 2002). A 2022 study (Hao et al. 2022) found that *S. divaricata* has a number of response mechanism to phosphorus stress, including a significant increase in chromones, a synergistic pH interaction, organic matter, alkaline hydrolysable nitrogen and acid phosphatase, which ensures the uptake and utilization of nutrients by the plant.

Other important problems of introduction, unavoidable in the initial stages of cultivation, are related to the propagation of the plant.

Seed propagation

The available data on the biology of seed germination are ambiguous. The fruit of *S. divaricata* is a cremocarp, consisting of 2 mericarps, inside the mericarp a seed with a single-layer seed coat without an endosperm with a large embryo (Yugrina et al. 2021). There were different studies in Korea; one reported very low seed germination, not higher than 1.6 % (Park et al. 2011), in the other case it was 40.8–48.0 % (Chao & Xueli 2015), and reached 74–92 % (Choi & Chon 2000) in the third one. Similar to the last one, the studies carried out in the Central Siberian Botanical Garden SB RAS, Novosibirsk, Russia, the seed germination was 84–92 %, and the bulk of seeds germinated within 17 days under the following conditions: seeds (collected in natural growing conditions, Buryatia) were germinated in mericarps in a climatostat under photoperiod 17 h and variable temperature (day: +27°C, night: +17°C) (Elisafenko et al. 2021). These data indicate shallow seed dormancy. It was noted that ground germination for many species is several times lower than laboratory one. Seed germination of *S. divaricata* was 7.5 % during summer (sowing date: June 15), while when seeds were sown in autumn, they did not germinate the following year.

A rather interesting phenomenon was observed during the introduction of the plant in the Moscow Region (Russia): in this case, only 40 % of the individuals were monocarpic; the rest bloomed for the two years in row, starting in the second year (Tsitsilin 2022). These interesting data can be associated with special environmental conditions within the natural range, which do not allow individuals to flower more than once, or with the peculiarities of the growing techniques used in that experiment.

According to other data, the seeds of *S. divaricata* have a low percentage of germination and a low germination rate due to the presence of endogenous inhibitors (Zhou et al. 2009). Presence of the endogenous obstacles may be supported by the fact that the germination period does not decrease after scarification of the mericarp has been applied. Korean and Chinese experts have identified some agronomic techniques to increase the rate of successful germination of *S. divaricata* seeds. The best way to store seeds for a long time is dry storage at a room temperature and also dry storage in the refrigerator. Soaking mericarp in warm water with an initial temperature of 45°C for 24 hours gives an increase in germination up to 67.5 %; washing in running water for 48 hours increases seed germination up to 75 % (Zhou 2009). Rinsing the mericarps with running water for 3–5 days at +15 – +20°C also provides a good germination (Ahn et al. 2012). In an experiment to stimulate germination of *S. divaricata* seeds by soaking mericarps for 30 minutes at -70°C, the following results were demonstrated: 79.67 % of the seed population remained active, 9.0 % died, and 9.33 % were embryoless. At the same time, the germination rate increased by 25.00 % within two weeks, finally reaching 54.17 % (Dou et al. 2010). In the moderately arid steppe conditions of Altai Territory, it was found that the germination ratio increases (32.8 %), and the germination rate decreases (28 days) at a temperature of 28–30°C. Consequently, for the cultivation of *S. divaricata* in a moderately arid steppe environment, it is necessary to select the time of sowing or use seedlings (Stupina & Chernetsova 2018). These data are confirmed by studies where the seeds germinated in 55 days at 20–22ºC, while in a warmer environment (28–30ºC) it took only 28 days (Jiang et al. 2018).

The researchers suggested improving the germination of *S. divaricata* seeds by stratification, incubation in polyethylene glycol (2 weeks), or in water (72 hours). Sowing with a seed rate of 2 kg/ha^{-1} or planting seedlings in spring (1 plant per stand, about 80,000 stand/ha^{-1}) gave fresh root yields of 8–12 t/ha^{-1}, and dried roots without fine rootlets – 2.3–3.5 t/ha^{-1} (Heuberger 2010).

Another study found increasing the seed germination by means of incubation under 20–25ºC along with the osmotic conditioning by polyethylene glycol (under 5–14 bar) and treatment by KNO_3. The germination rate has been increased (up to 50 %) also by the stratification during 30–50 days, as well as treatment by gibberellic acid (Yoon et al. 1999). An increase in germination (compared to the control, germination 22 %) was noted when seeds were treated for 10–15 minutes with a solution of laundry soap (pH 9, germination 42 %) and dihydroquercetin (5 ml of preparation per 1 Petri dish, germination 33 %) (Tsybikova et al. 2022).

Despite its disadvantages, seed propagation of *S. divaricata*, remains the main way of growing the plant. The mechanisms that reduce the seeding quality of seeds, as well as the leveling of these mechanisms, should be comprehensively studied to increase the efficiency of direct seeding of *S. divaricata*, as well as for obtaining seedlings.

To increase the efficiency of direct sowing of *S. divaricata*, and produce seedlings, it is necessary to further study the processes that reduce the seeding quality of seeds and their mitigation. The advantages of the seedling usage for the *S. divaricata* cultivation include faster yields, increased probability of seedling survival, lower seed consumption compared to direct seeding, and more rational use of the growing area.

Vegetative propagation method

An alternative to the seed method of plant propagation is a vegetative one. For example, Korean scientists divided annual roots of *S. divaricata* 1 cm or thicker into pieces 3–5 cm long and planted them using the method of oblique planting (Kim et al. 2010). This method resulted in the highest yield of fresh and dry mass of the obtained shoots and roots. At the same time, the pharmacological effects of the specimens produced by vegetative propagation were

not inferior to wild ones; and the plants grown by direct sowing showed even less pharmacological activity (Men et al. 2018).

The possibility of vegetative propagation of *S. divaricata* is controversial, but it is believed to be possible. Since this species often grows in sandy steppes, on slopes where exposure of the caudex due to erosion can occur, on which new shoots can form. Anyway, this method of propagation under *in situ* and *ex situ* conditions should be further examined.

Growing on hydroponics

This method considers helpful because the creation of semi-natural growing conditions (e.g. in uncharacteristic climatic zones) is impossible. Also, it is the most cost-effective method to obtain plenty of individuals for further laboratory studies.

The application of LEDs of blue, red, and white colors has been examined by Korean researchers in a power ratio of 1:2:1 along with irrigation with special nutrient media (MJ and YP) using a deep flow system (DFT) in special culture troughs for 350 days. This technique provided rather good results like a significant increase in the number of leaves of each seedling (Heo et al. 2018). In another study the passage was carried out for 90 days in mixed lighting conditions, in which blue and red LEDs were mixed in a ratio of 1:1 and 1:3, and fluorescent lamps were also used. The best indicators (an increase in the raw weight of seedlings by 3.7 times, dry weight by 2 times, the total number of newly formed leaves) were obtained using the FLBR 1:3 scheme (fluorescent lamps + blue + red LEDs in a ratio of 1:3 at a lighting intensity of 100 micromol/m2; growing on a urethane sponge; Yamazaki nutrient solution with pH and electrical conductivity values of 5.8 and 14 decimens/m, respectively) (Heo et al. 2013).

Agronomic methods

Mulching with the plant litter (in this study collected from pastures with the predominant species *Leymus chinensis* (Trin.) Tzvelev) in the amount of 50–100 g/m^2 was shown to stimulate seedling growth, but had an inhibitory effect when the content of the litter was increased over 100 g/m^2 (Liu et al. 2010). Young seedlings can also be affected by treatment with growth regulators. The effect of α-naphthyl acetic acid (α-NAA) and gibberellic acid on them was studied during cultivation. The highest content of chromones in the roots was observed when *S. divaricata* seedlings were treated with α-NAA at a concentration of 500 mg/kg (Meng et al. 2008). Mechanization can significantly reduce the time it takes to grow seedlings. The Japanese Paper Pot® system (rapid planting of seedlings), proved to be quite effective for *S. divaricata*. The plant raw material obtained did not differ in terms of the content of secondary metabolites from the raw material obtained in China (Otani et al. 2020).

Cultivation problems

It is known that the analgesic effect of the medicinal product made from generative specimens is 70–85 % of that of vegetative specimens. The antipyretic effect of flowering plants is only 55 % of that of non-flowering plants (Wan et al. 1999). Accordingly, it is recommended to prevent flowering of the plant to preserve its pharmacological properties. In the study, differences between the roots of generative and vegetative plants were established. It has been found that there is no significant difference in root diameter and chromone content between flowering and non-flowering individuals. Accordingly, flowering does not affect the root quality of *S. divaricata*, although it slightly reduces the yield (Sun & Meng 2008). The harm of premature flowering for the resulting raw materials lies in the lignification of root tissues. Accordingly, the biosynthetic pathways of phenylpropanoids (which, when polymerized, produce various forms of lignin and suberin) may be actively involved in the described process (Liu et al.). To date, the activity of genes responsible for premature flowering of *S. divaricata* has been identified – among them, auxin-related genes IAA and TIR1 are the key genes that trigger this process (Zhang et al. 2023). In a two-year study by Japanese scientists made in 1991-1992 in Nagano Prefecture, it was found that the root mass was maximal in November of the first year and mid-August of the second year. The amount of active substances was higher in plants in the second year than in plants in the first year. The content of *prim-O*-glucosylcimifugin, 4'-*O*-*β*-D-glucosyl-5-*O*-methylvisaminole, falcarinol, deltoin, and imperatorin decreased during the phases of inflorescence formation and flowering, but the content of cimifugin increased markedly during flowering. After the flowering or fruiting phase, the amounts of all six components were markedly higher (Ishizuka et al. 1998). An effective way to control unwanted flowering in three-year-old plants is to adjust the timing of sowing and remove emerging inflorescences in the late fall of the second year or early spring of the third year. Treating three-year-old plantings at a certain period keeps the level of unwanted inflorescence formation below 4 % (Wang et al. 2013).

