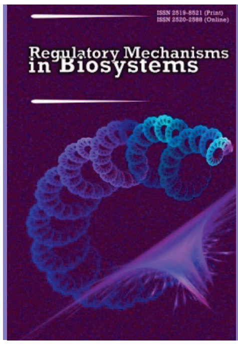

Regulatory Mechanisms in Biosystems

ISSN 2519-8521 (Print)
ISSN 2520-2588 (Online)
Regul. Mech. Biosyst.,
2024, 15(3), 599–605
doi: 10.15421/022484

Biological characteristics of the extremely rare, narrow-range plant species *Potentilla porphyrantha* (Rosaceae)

K. Janjughazyan, A. Ghukasyan, L. Khachatryan, H. Hovhannisyan, Z. Hovakimyan

Institute of Botany after A. Takhtajan of the National Academy of Sciences of Armenia, Yerevan, Armenia

Article info

Received 14.06.2024
Received in revised form 26.07.2024
Accepted 09.08.2024

Institute of Botany after A. Takhtajan of the National Academy of Sciences of Armenia, Acharyan st., 1, Yerevan, 0063, Armenia. Tel: +374-955-435-89. E-mail: anyaghukasyan@gmail.com

Janjughazyan, K., Ghukasyan, A., Khachatryan, L., Hovhannisyan, H., & Hovakimyan, Z. (2024). Biological characteristics of the extremely rare, narrow-range plant species Potentilla porphyrantha (Rosaceae). Regulatory Mechanisms in Biosystems, 15(3), 599–605. doi:10.15421/022484

Potentilla porphyrantha Juz. (Rosaceae) is a very rare stenotopic species with a fragmented distribution that includes small subpopulations in Armenia, Nakhichevan and Northern Iran. It has been assessed and listed in the Red Data Book of Armenia as a Critically Endangered species. The main threats to this species are anthropogenic factors (mainly the mining industry) and forecasted climate change. The purpose of this work was to identify the adaptive potential of the species, explore its conservation possibilities in ex situ conditions, assess the feasibility of its reintroduction into natural habitats, and evaluate the threat to natural populations from predicted climate change. The karyology of this species was investigated. The number of chromosomes and karyotype were determined using mitotic chromosome preparations from metaphase stages. During karyological examination of *P. porphyrantha*, it was determined that the diploid cytorace (2x), 2n =14 of this species grows in the alpine belt. Eco-physiological investigations were conducted to estimate the species' potential for adaptation to new environmental conditions. The study was carried out both in the species' natural habitat and in introduced environments, specifically the semi-desert and meadow-steppe belts (Yerevan and Sevan Botanical Gardens). Special attention was given to the species' potential adaptation to forecast climate changes by using meteorological data from both natural populations and the botanical gardens where the species was grown ex-situ. The individual features of specimens in different conditions were compared. The results showed that specimens growing in the meadow-steppe belt (Sevan Botanical Garden, 1900 m) are in very good condition, comparable to those in natural populations, and can be used