Other serious problems occurring in the cultivation of *S. divaricata* are some pests and diseases. So far, cases of leaf spot caused by *Botrytis cinerea* Pers. (Hao et al. 2015), gray rot caused by the same pathogen (Ma et al. 2015); leaf spot caused by *Pseudomonas viridiflava* (Burkholder, 1930) Dowson, 1939 (Wang et al. 2015); phytophthora caused by *Mazzantia angelicae* (Berk.) Lar.N. Vassiljeva (Li et al. 2017); phytophthora and fusarium wilt caused by *Rhizoctonia solani* J.G. Kühn and *Fusarium* sp.; leaves darkening and shrinking caused by *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. (Lee & Kwak 2014); chlorosis caused by CMV-L viruses (cucumber mosaic cucumovirus) (Kim et al. 2020). The main causes of such diseases are poor ventilation, poor drainage of the soil, and high density of planting (Yao et al. 2000). Some methods of controlling *S. divaricata* pathogens have been developed. Fungicides have proven to be quite effective against leaf rot caused by *Septoria* sp.: 40 % flusilazole (EC_{50} = 37.80 μg/mL), 50 % nicotinamide (EC_{50} = 1642.11 μg/mL), 250 g/L pyraclostrobin (EC_{50} = 681.91 μg/mL), 25 % pyridoxazole (EC_{50} = 30.09 μg/mL), 20.67 % flusilazole (EC_{50} = 142.78 μg/mL), and oxazolidone (EC_{50} = 22.11 μg/mL) (Guan et al. 2010). In addition to fungicides, the phytotoxic effects of some herbicides on the plant were stu-

died. Fenoxaprop-P-ethyl, clethodim, haloxyfop-P-methyl, quizalofop-P-ethyl, quizalofop-ethyl, tribenuron-methyl, and nicosulfuron proved safe (Yuan et al. 2011). At the same time, paraquat caused plant death at a dose of 735 g/ha^{-1} of the cultivated area (Kim & Chum 1992). In addition to artificial measures to protect the plants, it is important to study their natural defense mechanisms, which can also be enhanced during selection. For example, induced defense responses against larvae of *Papilio machaon* C. Felder et R. Felder have been studied. In response to *a*-linolenic acid secreted by larvae, *S. divaricata* released volatile compounds, *a*- and *β*-pinene, and camphene (Nishidono et al. 2021). Also, in response to egg deposition by this pest, many of Umbelliferae plants (including *S. divaricata*) released protective agents such as germacrene D, *a*-humulene, and *trans*-caryophyllene. Repellents containing these agents reduced the number of eggs laid on plants by 40 % (Morino et al. 2018). Plantations of *S. divaricata* as well as of other Umbelliferae plants have also seriously damaged by *Sitochroa palealis* [Denis & Schiffermüller] 1775 (=*Loxostege palealis* Schiffermüller et Denis). Besides (Wu 1963), another pest species *Thrips hawaiiensis* (Morgan 1913) and *T. tabaci* (Lindeman 1889) has been occurred on *S. divaricata* on Jeju Island, Korea (Lee et al. 2001, Kang et al. 2012). The allelopathic effects of inhibiting plants on *S. divaricata* were also investigated, and it was shown that this species was significantly inhibited by *Hippophaë rhamnoides* L. in the humus soil. These studies may help to avoid co-planting of these species (Liang et al. 2016). Several species of harmful fungi from cultivated *S. divaricata* have been isolated by Japanese researchers, namely *Rhizoctonia* sp., *Fusarium* spp., *Phoma* sp. и *Pyrenochaeta* sp. (Sato et al. 1992).

Mutualistic relationships of *S. divaricata* with other organisms were also investigated. It was found that many endomycorrhizal fungi can contribute to plant's growth and productivity. The group of dark septate endophytes (DSE) represents poorly studied endosymbionts of many species; their study can help to develop ways to increase the crop productivity, resistance to various diseases and pests, as well as to determine the mechanisms of synthesis of some metabolites. The DSE colonization rate for *S. divaricata* was 10 %, which indicates a rather weak participation of the species in symbiotic relationships with this group (Han et al. 2021). In recent years, it has been proved that some endophytic fungi in *S. divaricata* can produce biologically active substances such as uracil and allantoin (Yang et al. 2018). The endophyte *Alternaria* sp. found in *S. divaricata* in 2019 may also be a source of antibacterial substances (Zheng 2019). It was also found that the strain of the rhizosphere fungus *Sirastachys castanedae* L. Lombard & Crous MR-43 demonstrated a strong degree of inhibition against *Fusarium oxysporum* Schltdl. и *F. equiseti* (Corda) Sacc. (inhibition up to 57 %). Multiple tests confirmed that the antifungal effect was relatively stable. *S. castanedae* MR-43 successfully colonized the soil and established a stable population in the area where *S. divaricata* grew (Sun et al. 2023). Another beneficial organism that suppresses the growth of *F. equiseti* in *S. divaricata* was *Acremonium persicinum* (Nicot) W. Gams (strain MR-47) (Han et al. 2022). Further study of the identified metabolites can not only help to protect the plants, but also use them for medical purposes. Unfortunately, for a huge number of medicinal plants, the relationship between the content of secondary metabolites in them and the activity of symbiotic organisms has not yet been investigated.

The final stage of cultivation is harvesting. The late period of autumn (October 6–12, in China) is considered the optimal for harvesting *S. divaricata* raw material due to its higher chromone content and faster drying of roots (Liu et al. 2007). Another study also revealed that the best harvesting period is the end of October; it was noted that replanted two-year-old specimens contain more active substances (0.32 %) and higher yields (about 15 t/ha) can be harvested (Ji 2014). In another study, plants of 2–6 years old were examined. It was shown that the total amount of four chromones was higher in 3-years-old *S. divaricata* than in others; the best harvesting season is the spring period before the emergence of seedlings (Cao 2003). The best time for harvesting *S. divaricata* roots in Nagano Prefecture of Japan is November of the first year of cultivation (Ishizuka et al. 1998). Analysis of the data on the timing of harvesting shows that the optimal time is highly dependent on the specific conditions in which *S. divaricata* grows: it should be selected for a particular area. Cultivation of *S. divaricata* was initiated in China, where the first successes were later reported. Moreover, orbital studies of mutagenesis (the appearance of new mutations useful for breeders) were also conducted. In March 2002, seeds of *S. divaricata* were sent to the near space on the Chinese "Shenzhou 3" space shuttle and delivered back to Earth in 2008. The X-ray fluorescence method was used to measure the element and substances content both in control ground samples and samples delivered by the space shuttle. It was found that the content of Zn, Fe, Mn, and Cu in the experimental group increased 4.39, 1.23, 0.84, and 0.9 times, respectively, compared with the control group (Guan et al. 2008a). Also, increased content of chromones, polysaccharides, glycosides, and coumarins was noted in the samples of the experimental group (Guan et al. 2008b). An important result of plant breeding in China is the creation of a new variety of *S. divaricata* – "Guangfangfeng 1" (a sort of xerophilic ecotype) in 2016 in Hailar District of Hulun-Buir Province. Faster emergence of seedlings and high yield are among the advantages of this variety (Xu et al. 2016). However, the shrinking of *S. divaricata* plantations area because of excessive reclamation and plowing has been reported from that Province. Instead, the plantations area should be expanded, and at the same time principles of organic farming are strongly recommended to be applied (Du & Yan 2002). Apart from this, the latest study has recognized the two specifications (wild and cultivated) of *Saposhnikoviae Radix* that were divided into three grades each based on the length and diameter. In addition, the grade standards of *Saposhnikoviae Radix* were established based on the eight aspects: shape, surface characteristics, texture, cross section, taste, *prim*-*O*-glucosylcimifugin content, 5-*O*-methylvisamminoside content and length. Significant positive correlations between cimicifugin glycoside and 5-*O*-methylvisamminoside ($P < 0.01$), between cimicifugin and

helonoside ($P < 0.05$), and between cimicifugin glycoside and the length ($P < 0.05$) have been revealed (Lyu et al. 2022). Normalized Difference Vegetation Index (NDVI) indicating the quantity of total photosynthetic biomass has been estimated in Korea using a drone equipped with a multispectral camera. The absence of the correlation between NDVI and morphometric parameters (i.e., height of individuals, length and width of leaves, stem diameter) has been revealed. This was attributed to the complicated pattern of the leaf canopy in *S. divaricata* (Nam et al. 2018). Given the success of the plant breeders, one can assume that the number of *S. divaricata* varieties with higher yields will increase, and many problems, including poor seed germination as well as uncovering the most appropriate moisture regime, will be solved.

CULTIVATION *IN VITRO*

Along with the classical methods of producing medicinal plant raw materials, biotechnological methods have also been developed in recent decades. It is known that the success in growing established cell lines (whether callus or cell suspension) depends on the careful selection of the mineral composition of nutrient media, as well as the type, concentration, and ratio of growth regulators, adjusting the duration of the passage. For species that are difficult to reproduce, such as *S. divaricata*, the clonal micropropagation can be used to produce viable regenerants. It is possible to retrospectively trace how methods of obtaining quality cell cultures of *S. divaricata* were improved with the subsequent research on the prospects of their application both in medicinal plant growing and biotechnology.

Back in 1990, the embryogenic callus of *S. divaricata* was obtained from the young root, hypocotyl, and petiole explants. Plant material was cultured on the Murashige and Skoog medium (MS) with the addition of 1 mg/L 2,4-dichlorophenoxyacetic acid (2,4-D). The suspension cultures were obtained by culturing in the liquid nutrient medium on a shaker. Protoplasts were isolated enzymatically from these cells, which began to divide after 4 days and formed cell clusters after 50 days. From these clusters, calluses were obtained on the agarized MS with 0.5 mg/L 2,4-D. Embryoids were formed on the medium supplemented with 0.1 mg/L 6-benzyl adenine (6-BAP) or 0.1 mg/L 2,4-D + 0.5 mg/L 6 BAP. Seedlings (plantlets) were obtained on the hormone-free medium of the same mineral composition (Sheng & Chen 1990).

Then, in 1995, in a book of the Biotechnology in Agriculture and Forestry Series, the same authors published similar work on the successful isolation of protoplasts and the formation of embryogenic calluses from them using 'snailase' (a mixture of enzymes to dissolve the cell wall). The first isolated protoplasts began to divide on day 4, grew into small clusters of a few cells within 15 days, and into clusters of approximately 100 cells – after 1 month of cultivation. Cytoplasmic protoplasts that were too large or too small did not divide or died. It was found that 1 mg/L of 2,4-D combined with 0.5 mg/L of zeatin when added to the medium gave the best result in time and quality of the callus formation. Embryoids differentiated earlier in the callus mass. When the callus tissue was transferred to the solid MS nutrient medium with 0.1 mg/L 6-BAP or 0.1 mg 2,4-D combined with 0.5 mg 6-BAP, the appearance of small embryoids was observed after about 40 days of cultivation (Chen & Sheng 1995).

In 1996, the authors of (Zhong-ling & Hui-Min 1996) carried out a microscopic analysis of embryonic cells of *S. divaricata* and noted that the cortical endoplasmic reticulum appears in cells at the stage of embryogenic clump formation, but is absent at other stages, which is associated with the specific metabolism of the somatic embryo. Spherosomes were observed at the stage of embryogenesis. Their number significantly increased at the stage of proglobular embryo, indicating the participation of spherosomes in the protein storage at the early stages of embryogenesis.

In 2005, in the Journal of Northwest University the results on the effect of growth regulators on the embryogenesis of *S. divaricata* callus were presented. Thus, the replacement of α-NAA with 2,4-D was found to reduce the probability of abnormal embryogenesis, and the best concentration of 2,4-D for the induction of *S. divaricata* embryogenic callus was 0.5 mg/L. Somatic embryogenesis and embryoid growth can be stimulated by gradually reducing the concentration of auxins and cytokinins, and seedling regeneration can occur when somatic embryoids are transferred to the MS base medium without growth regulators or with the addition of 0.5 mg/L 6-BAP combined with 0.2 mg/L α-NAA (Qiao et al. 2005).

Also in 2005, the journal Northwest Botany published an article with the data on the selection of the optimal composition of nutrient medium to obtain embryogenic callus and stimulation of somatic embryogenesis of *S. divaricata* by indirect route (through the stage of callus formation). It was found that the 0.5 % concentration of auxin solution is optimal for the induction of embryogenic callus development, and the addition of cytokinin plays a synergistic role in the differentiation and further development of somatic embryos (Ji et al. 2005).

Further studies showed that the appearance of starch granules in *S. divaricata* tissue culture is a marker of embryogenic cell differentiation. It was also determined that the amount of auxins is a key factor in the induction of embryogenic cell formation, cytokinins play a synergistic role, and abscisic acid (ABA) can effectively control the occurrence of mutations in somatic embryos. An appropriate increase in sucrose concentration in the differentiation medium to 4–5 % helped to increase the osmotic potential, reduce the appearance of vitrified embryos, and suppress the tendency to premature germination. The frequency of deformed embryos was lowered by reducing the seeding density and dividing the callus into smaller aggregates according to its natural state or by culturing the plant material as a suspension for 24 hours with subsequent transfer to a solid medium for callus formation (Qiao 2005).

The study by Chen (2007) reported the possibility of obtaining a hairy roots culture using *Agrobacterium rhizogenes* (Riker et al. 1930) Conn 1942 (= *Rhizobium rhizogenes* (Riker et al. 1930) Young et al. 2001). This article revealed the optimal composition of growth regulators (0.6 mg/L α-NAA,

0.5 mg/L kinetin (KT), and 1.0 mg/L 6-BAP) in an MS nutrient medium suitable for indirect embryogenesis (through the callus formation stage). It was noted that when the regenerants reached a shoot height of 5 cm and a root length of 3–4 cm, the plants could be hardened and replanted.

In 2008, the results of an *in vitro* histological study of somatic embryos of *S. divaricata* have been published. A large amount of starch was observed in the embryogenic cell, a gradual decrease in its content accompanied the beginning of cell division and differentiation (Qiao & Xiao 2008).

In 2009, the results of a study of somatic embryogenesis of *S. divaricata* after long-term subculturing were presented. Embryogenic callus was initiated using roots, internodes, and leaves as explants on the MS nutrient medium containing 2.26 mM 2,4-D and 2.69 mM α-NAA was added to maintain it. The optimal medium for somatic embryo differentiation was MS nutrient medium containing 1.74 mM α-NAA, 4.44 mM 6-BAP, and 1.90 mM ABA. Mature somatic embryos progressed to the seedling stage within 5 weeks and were suitable for field planting after 1 month with a survival rate of about 81 %. It was found that low concentrations of paclobutrazol (PBZ), 0.34–1.36 mM or ethephon (ET), 1–4 mM, could promote flowering *in vitro* to 26 % or 21 % of the total number of treated plants, respectively. These cultures of *S. divaricata* were grown on the media containing 4–5 % sucrose, which could also promote flowering induction. It is noteworthy that some vitrified embryos which did not form roots could also develop and form flowers and fruits under *in vitro* conditions. In addition, these studies revealed for the first time that within 15 months, callus plants can already produce flowering and fruiting plants, whereas in nature they can reach the flowering phase after 2–3 years only. These important results can be used to obtain *S. divaricata* seeds more quickly *in vitro* (Qiao et al. 2009).

Another study made in 2009 included several experiments on the regenerative capacity of different types of explants of *S. divaricata* (such as roots, stems, young leaves, cotyledons, and axillary buds). In the MS medium supplemented with 1.0 mg/L 6-BAP and 0.2 mg/L α-NAA, the cotyledons showed the best callus formation rate. The MS medium including 3 % sucrose and growth regulators (2 mg/L 6-BAP with 0.4 mg/L α-NAA) was the best for adventive bud formation at 12/12 – 14/10 h (light/dark) photoperiod. The best medium for rooting of regenerants was ½ MS + 0.5 mg/L α-NAA (Tong et al. 2009).

A study conducted in 2010 showed the presence of a large amount of starch in embryogenic cells inducing the beginning of embryogenesis in the callus. The highest polysaccharide content was found in the embryogenic callus on the medium with 4 % sucrose. That is, the active carbohydrate metabolism can provide the formation of intermediate synthesis products and energy resources directly for differentiation and development of embryogenic cells, and the abundant appearance of starch is one of the signals for the induction of embryogenic cells (Qi & Yaping 2007). This opens broad prospects for identifying the quality of embryogenic clusters suitable for growing regenerants, which can significantly improve the culling of poor-quality cell lines.

In 2010, the study (Han 2010) described in detail the technique of microclonal propagation of *S. divaricata*. The rate of callus differentiation was high when either 2.5 mg/L 6-BAP, 0.4 mg/L KT, 0.2 mg/L α-NAA; or 1.0 mg/L 6-BAP, and 0.2 mg/L KT were added to the medium. The optimal passage duration for normal callus development was 25 days, and the rate of differentiation of adventitious buds was higher after two replantings. When photosynthetic photon flux density (PPFD) was increased from 5 to 26.5 μmol/m^2·s, the number of buds producing callus increased as did their viability. The root formation was stimulated by the addition of 0.4 mg/L α-NAA; and in combination with NH_4^+ and NO_3^- ions (in a 1:4 ratio), the maximum effect was observed. As the pH value of the medium increased, the number of adventitious buds and then shoots increased continuously; pH 6.0 was the most suitable for this process. It was also determined that 3-indolyl butyric acid (IBA) should be added to MS medium with neutral pH to increase survival, the concentration of salts (macrocomponents) should be halved. The seedlings were hardened (as preparation for *ex vitro* conditions) at PPFD of 26.5 μmol/m^2·s illumination and a temperature of 15°C. The soil mixture for adaptation of the regenerant plants to environmental conditions (*ex vitro*) consisted of vermiculite, field soil, and fine sand in a 1:2:1 ratio. This composition provided the highest rooting ability of seedlings, reaching 74.7 %.

In 2011, several experiments were conducted to stimulate mutagenesis in *S. divaricata* callus cells which may accelerate the varietal formation and creation of polyploid plants. Treatment of callus cells with colchicine solution has been shown to have a positive effect, resulting in a high rate of variability. Thus, a callus treated with 0.2 % colchicine solution demonstrated a variation rate of 47 %. High concentrations of α-NAA and riboflavin (above 1.0 mg/L) had an inhibitory effect on the formation of adventitious roots on the callus surface. Medium ½ MS combined with 1.0 mg/L riboflavin was used to induce the formation of adventitious roots, which reached a rate of 88.89 %. The phenotype of the resulting mutant was characterized by thicker roots, darker and larger leaves, and thicker stems; its karyotype formula was $2n = 4x = 32$ (Bi 2011).

Another area of research on cell cultures is related to the effect of ultralow temperatures on them. Cryogenic freezing allows the transport and long-term storage of cell lines for later use. The results of the experiment on cryogenic freezing of *S. divaricata* callus were published in 2014. The recommended preparation for deep freezing of three-day-old callus is as follows: pre-culture in the MS medium supplemented with 1.0 mg/L 6-BAP, 1.0 mg/L α-NAA and 5 % DMSO (cryoprotectant) for 3 days at 4ºC, then placement in 60 % PVS2 solution (cryoprotectant) at the room temperature for 20 min, dehydration in 100% PVS2 at 2°C for 45 min, and then placement of callus in the liquid nitrogen. Then washing with 1.0 mol/L sucrose solution and culturing in darkness (MS medium) for more than 14 days promotes further callus recovery and growth after freezing (Ma 2014). However, vitrified shoots obtained from the frozen callus have abnormal morphology (as compared to normal shoots), increased water content in tissues, significant decrease in chlorophyll content, and weakened

activity of peroxidase isoenzymes. These shoots can be restored to the normal conditions by changing the cultivation medium (Ma et al. 2013).

One of a few studies on the chemical composition of *S. divaricata* callus was published in 2018. The content of cimifugin in *in vitro* culture was changed by 0.89 times and 5-*O*-methylvisamitol by 0.74 times than in the dried roots of the native plant (Fu 2018). These results are in consistence with the fact that the content of secondary metabolites (e.g., glycosides) in many plants usually decreases, when using cell cultivation techniques (Tomilova 2020).

A 2021 study considered the culturing cell suspensions techniques applicability for some medicinal plants, including *S. divaricata* (Kolomietc et al. 2021). The species was cultured in a liquid MS nutrient medium supplemented with 100 mg/L myo-inositol, 50 mg/L casein hydrolysate, 0.1 mg/L thiamine, and growth regulators – 0.5 mg/L 6-BAP and 2 mg/L α-NAA. Triton X-100 (a nonionic surface-active agent) was added to the suspension culture at an amount of 2 mg/L.

The maximum viability rates for medicinal plant cell cultures, as well as optimal biochemical composition, economic coefficient, growth index and specific growth rates were observed at a temperature of 26°C and a passage duration of 21 days. Another important parameter for growing a cell culture suspension is the stirring frequency, the optimal value of which is 100 rpm. Another study confirmed, that extracts from dried biomass of callus and suspension cultures of plant cells have no toxic effect on glioblastoma cells when evaluated by MTT assay. As for the extracts obtained from dried root culture biomass, the presence of cytotoxic effect on the studied cancer cells was noted for them. The cancer cell survival rate was 99.0±11.4 in the case of the callus extract; 95.1±14.0 in the case of the suspension extract, and 48.0±6.2 in the case of the root cultures extract (Babich et al. 2021). The following study considered the antioxidant and antimicrobial activities of callus cultures, cell suspension, and culture of genetically modified roots of *S. divaricata*. Callus cultures were grown on a modified MS nutrient medium, and the first regenerants appeared after 6–8 weeks, forming 2–4 leaves. These leaves were cut into pieces and placed on the agarized medium; primary calluses were formed on days 7–14. Suspension cultures were also grown on the ½MS medium. The root cultures were obtained by the agrobacterial transformation of leaves of 14- to 28-day-old seedlings. Inoculation was performed with A4 strain of *A. rhizogenes* (*R. rhizogenes*) pre-cultured on a YEB medium (Vervliet et al. 1975). After co-cultivation, the plant material was transferred to an agarized Gamborg medium (B5) containing 500 mg/L claforan to eliminate *A. rhizogenes* (*R. rhizogenes*). Transformed roots were formed in the light chamber and then replanted into a hormone-free B5 nutrient medium. The antioxidant activity of the extracts from the root biomass was several times higher than that of the callus and suspension culture extracts. All samples exhibited antimicrobial activity against test strains of *Escherichia coli* (Migula, 1895) Castellani & Chalmers, 1919, *Staphylococcus aureus* Rosenbach, 1884, *Proteus vulgaris* Hauser, 1885, *Pseudomonas aeruginosa* (Schroeter, 1872) Migula, 1900, *Candida albicans* (C.P. Robin) Berkhout, *Leuconostoc mesenteroides* (Tsenkovskii, 1878) van Tieghem, 1878, *Shigella flexneri* Castellani & Chalmers, 1919, and *Sh. sonnei* (Levine, 1920) Weldin, 1927. The extract derived from root cultures proved the most effective (Milentyeva et al. 2021).

DISCUSSION

Both *ex situ* and *in situ* cultivation possess the advantages as well as disadvantages. Advantages of *in situ* cultivation are following: the relative affinity of cultivated areas to natural habitats (importantly, in the case of rejection the fertilizers and pesticides) provides an opportunity to get the raw material of a higher quality; there is a chance for plants to disperse their seeds beyond the area of cultivation, so *in situ* cultivation can facilitate rehabilitation or restoration of the disturbed *S. divaricata* populations. From the other side there are three main disadvantages of *in situ* cultivation. Densely grown individuals are prone to closely related crossbreeding (which further leads to degeneration), outbreaks of pests and diseases can appear and expand in a very fast manner, premature depletion of soils can occur on plantations, are among them.

The main advantage of the *ex situ* cultivation is the opportunity to conserve the natural populations, which is especially important for rare and endangered plant species. The *ex situ* cultivation can provide the propagules supply for further restoration of natural populations, or for conserving the genetic materials (seeds, or plants' organs). Disadvantages of the *ex situ* cultivation are related to the genetic diversity decreasing, inbreeding, and accumulation of harmful alleles. The same disadvantages can be manifested in the course of *in situ* cultivation as well, namely when plants are growing in a greenhouse, the pesticides are applied, the watering regime is non-natural, etc. The latter makes unclear the borderline between consequences of *ex situ* and *in situ* cultivation techniques.

Thus, this review devoted to the methods of obtaining viable regenerants of S. divaricata showed that in most cases, the nutrient medium MS with 2,4-D (0.5 to 2.26 mg/L) was used for this purpose, with the use of hypocotyl as an explant was the best option. Further, for callus proliferation as well as its maintenance, the MS nutrient medium supplemented with 0.5 mg/L 2,4-D and 0.4–0.6 mg/L α-NAA was better suited. For induction of somatic embryogenesis, the most common formulation was the MS medium supplemented with 0.5–0.6 mg/L α-NAA and 1 mg/L 6 BAP. For the cultivation of regenerants, in most cases a hormone-free medium was used, or a medium with the addition of 0.4–0.5 % α-NAA (Table 2).

The plant material obtained this way had significant antioxidant and antimicrobial activity and low cytotoxicity. It is known that different strains of gram-negative phytopathogenic bacterium *A. rhizogenes* (*R. rhizogenes*) have different capabilities of hairy root growth induction (Kuluev et al. 2015). A few studies on the selection of *A. rhizogenes* (*R. rhizogenes*) strains have been performed for *S. divaricata*, although the results of such works could be promising for increasing the yield of secondary metabolites obtained *in vitro*.

There are both advantages and disadvantages of *S. divaricata in vitro* cultivation. The most important advantage is that a large generation of clone regenerants, or pure cell

Table 2. Modifications of MS nutrient media for different *Saposhnikovia divaricata* cultivation tasks.

Application areas	Phytohormones, growth regulators	Notes	References
Induction of callogenesis	1 mg/L 2,4-D		Sheng & Chen 1990
	0.5-2 mg/L 2,4-D		Zhong-ling & Hui-Min 1996
	2.26 mM 2,4-D		Qiao et al. 2009
	1 mg/L 6-BAP; 0.2 mg/L α-NAA		Tong et al. 2009
	0.2 mg/L α-NAA; 2.5 mg/L 6-BAP; 0.4 mg/L KT or 0.2 mg/L KT; 1 mg/L 6-BAP		Han 2010
	0.9 mg/L 6-BAP; 1.05 mg/L 2,4-D; 0.96 mg/L KT		Fu 2018
	1 mg/L KT; 0.5 mg/L 2,4-D		Milentyeva et al. 2021
Callus culture proliferation	0.5 mg/L 2,4-D		Sheng & Chen 1990, Ji et al. 2005
	1 mg/L 6-BAP; 0.6 mg/L α-NAA		Chen 2007
	2.69 mM α-NAA		Qiao et al. 2009
	2 mg/L 6-BAP; 0.4 mg/L α-NAA	Lighting 12-14 hours per day	Tong et al. 2009
	0.4 mg/L α-NAA	NH_4^+ and NO_3^- (in a 1:4 ratio); increasing pH up to 6.0	Han 2010
	0.56 mg/L 6-BAP; 0.48 mg/L 2,4-D; 0.4 (mg/L) KT	Lighting 12 hours a day	Fu 2018
Induction of somatic embryogenesis	0.1 mg/L 6-BAP or 0.1 mg/L 2,4-D; 0.5 mg/L 6-BAP		Sheng & Chen 1990
	0.5 mg/L 2,4-D	Adding 10% coconut milk	Zhong-ling & Hui-Min 1996
	1 mg/L 6-BAP; 0.2 (mg/L) αNAA; 0.5 mg/L ABA	Sucrose concentration 4-5%	Ji et al.2005
	0.6 mg/L α-NAA; 0.5 (mg/L) KT; 1 mg/L 6-BAP		Chen 2007
	1.74 mM α-NAA; 4.44 mM 6-BAP; 1.9 (mg/L) ABA		Qiao et al. 2009
	IBA (unknown concentration)	½ MS; using fructose instead of sucrose, neutral pH	Han 2010
	0.6 mg/L α-NAA; 1 mg/L 6-BAP		Fu 2018
Cultivation of adventitious microshoots	–		Sheng & Chen 1990
Induction of rooting of microshoots	0.5 mg/L^{-1} α-NAA	½ MS	Tong et al. 2009
	0.4 mg/L α-NAA; 0.4 mg/L 6-BAP	Lighting 12 hours a day	Fu 2018
Induction of flowering and fruiting *in vitro*	0.34-1.36 mM PBZ or 1-4 mM ET	Sucrose concentration 4-5%	Qiao et al. 2009
Hairy root cultivation	0.6 mg/L 2,4-D; 0.5 mg/L 6-BAP		Chen 2007
	Gamborg nutrient medium (B5) instead of MS medium	500 mg/L claforan to eliminate *R. rhizogenes*, followed by hormone-free B5	Milentyeva et al. 2021
Cultivation of cell suspensions	0.5 mg/L 2,4-D	Adding 10% coconut milk	Zhong-lin & Hui-Min 1996
	1 mg/L KT; 0.5 mg/L 2,4-D	½ MS	Milentyeva et al. 2021
	0.5 mg/L 6-BAP; 2 mg/L *s*-NAA	50 mg/L of casein hydrolysate, 2 mg Triton X-100	Kolomietc et al. 2021
Cultivation of cell suspensions to form cell clusters	1 mg/L 2,4-D; 0.5 mg/L zeatin		Chen et al. 1995

Note: MS – Murashige and Skoog medium; B5 – Gamborg medium; 2,4-D – 2,4-dichlorophenoxyacetic acid; 6-BAP – 6-benzyl adenine; α-NAA – α-naphthalene acetic acid; IBA – indole-3-butyric acid; KT – kinetin; ABA – abscisic acid; PBZ – paclobutrazol; ET – ethephon.

culture can be grown and this result is sufficiently reliable. However, the methods of preparation of media, disinfection of explants, frequency of passages, etc. must be complied rigorously. Application of the cell culture method can accelerate the selection process and provides relatively fast creation of new sorts by means of the artificial selection and cell hybridization. Moreover, cell cultures can be used to conserve the genetic information of rare and endangered species. Disadvantages of *S. divaricata in vitro* cultivation are following: the lower content of secondary metabolites in the cell cultures comparing to wild grown individuals, the time and money consuming regenerants acclimatization, high expenses for the process of explants preparation itself, as well as for the callus growing, and media preparation.

CONCLUSION AND FUTURE PROSPECTS

The increased attention to *S. divaricata* by researchers from China, Japan and Korea is due to the rich history of the use of this plant in traditional medicine and the effectiveness of medicines derived from it. Unfortunately, the popularity of this plant's raw material has negatively affected the natural populations of this species, including the Russian part of its geographical range. Existing plantations in Asian countries do not meet the existing demand – this plant raw material is actively exported from Russia by foreign entrepreneurs. In this situation, it is important to solve the problems of restoration of natural populations and the shortage of high-quality raw materials of *S. divaricata*. It is important to recognize the gained experience of Chinese, Korean and Japanese colleagues in developing methods of cultivation of *S. divaricata* (seed treatment, irrigation mode, soil composition, temperature, time of planting and harvesting).

It was found that the moisture availability and the organic-mineral composition of soils are some of the limiting factors, and their consideration can help to achieve the required amounts of metabolites in the plant. The introduction of the species in similar natural environments seems very promising from both biological and phytochemical points of view.

At the same time, *in vitro* cultivation of *S. divaricata* is a promising biotechnological method that allows obtaining rich secondary metabolites in a short period of time. Further research in this direction can help, firstly, to produce regenerant plants by applying clonal micropropagation methods, thus contributing to the restoration of natural populations; and secondly, to reproduce standardized plant raw materials on an industrial scale for pharmaceutical, cosmetic and food purposes. To date, the composition of nutrient media capable of providing growth and maintenance of callus and suspension cultures, regeneration through somatic embryogenesis, as well as rhizo- and hemmogenesis has been sufficiently well adapted. In addition, preliminary protocols for clonal micropropagation have been developed; the possibility of cryogenic storage and subsequent recovery of cell cultures has been studied; markers of embryogenesis beginning in cell culture have been determined.

At the same time, many gaps in the studies of *S. divaricata* still remain. For example, there are not enough data on the continuous cultivation of suspension cultures in bioreactors and obtaining secondary metabolites from them; the biochemical compositions of callus, suspension, and hairy root cultures are poorly studied; the effect of increased humidity under *in vitro* cultivation conditions on chromone content has not been investigated; the issue of somaclonal variability of regenerants has been little studied; there are no data on producing hybrid and artificial seeds.

The presented overview summarizes wide scope of information on the *S. divaricata* cultivation and shows the main achievements as well as gaps in knowledge concerning this important plant species. Authors believe that this work will be helpful for further development of the *S. divaricata* cultivation techniques and also will contribute to the species conservation.

ACKNOWLEDGEMENTS

This research was funded by the framework of the State Assignment of Baikal Institute of Nature Management SB RAS (projects No FWSU-2024-0001, FWSU- 2021-0004); Institute of General and Experimental Biology SB RAS (No 121030900138-8); Central Siberian Botanical Garden SB RAS (No AAAA-A21-121011290025-2); Institute of Cytology and Genetics SB RAS (No FWNR-2022-0017); the Biological Resources Programme of Chinese Academy of Sciences (KFJBRP-017–101), the Biological Resources Programme of Chinese Academy of Sciences (KFJBRP-017–101), CAS "Light of West China" Program (2025); and in the aspects of work of Interregional Scientific and Educational Center "Baikal".

The authors would like to acknowledge Dr. Innokenty G. Aktamov, a Head of Oriental Languages Translations Center (Institute of Mongolian, Buddhist, and Tibetan Studies SB RAS) for his professional and kind assistance in the translation of the scientific sources.

LITERATURE CITED

Ahn, Y.-S., T.-J. An, M. Hur, H.-J. Tun & C.-B. Park 2012. Study for the improvement of seed germination rate on *Angelica dahurica*, *Saposhnikovia divaricata* and *Bupleurum falcatum*. *Korean Society of Medicinal Crop Science* 05a:25–26 (in Korean).

Anenkhonov, O.A., M.V. Kazakov, D.V. Sandanov & N.S. Gamova 2023. *Saposnikovia divaricata* (Turcz.) Schischk. In: *The Red Data Book of the Republic of Butyatia: Rare and Endagered Species of Plants and Fungi, 4th ed., revised and updated* (O.A. Anenkhonov, ed.), p. 207, Constanta Ltd., Belgorod, Russia (in Russian). [Аненхонов О.А., Казаков М.В., Санданов Д.В., Гамова Н.С. 2023. Сапожниковия растопыренная // Красная книга Республики Бурятия: Растения и грибы / отв. ред. О.А. Аненхонов. 4-е изд., доп. и перераб. Белгород: Константа. С. 207].

Babich, O.O., S.A. Sukhin, A.V. Pungin, L.K. Asyakina & E.V. Ulrikch 2021. Investigation of the cytotoxic activity of extracts from dried biomass of callus, suspension cell cultures and root cultures *in vitro* of nedicinal hyssop, cobbler, and Amur maakia. *Innovatsionnye nauchnye issledovaniya* 4–1(6):51–60 (in Russian). [Бабич О.О., Сухих С.А., Пунгин А.В., Асякина Л.К., Ульрих Е.В. 2021. Изучение цитотоксической активности экстрактов из высушенной биомассы каллусных суспензионных культур клеток и корневых культур *in vitro* иссопа лекарственного, сапожниковии растопыренной и маакии

амурской // Инновационные научные исследования. Вып. № 4–1(6). С. 51–60].

Bi, B. 2011. *Research on innovative technology of Saposhnikovia divaricata polyploidy germplasm resources*. Master's thesis, Jilin Agricultural University, Jilin, China (in Chinese).

Cao, L. 2003. *Quality evaluation of standardized planting medicinal materials*. PhD thesis, Heilongjiang University of Traditional Chinese Medicine, Harbin, PRC (in Chinese).

Cao, S., L. Shi, Y. Shen, L. He & X. Meng 2022. Ecological roles of secondary metabolites of *Saposhnikovia divaricata* in adaptation to drought stress. *PeerJ* 10:e14336.

Chang, C.-S., H. Kim & K.S. Chang 2014. *Provisional checklist of vascular plants for the Korea Peninsula flora (KPF), Version 1*. Designpost, Korea, 660 pp.

Chao, H. & H. Xueli 2015. Germination characteristics of the seeds of Fangfeng and *Angelica dahurica*. *Guizhou Agricultural Science* 11:144–146 (in Chinese).

Chen, B., H. Zou, B. Zhang, X. Zhang, X. Jin, C. Wang & X. Zhang 2022. Distribution pattern and change prediction of *Saposhnikovia divaricata* suitable area in China under climate change. *Ecological Indicators* 143:109311.

Chen, H.M., G.M. Xia & S.H. Sheng 1995. Regeneration of plants from protoplasts of *Bupleurum scorzonerifolium* (Red Thorowax) and *Saposhnikovia divaricata* (Divaricate Saposhnikovia). In: *Plant protoplast and genetic engineering. VI. Biotechnology in agriculture and forestry, vol. 34* (Y.P.S. Bajaj, ed.), pp. 14–24, Springer, Berlin, Heidelberg, Germany.

Chen, X. 2007. *Study on tissue culture of Fangfeng and its establishment of root system*. Master's thesis, Heilongjiang Bayi Agricultural University, Heilongjiang, PRC (in Chinese).

Choi, S.-K. & S.-U. Chon 2000. Temperature effect on seed germination and seedling growth of medicinal Umbelliferae plants. *Plant Research* 3:66–70.

Cui, Z. 2014. The use of traditional Chinese medicinal materials for Fangfeng and the application of its cultivation and planting technology. *Heilongjiang Medicine Journal* 27(4):817–821 (in Chinese).

Dou, T.-L., Y.-Q. Wang, L.-F. Zhang, Q.-H. Zuo & X.-G. Zhang 2010. Study on improving germination of *Saposhnikovia divaricata* seed. *Seed* 02:66–68 (in Chinese).

Downie, S.R., K. Spalik, D.S. Katz-Downie & J.-P. Reduron 2010. Major clades within Apiaceae subfamily Apioideae as inferred by phylogenetic analysis of nrDNA ITS sequences. *Plant Diversity and Evolution* 128(1–2):111–136.

Du, G.P. & R.T. Yan 2002. Chinese medicinal materials – "windfang" cultivation technology. *Agricultural Science and Technology Newsletter* 10:12. (in Chinese).

Elisafenko, T.V., E.A. Korolyuk, P.N. Yugrina, B.M. Urbagarova & V.V. Taraskin 2021. Results of the primary introduction of *Saposhnikovia divaricata* (Turcz.) Schischk. in the Central Siberian Botanical Garden SB RAS. *Rastitel'nyi Mir Aziatskoi Rossii* 14(4):293–302 (in Russian with English summary). [Елисафенко Т.В., Королюк Е.А., Югрина П.Н., Урбагарова Б.М., Тараскин В.В. Результаты первичной интродукции *Saposhnikovia divaricata* (Turcz.) Schischk. в Центральном сибирском ботаническом сады СО РАН // Растительный мир Азиатской России: Вестник Центрального сибирского ботанического сада СО РАН. Т. 14, № 4. С. 293–302].

Fu, H. 2018. *Establishment of regeneration system of Saposhnikovia divaricata and determination of active ingredient content*. Master's thesis, Jilin Agricultural University, Jilin, PRC (in Chinese).

Fuchino, H., S. Murase, A. Hishida & N. Kawahara 2021. Simultaneous UHPLC/MS quantitative analysis and comparison of Saposhnikoviae radix constituents in cultivated, wild and commercial products. *Journal of Natural Medicines* 75:499–519.

GBIF 2022. *GBIF Occurrence Download (27 July 2022)* https://doi.org/10.15468/dl.wxnvft

Gombo, O., B. Tsambaa, A. Jukov, A. Narantsetseg & D. Munkhtur 2022. Intraspecific differences of section on root head of siler (*Saposhnikovia divariacata* (Turcz.) Schischkin) in Mongolia. *Mongolian Journal of Biological Sciences* 20(2):27–34.

Government of Trans-Baikal Territory 2018. Decree of the Government of Trans-Baikal region, dated 28 August 2018, No 350 "On amendments to Red List of Trans-Baikal region, Section 1, "Angiospermae". Available from: http://publication.pravo.gov.ru/document/7500201809040011. Last accesed 09.08.2024 (in Russian). [Правительство Забайкальского края 2018. Постановление № 350 от 28.08.2018 о внесении изменения в раздел 1 "Отдел Покрытосеменные – Angiospermae" Перечня объектов растительного мира, занесенных в Красную книгу Забайкальского края, утвержденного постановлением Правительства Забайкальского края от 16.02.2010 № 52].

Guan, Y., L.H. Yang, X.F. Ding, H.F. Guo, Y.Y. Zhu & J.S. Shi 2008. Research on the fourth generation of *Saposhnikovia divaricata* by XRF. *Guang pu xue yu Guang pu fen xi = Guang pu* 28(5):1191–1193 (in Chinese).

Guan, Y., X.H. Guo, L.J. Di, Z.Z. Wang, Z.H. Meng & Y.Y. Zhu 2008. Study of the *Saposhnikovia divaricata* with space mutagenesis by Fourier transform infrared spectroscopy. *Guang pu xue yu Guang pu fen xi = Guang pu* 28(6):1283–1285 (in Chinese).

Guan, Y., Y. Wang, L. Wu & X. Kong 2010. Occurrence of leaf blight of Radix Saposhnikoviae and the inhibitive effect of fungicides to *Septoria* sp. infecting leaf bligh. *Forest By-product and Speciality in China* 4:9–11 (in Chinese).

Guo, X., X. Tian, J. Hao, Y. Wang, L. Yang, M. Han & Z. Han 2020. Relationships between *Saposhnikovia divaricata* chromone content and soil factors in different regions. *Journal of South China Agricultural University* 41(4):30–37.

Han, L., Y. Zuo, X. He, Y. Hou, M. Li & B. Li 2021. Plant identity and soil variables shift the colonisation and species composition of dark septate endophytes associated with medicinal plants in a northern farmland in China. *Applied Soil Ecology* 167:104042.

Han, S. 2010. *Study on proliferation and optimal transplanting conditions of Fangfeng tissue cultured seedlings*. Master's thesis, Heilongjiang Bayi Agricultural University, Heilongjiang, PRC (in Chinese).

Han, Z., X. Shao, Y. Wang, Y. Li, M. Han & L. Yang 2011. Growth characteristics and physiological and photosynthetic abilities of *Saposhnikovia divaricata* in response to water supply. *Journal of Food Agriculture & Environment* 9(2):578–582.

Han, Z., Y. Wang, M. Xu, S. Yu, L. Yang & M. Han 2017. Effect of drought stress on physiological characteristics and quality of *Saposhnikovia divaricata*. *Journal of Northwest A&F University – Natural Science Edition* 45(11):100–106.

Han, Z., Z. Sun, Y. Wang, F. Zhang, F. Ma, Q. Luo & L. Yang 2022. Screening, identification and biological control of antagonistic fungus against root rot of *Saposhnikovia divaricata*. *Chinese Journal of Biological Control* 38(5):1288–1295.

Han, Z.M., Y.H. Wang, S. Zhao, M. Han & L.M. Yang 2009. Effects of water supply on growth and quality of *Saposhnikovia divaricata*. *Journal of South China Agricultural University* 30(3):4–7 (in Chinese).

Hao, J., Y. Liu, J. Yin, J. Liu, X. Tian, Z. Han, Y. Wang, M. Han & L. Yang 2022. Effects of different phosphorus concentrations on soil physicochemical property, growth and medicinal materials quality of *Saposhnikovia divaricata*. *Journal of South China Agricultural University* 43(3):59–67.

Hao, N., Y. Yuan, R. Zhou, Z. Piao & H. Li 2015. First report of *Botrytis* leaf blight on *Saposhnikovia divaricata* caused by *Botrytis cinerea* in China. *Plant Disease* 99(9):1277.

Heo, J., K. Park, C. Park, J. Lee, J. Baek, S. Hong & G. Lee 2018. Control of culture mediums on hydroponic growth of *Ledebouriella seseloides* seedlings under the smart greenhouse of artificial light type. In: *Proceedings of the 9th International symposium on machinery and mechatronics for agricultural and biosystems engineering*, p. 153, Jeju, Korea.

Heo, J.-W., D.-E. Kim, K.-S. Han & S.-J. Kim 2013. Effect of light-quality control on growth of *Ledebouriella seseloides* grown in plant factory of an artificial light type. *Korean Journal of Environmental Agriculture* 32(3):193–200.

Heuberger, H., R. Bauer, F. Friedl, G. Heubl, J. Hummelsberger, R. Nögel, R. Seidenberger & P. Torres-Londoño 2010. Cultivation and breeding of Chinese medicinal plants in Germany. *Planta Medica* 76(17):1956–1962.

Heuberger, H., U. Bomme, B. Friedmann, J. Groß, L. Kabelitz, K. Reif, R. Schmücker & P. Torres Londoño 2008. Drogenqualität chinesischer Heilpflanzen aus bayerischem Versuchsanbau im Vergleich zur Importware: Identität, sensorische Eigenschaften, Inhaltsstoffe und Reinheit. *Chinesiche Medizin* 23(3):119–35.

Heuberger, H., U. Bomme, J. Groß, L. Kabelitz, K. Reif & R. Schmücker 2008. Inhaltsstoffgehalte ausgewählter chinesischer Heilpflanzen aus deutschem Versuchsanbau im Vergleich zu Importware aus Asien. *Z Arznei-Gewurzpfla* 13:173–181.

Ishizuka, Y., K. Hayashi & A. Moriya 1998. Studies on the cultivation of *Saposhnikovia divaricata* (Turcz.) Schischkin. (II). Seasonal variation of root growth, methanol extract and constituent contents. *Natural Medicines* 52(2):151–155 (in Japanese).

Japanese Pharmacopoeia Editorial Board 2016. *The Japanese Pharmacopoeia, 17th edition*. Ministry of Health, Labour and Welfare, Tokyo, Japan.

Ji, L. 2014. *Study on the growth and development dynamics and harvest period of Fangfeng in different growth years*. PhD thesis, Gansu Agricultural University, Lanzhou, PRC (in Chinese).

Ji, M., Q. Qi, X. Yaping, W. Peixiang & W. Zhezhi 2005. Occurrence and control of abnormal somatic embryos in *Saposhnikovia divaricata* tissue culture. *Acta Botanica Boreali-occidentalia Sinica* 25(3):552–556 (in Chinese).

Jia, J.-Y., R. Cao, X.-B. Zhang, T.-T. Shi, M. Yang & M.-H. Li 2019. Monitoring of *Saposhnikovia divaricata* planting area based on texture and pop information in Naiman banner. Zhongguo Zhong Yao Za Zhi 44(19):4111–4115 (in Chinese).

Jiang, H., J.M. Yang, G.Z. Jia, H.L. Dai, L. Cao & X.C. Meng 2018. Physical and ecological impacts of chromones of fresh root of *Saposhnikovia divaricata* exposure to high temperature. *Russian Journal of Plant Physiology* 65:680–687.

Kang, T.-J., S.-J. Ahn, T.-J. Ahn, M.R. Cho, H.-Y. Jeon & J.-A. Jeong 2012. Types and damage of thrips occurring on major medicinal crops in Korea. *Korean Journal of Medicinal Crops* 20(6):487–492 (in Korean).

Khan, S. & Y.Sh. Kim 2013. Molecular mechanism of inflammatory signaling and predominant role of *Saposhnikovia divaricata* as anti-inflammatory potential. *Natural Product Sciences* 19(2):120–126.

Kim, J.S. & J.C. Chun 1992. Resistance of the medicinal plant Jiwhang *(Rehmannia glutinosa*) on paraquat. *Korean Journal of Weed Science* 12(4):374–379 (in Korean).

Kim, M., K.-S. Seo & K.W. Yun 2018. Antimicrobial and antioxidant activity of *Saposhnikovia divaricata*, *Peucedanum japonicum* and *Glenhia littoralis*. *Indian Journal of Pharmaceutical Sciences* 80(3):560–565.

Kim, N.-K., H.J. Lee, H.-W. Jeong, S.-M. Go, N.-Y. Kim T.H. Ryu, S.-Y. Cho, M.-R. Park & R.-D. Jeong 2020. First report of cucumber mosaic virus infecting *Ledebouriella seseloides* in Korea. *Journal of Plant Pathology* 102:909–910.

Kim, Y.-G., S.-H. Han, S.H. Lee, Y.-G. Kang, Y.-S. Ahn & C.B. Park 2010. The study on vegetative propagation of *Saposhnikovia divaricata*. *Korean Society of Medicinal Crop Science* 10a:173–174 (in Korean).

Kolomietc, A., N. Nicolaeva, V. Larina & N. Chupakhina 2021. Growing optimization of suspension cultures of medicinal plant cells – Proceedings of the IV International scientific and practical conference "Sustainable development and green growth on the innovation management platform", Kaliningrad, Russia. *E3S Web Conf.* 291:02022.

Korea Food and Drug Administration 2012. *The Korean Pharmacopoeia, 10th edition*. The KFDA Notification No. 2012-129.

Korsun, O.V. 2018. Transboundary demand poses a threat to the plants of the Daurian steppes. *Stepnoi Byulleten'* 51–52:49–51 (in Russian) [Корсун О.В. 2018. Трансграничный спрос создает угрозу растениям Даурских степей // Степной бюллетень. № 51–52. С. 49–51].

Kreiner, J., E. Pang. G.B. Lenon & A.W.H. Yang 2017. *Saposhnikovia divaricata*: a phytochemical, pharmacological, and pharmacokinetic review. *Chinese Journal of Natural Medicines* 15(4):255–264.

Kulishova, I.V., J.M. Yakhtanigova & A.V. Afanasyev 2022. Introduction of medicinal and aromatic plants. In: *Proceedings of the International scientific conference dedicated to the 90th anniversary of the Central Botanical Garden of the National Academy of Sciences of Belarus "Introduction, conservation and use of biological diversity of flora"*, pp. 180–182, Minsk, Belarus (in Russian with English abstract). [Кулишова И.В., Яхтанигова Ж.М., Афанасьев А.В. 2022. Интродукция лекарственных и ароматических растений // Материалы международной научной конференции, посвященной 90-летию Центрального ботанического сада Национальной академии наук Беларуси «Интродукция, сохранение и использование биологического разнообразия флоры». Минск: Белтаможсервис. С. 180–182].

Kuluev, B.R., Z.R. Vershinina, A.V. Knyazev, D.A. Chemeris, A.K. Baymiev, M.I. Chumakov, A.K. Baymiev & A.V. Chemeris 2015. "Plant hairy" roots are important instrumentation for researchers and powerful phytochem-biofactory for manufacturers. *Biomika* 7(2):70–120 (in Russian). [Кулуев Б.Р., Вершинина З.Р., Князев А.В., Чемерис Д.А., Баймиев А.Х., Чумаков М.И., Баймиев А.Х., Чемерис А.В. 2015. "Косматые" корни растений – важный инструментарий для исследователей и мощная фитохимбиофабрика для производственников // Биомика. Т. 7, № 2. С. 70–120].

Lee, G.-S., J.-H. Lee, S.-H. Kang & K.-S. Woo 2001. Thrips species (Thysanoptera: Thripidae) in winter season and their vernal activities on Jeju Island, Korea. *Journal of Asia-Pacific Entomology* 4(2):115–122.

Lee, J.H. & Y. Kwak 2014. First report of anthracnose of *Ledebouriella seseloides* caused by *Colletotrichum gloeosporioides* in Korea. *Journal of Phytopathology* 162(5):342–344.

Li, H.Y., Q.R. Bai, C.Y. Wei, H.B. Li, L.L. Liu & Y. Cai 2017. First report of *Saposhnikovia divaricata* blight caused by *Diaporthe angelicae* in China. *Plant Disease* 101(1):246.

Li, L., M. Geng, Y. Li, Z. Xu, M. Xu & M. Li 2020. Characterization of the complete plastome of *Saposhnikovia divaricata* (Turcz.) Schischk. *Mitochondrial DNA Part B* 5(1):786–787.

Liang, X., X. Liu, X. Zhang, Z. Liu, G. Gokul & J. Zhang 2016. Allelopathic effects of humus forest soil of *Hippophae rhamnoides*, *Caragana korshinskii* and *Amorpha fruticosa* in medicinal plants. *Emirates Journal of Food and Agriculture* 28(7):468–476.

Liu, C., Y.-K. Xu, W.-J. Huang, Z.-S. Tang, P.-W. Kou, Z.-X. Song & S. Li 2022. *Transcriptomic-metabolomic combined analysis of the effects of bolting on the accumulation of lignin in the roots of Fang Feng*. (Preprint) Available at SSRN: https://ssrn.com/abstract=4284472.

Liu, G.X., Q.Q. Wang & D.D. Zhang 2010. Effects of plant litters and soil coverage on seed emergence and early growth of *Saposhnikovia divaricata*. *Pratacultural Science* 27(2):28–31 (in Chinese).

Liu, S.-L., C.-H. Zhang & L.-X. Zhang 2007. Study on quality development analyzing of cultured Radix *Saposhnikovia divaricata* growed three years. *Special Wild Economic Animal and Plant Research* 1:36–38 (in Chinese).

Lyu, L., X. Li, E. Zang, Y. Yan, M. Yang, W. Wang, C. Zhang & M. Li 2022. Specification and grade of Saposhnikoviae Radix (*Saposhnikovia divaricata*). *Chinese Herbal Medicines* 14(4):543–553.

Ma, J.J., B.H. Lu, X. Wang & J. Gao 2015. First report of gray mold of *Saposhnikovia divaricata* caused by *Botrytis cinerea* in Jilin Province, China. *Plant Disease* 99(11):1644.

Ma, X. 2014. *Study on cryopreservation and vitrification of Fangfeng callus*. Master's thesis, Shandong Agricultural University, Shandong, PRC (in Chinese).

Ma, X., J. Zhang & Y. Yu 2013. Vitrification in Fangfeng (*Saposhnikovia divaricata*) tissue culture. *Molecular Plant Breeding* 3:421–430 (in Chinese).

Malyshev, L.I. & G.A. Peshkova 1984. *Features and genesis of the flora of Siberia (Pre-Baikalia and Transbaikalia)*. Nauka, Moscow, 266 pp. (in Russian). [Малышев Л.И., Пешкова Г.А. Особенности и генезис флоры Сибири (Предбайкалье и Забакалье). Москва: Наука. 266 с.].

Men, Y., D. Wang, B. Li, Y. Su & G. Chen 2018. Effects of drought stress on the antioxidant system, osmolytes and secondary metabolites of *Saposhnikovia divaricata* seedlings. *Acta Physiologiae Plantarum* 40:191.

Meng, X., X. Sun, H. Sun & X. Wang 2008. Effects of lateral roots and growth regulator on the quality of *Saposhnikovia divaricata*. *World Science and Technology – Modernization of Traditional Chinese Medicine and Materia Medica* 10(5):68–71 (in Chinese).

Meng, X.-C., H. Sun, X.-L. Sun, Y. Han & X.-J. Wang, 2012. Comparition of pharmacological effects of direct seeding, transplanting and bolting root from *Saposhnikovia divaricata* with the wild Chinese. *Research and Practice on Chinese Medicines* 5:31–33 (in Chinese)

Milentyeva, I.S., V.M. Le, O.V. Kozlova, N.S. Velichkovich, A.M. Fedorova, A.I. Loseva & V.P. Yustratov 2021. Secondary metabolites in *in vitro* cultures of Siberian medicinal plants: content, antioxidant properties, and antimicrobial characteristics. *Food and Raw Materials* 9(1):153–163.

Morino, C., Y. Morita, K. Minami, Y. Nishidono, Y. Nakashima, R. Ozawa, J. Takabayashi, N. Ono, S. Kanaya, T. Tamura, Y. Tezuka & K. Tanaka 2018. Oviposition inhibitor in Umbelliferous medicinal plants for the common yellow swallowtail (*Papilio machaon*). *Journal of Natural Medicines* 72:161–165.

Nam, H.H., Y.J. Seo, B.S. Kim, T.Y. Oh, W.C. Jang & D.Y. Kim 2018. Growth diagnosis with normalized difference vegetation index in medicinal crops. In: *Korean Medicinal Crops Fall Conference Presentation Book*, p. 2. Seoul, Korea.

Nishidono, Y., K. Niwa, A. Kitajima, S. Watanabe, Y. Tezuka, M. Arita, J. Takabayashi & K. Tanaka 2021. α-Linolenic acid in *Papilio machaon* larvae regurgitant induces a defensive response in Apiaceae. *Phytochemistry* 188:112796.

Nishihara, M., K. Nukui, Y. Osumi & H. Shiota 2018. Quality evaluation of Saposhnikoviae Radix (differences between wild-type and cultivated products). *Yakugaku Zasshi* 138:571–579 (in Japanese).

Noh, K.-S., M-O. Yang, E.-J. & Cho 2002. Nitrite scavenging effect of Umbelliferaeceae. *Korean Journal of Food and Cookery Science* 18(1):8–12 (in Korean).

Oh, T.Y., Y.J. Seo, H.H. Nam, B.S. Kim & W.C. Jang 2018. Growth characteristics of *Angelica dahurica*, *Ligusticum sinense*, and *Ledebouriella seseloides* collecting germplasm. In: *Proceedings of the Korean Society of Medicinal Crops Conference*, p. 97, Korea (in Korean).

Okuyama, E., T. Hasegawa, T. Matsushita, H. Fujimoto, M. Ishibashi & M. Yamazaki 2001. Analgesic components of saposhnikovia root (*Saposhnikovia divaricata*). *Chemical and Pharmaceutical Bulletin (Tokyo)* 49(2):154–160.

Otani, M., M. Nishihara & H. Asao 2020. Use of paper pots for *Saposhnikovia divaricata* Schischkin seedlings. *Bulletin of the National Agricultural Research Center* 51:43–47 (in Japanese).

Park, C.-G., C.-B. Park, J.-G. Woo, Y.-K. Kang, A.-J. Choi, J.-H. Lee & S.-M. Kim 2011. Seed characteristics of germplasm in medicinal Umbeliferae plants. In: *Proceedings of the Korean Society of Medicinal Crops Conference*, pp. 216–217, Korea.

Pimenov, M.G. & T.A. Ostroumova 2012. *Umbelliferae of Russia*. KMK Scientific Press, Moscow, 477 pp. (in Russian). [Пименов М.Г., Остроумова Т.А. 2012. Зонтичные (Umbelliferae) России. Москва: КМК. 477 с.].

Polovinkina, S.V. 2022. Morphological features and productivity of *Saposhnikovia divaricata* (Turcz.) Schischkin in the conditions of Irkutsk region. In: *Proceedings of the XI International Research-to-Practice Conference "Climate, Ecology, Agriculture of Eurasia"*, pp. 67–74, Molodezhnyi village, Irkutsk Region (in Russian with English abstract). [Половинкина С.В. 2022. Морфологические особенности и продуктивность *Saposhnikovia divaricata* (Turcz.) Schischkin в условиях Иркутского района // Материалы XI Международной научно-практической конференции «Климат, экология, сельское хозяйство Евразии». п. Молодежный: Иркутский государственный аграрный университет им. Е.Е. Ежевского. С. 67–74].

Prokop'ev, E.P. 2001. *Ecology of plants (individuals, species, ecogroups, life forms)*. Tomsk State University, Tomsk, 340 pp. (in Russian) [Прокопьев Е.П. 2001. Экология растений (особи, виды, экогруппы, жизненные формы. Томск: ТГУ. 340 с.].

Qi, Q. & X. Yaping 2007. Changes of starch and polysaccharides during the somatic embryogenesis and development of *Saposhnikovia divaricata*. *Acta Botanica Boreali-Occidentalia Sinica* 27(2):388–391 (in Chinese).

Qiao, Q. 2005. *Research on somatic embryogenesis and development of Saposhnikovia divaricata*. Master's thesis, Shaanxi Normal University. Shaanxi, PRC (in Chinese).

Qiao, Q. & Y.-P. Xiao 2008. Histological study on the somatic embryogenesis and development of *Saposhnikovia divaricata*. *Guihaia* 1:113–116 (in Chinese).

Qiao, Q., Y.-P. Xiao & Z.-Z. Wang 2005. The effect of plant external hormones on the somatic embryogenesis and embryoid growth of *Saposhnikovia divaricata*. *Journal of Northwest University (Natural Science Edition)* 35(3):316–319 (in Chinese).

Qiao, Q., F.-W. Xing, Y.-P. Xiao & H.-F. Chen 2009. Somatic embryogenesis and *in vitro* flowering in *Saposhnikovia divaricata*. *Journal of Plant Growth Regulation* 28:81–86.

Sato, T., M. Matsuhashi & O. Lida 1992. Fungi isolated from diseased medicinal plants. *Eisei Shikenjo hokoku. Bulletin of National Institute of Hygienic Sciences* 110:60–66 (in Japanese).

Serebryakov, I.G. 1962. *Ecological morphology of plants. Life forms of angiosperms and conifers*. Vysshaja shkola, Moscow, 378 pp. (in Russian). [Серебряков И.Г. 1962. Экологическая морфология растений. Жизненные формы покрытосеменных и хвойных. Москва: Высш. школа. 378 с.].

Sheng, S.-H. & H.-M. Chen 1990. Plant regeneration from protoplasts of suspension cells of *Saposhnikovia divaricata* (Turcz.) Schischk. *Journal of Integrative Plant Biology (Acta Botanica Sinica)* 32(4):268–273 (in Chinese).

Shishkin, B.K. 1951. *Saposhnikovia divaricata*. In: *Flora of the USSR, vol. 17* (B.K. Shishkin, ed.), pp. 54–57, Izdatel'stvo AN SSSR, Moscow, Leningrad (in Russian). [Шишкин Б.К. 1951. *Saposhnikovia divaricate* // Флора СССР / под ред. Б.К. Шишкина. Москва, Ленинград: Изд-во АН СССР. Т. 17. С. 54–57].

Shishmaryov, M.V., T.M. Shishmaryova & T.A. Aseeva 2018. *Development of medicinal plant growing in Baikal nature area*. Izdatel'stvo BSC SB RAS, Ulan-Ude, 152 pp. (in Russian) [Шишмарев М.В., Шишмврева Т.М., Асеева Т.А. 2018. Развитие лекарственного растениеводства на Байкальской природной территории. Улан-Удэ: Изд-во БНЦ СО РАН. 152 с.].

State Pharmacopoeia Commission of P.R. China 2015. *Pharmacopoeia of the People's Republic of China, vol. 1*. China Medical Science Press, Beijing, p. 232.

Stupina, L.A. & N.V. Chernetsova 2018. Germination of introduced seeds of medicinal plants under the conditions of the moderately dry steppe of the Altai region. In: *Proceedings of the XIII International Research to practice conference "Agrarian Science to Agriculture"*, pp. 424–425, Barnaul (in Russian). [Ступина Л.А., Чернецова Н.В. 2018. Всхожесть интродуцированных семян лекарственных растений в условиях умеренно засушливой степи Алтайского края // Сборник материалов XIII Международной научно практической конференции «Аграрная наука – сельскому хозяйству». Барнаул: Алтайский государственный аграрный университет. С. 424–425].

Sun, H. & X.X. Meng 2008. Bolt effect on quality and yield of *Saposhnikovia divaricata* roots. *World Science and Technology-Modernization of Traditional Chinese Medicine and Materia Medica* 10:101–104 (in Chinese).

Sun, J.-B., H. Yang & L.-X. Zhang 2013. Study on correlation between volatile oil and rhizosphere soil from roots of *Saposhnikovia divaricata*. *Chinese Traditional and Herbal Drugs* 44(7):891–895 (in Chinese).

Sun, Z., Y. Wang, Z.-M. Han, Y.-H. Wang, S.-J. Zhao & L.-M. Yang 2023. Isolation, identification and biocontrol potential of rhizospheric fungus of *Saposhnikovia divaricata*. *Biotechnology Bulletin* 1:264–273.

Sung, J.S., C.G. Park, D.H. Kim, J.H. Lee & H.D. Jang 2008. Discrimination of "*Ledebouriella seseloides* (Hoffm.) Wolff" by seed morphological characteristics and selection of cultivated area in South Korea. *Korean Society of Medicinal Crop Science* 2008.11a:177–178 (in Korean).

Tai, J. & S. Cheung 2007. Anti-proliferative and antioxidant activities of *Saposhnikovia divaricata*. *Oncology Reports* 18(1):227–234.

Tomilova, S.V. 2020. *Growth and biosynthetic characteristics of cell cultures from plants-producers of steroid and cardiac glycoside*. PhD Thesis in Biology, Lomonosov Moscow State University, Timiryazev Institute of Plant Physiology RAS, Moscow, 162 pp. (in Russian). [Томилова С.В. 2020. Особенности ростовых и биосинтетических характеристик культур клеток, полученных из растений-продуцентов стероидных и сердечных гликозидов. Диссертация на соискание ученой степени кандидата биологических наук. Москва: МГУ имени М.В. Ломоносова, ИФР РАН. 162 с.].

Tong, W., R. Fan, S. Guo & Y. Chang 2009. Experiment on tissue culture technique of *Saposhnikovia divaricata* (Turcz.) Schischk. *Journal of Northeast Agricultural University* 16(1): 19–24 (in Chinese).

Tsitsilin, A.N. 2022. The introduction of the *Saposhnikovia divaricata* (Turcz.) Schischk. in the VILAR Botanical Garden. In: *Proceedings of the All-Russian scientific conference with international participation dedicated to the 85th anniversary of the Botanical garden named after Professor B.M. Kozo-Polyansky and the 80th anniversary of E.A. Nikolaev "Modern problems of introduction and conservation of plant biodiversity"*, pp. 118–122, Voronezh (in Russian with English abstract). [Цицилин А.Н. 2022. Интродукция сапожниковии растопыренной (*Saposhnikovia divaricata* (Turcz.) Schischk.) в ботаническом саду ВИЛАР // Материалы Всероссийской научной конференции с международным участием, посвященной 85-летию Ботанического сада имени профессора Б.М. Козо-Полянского и 80-летию Е.А. Николаева «Современные проблемы интродукции и сохранения биоразнообразия растений». Воронеж: Цифровая полиграфия. С. 118–122].

Tsybikova, O.M., M.M. Namsaraeva & O.Yu. Davydova 2022. Results of phytotesting on seeds of saposhnikovia spayed (*Saposhnikovia divaricata* (Turcz.) Schischk.). In: *Proceedings of the International research to practice conference dedicated to the Day of Russian Science "Sustainable development of rural territories and agricultural production at the present stage"*, pp. 283–289, Ulan-Ude (in Russian with English summary). [Цыбикова О.М., Намсараева М.М., Давылова О.Ю. 2022. Результаты фитотестирования семян сапожниковии растопыренной (*Saposhnikovia divaricata* (Turcz.) Schischk.) // Материалы Международной научно-практической конференции, посвященной Дню Российской науки «Устойчивое развитие сельских территорий и аграрного производства на современном этапе». Улан-Удэ: Бурятская государственная сельскохозяйственная академия имени В.Р. Филиппова. С. 283–289].

Urbagarova, B.M., E.E. Shults, V.V. Taraskin, L.D. Radnaeva, T.N. Petrova, T.V. Rybalova, T.S. Frolova, A.G. Pokrovskii & J. Ganbaatar 2020. Chromones and coumarins from *Saposhnikovia divaricata* (Turcz.) Schischk. growing in Buryatia and Mongolia and their cytotoxicity. *Journal of Ethnopharmacology* 261:112517.

Urbagarova, B.M., V.V. Taraskin, T.V. Elisafenko, E.E. Shults, E.A. Korolyuk & L.D. Radnaeva 2021. Quantitative content of the main active substances in the roots of the natural and introduced plant *Saposhnikovia divaricata* (Turcz.) Schischk. *Khimiya Rastitel'nogo Syr'ya* 3:143–151 (in Russian with English summary). [Урбагарова Б.М., Тараскин В.В.,

Елисафенко Т.В., Шульц Э.Э., Королюк Е.А., Раднаева Л.Д. 2021. Содержание основных действующих веществ в корнях природного и интродуцированного растения *Saposhnikovia divaricata* (Turcz.) Schischk. // Химия растительного сырья. № 3. С. 143–151].

Urgamal, M. 2015. *Saposhnikovia divaricata*. In: *Mongolian Red Book* (Ts. Shiirèvdamba, Ya. Adiya, E. Ganbold & G. Tserenkhand, ed.), pp. 379–380, Admon Print, Ulaanbaatar, Mongolia.

Vervliet, G., M. Holsters, H. Teuchy, M. van Montagu & J. Schell 1975. Characterization of different plaque-forming and defective temperate phages in *Agrobacterium* strains. *Journal of General Virology* 26(1):33–48.

Wan, Y., G. Li, G. Wang & L. Sun 1999. Analysis and identification of components of Fangfeng from undrawn stems and Fangfeng with drawn stems. *Clinical Medicine (Chinese Journal for Clinicians)* 6:54 (in Chinese).

Wang, X., X. Jiang, X. Yu, H. Liu, Y. Tao, G. Jiang & M. Hong 2017. Cimifugin suppresses allergic inflammation by reducing epithrlial derived initiative key factors via regulating tight functions. *Journal of Cellular and Molecular Medicine* 22(11):2926–2936.

Wang, Y., C.Y. Zeng, X.R. Chen & C.D. Yang 2015. First report of leaf blight on *Saposhnikovia divaricata* by *Pseudomonas viridiflava* in Gansu, China. *Plant Disease* 99(2):281.

Wang, Z.-H., J.-H. Song, S.-X. Feng & H.-W. Wang 2013. Effects of sowing date and eradication of reed head on bolting and yield of *Saposhnikovia divaricata*. *Hubei Agricultural Sciences* 20:4977–4979 (in Chinese).

Wu, S. 1963. Preliminary study on the fennel borer in Zuojia area of Jilin. *Journal of Plant Protection* 2:276 (in Chinese).

Xu, M. 2016. *Effects of water stress on Fangfeng quality, physiological and ecological characteristics and key enzyme activities*. PhD thesis, Jilin Agricultural University, Jilin (in Chinese).

Xu, Y.-H., Z.-J. Huang, S.-L. Liu, H. Yang & C. Wang 2016. A new *Saposhnikovia divaricata* cultivar 'Guanfangfeng 1'. *Acta Horticulturae Sinica* 43(6):1221–1222 (in Chinese).

Yang, J.-M., H. Jiang, H.-L. Dai, Z.-W. Wang, G.-Z. Jia & X.-C. Meng 2017. Feeble antipyretic, analgesic, and anti-inflammatory activities were found with regular dose 4'-O-β-D-glucosyl-5-O-Methylvisamminol, one of the conventional marker compounds for quality evaluation of radix Saposhnikoviae. *Pharmacognosy Magazine* 13(49):168–174.

Yang, M., C.C. Wang, W.L. Wang, J.P. Xu, J. Wang, C.H. Zhang & M.H. Li 2020. *Saposhnikovia divaricata* – an ethnopharmacological, phytochemical and pharmacological review. *Chinese Journal of Integrative Medicine* 26:873–880.

Yang, S. 1992. *The divine farmer's material medica: a translation of the Shan Nong Ben Cao Jing*. Blue Poppy Enterprises, Inc., Portland, 214 pp.

Yang, X., Y. Wu, Z. Qu, Y. Ma & X. Cao 2018. Chemical constituents of the secondary metabolites of endophytic fungi DL02 from *Saposhnikovia divaricata* and their biological activities. *Chinese Traditional Patent Medicine* 12:1325–1328 (in Chinese).

Yao, G., Y. Shu & S. Chen 2000. Diagnosis of blight and *Fusarium* wilt. *Inner Mongolia Grass Industry* 2:8–9 (in Chinese).

Yi, S., H. Lu, W. Wang, G. Wang, T. Xu, M. Li, F. Gu, C. Chen, B. Han & D. Liu 2022. The chloroplast genome of wild *Saposhnikovia divaricata*: genomic features, comparative analysis, and phylogenetic relationships. *Genes* 13:931.

Yoon, S.T., D.J. Lee & Y.H. Kim 1999. The technology for increasing viability by priming treatment and plant growth regulators in medicinal plants. *Journal of the Korean Society of International Agriculture* 11(1):85–95.

Yu, X., Y. Niu, J. Zheng, H. Liu, G. Jiang, J. Chen & M. Hong 2015. Radix Saposhnikovia extract suppresses mouse allergic contact dermatitis by regulating dendritic-cell-activated Th1 cells. *Phytomedicine* 22(13):1150–1158.

Yuan, X.-Y., X. Wang, P.-Y. Guo, J.-H. Zhang & Y.-Y. Wen 2011. Study on phytotoxicity symptoms of foliar application herbicide to Chinese medicinal herbs of *Saposhnikovia divaricata* (Turcz.) Schischk. *Journal of Shanxi Agricultural Sciences* 39(3):262–265, 275.

Yugrina, P.N., B.M. Urbagarova & T.V. Elisafenko 2021. Morphological features of fruits and seeds of *Saposhnikovia divaricata* (Apiaceae). In: Proceedings of the Northern Asia Plant Diversity, Novosibirsk, Russia. *Bio Web of Conferences* 38:00141.

Zhang, L., A.S. Ravipati, S.R. Koyyalamudi, S.C. Jeong, N. Reddy, J. Bartlett, P.T. Smith, M. Cruz, M.C. Monteiro, Á. Melguizo, E. Jiménez & F. Vicente 2013. Anti-fungal and anti-bacterial activities of ethanol extracts of selected traditional Chinese medicinal herbs. *Asian Pacific Journal of Tropical Medicine* 6(9):673–681.

Zhang, M., W. Wang, Q. Liu, E. Zang, L. Wu, G. Hu & M. Li 2023. Transcriptome analysis of *Saposhnikovia divaricata* and mining of bolting and flowering genes. *Chinese Herbal Medicines* 15(4):574–587.

Zheng, Z. 2019. *Studies on the chemical constituents of secondary metabolites of Saposhnikovia divaricata* (Turcz.) Schischk. *Endophytic Fungus Alternaria* sp.*, Polygonum aviculare* L. *and Notopterygium franchetii* De Boiss. MD Thesis, Lanzhou University of Technology, Lanzhou (in Chinese).

Zhi, G. & L. Ming-yuan 1997. Study on comparing morphology and anatomy of roots system of wild and cultivated *Saposhnikovia divaricata*. *Bulletin of Botanical Research* 17(3):344–347.

Zhong-ling, C. & C. Hui-Min 1996. Somatic embryogenesis in cell suspension culture of *Saposhnikovia divaricata*. *Journal of Integrative Plant Biology (Acta Botanica Sinica)* 38(5):379–383 (in Chinese).

Zhou, Y. 2009. *Research on dormant physiology and cultivation techniques of Saposhnikovia divaricata seeds*. PhD thesis, Northeast Forestry University, Harbin (in Chinese).

Zhou, Y., M. Zhao & Y. Zhao 2009. Seed dormancy mechanism for *Saposhnikovia divaricata*. *Journal of Northeast Forestry University* 3:16–17 (in Chinese).

Zubova, K.A. 2020. Cultivation and use of medicinal plants of the South Siberian Botanical Garden. In: *Proceedings of the X International Research-to-Practice Conference "Young Scientists solving current problems of science"*, pp. 69–71, Vesta, Vladikavkaz (in Russian with English abstract). [Зубова К.А. 2020. Выращивание и использование лекарственных растений Южно-сибирского ботанического сада // Материалы X Международной научно-практической конференции «Молодые ученые в решении актуальных проблем науки». Владикавказ: Веста. С. 69–71].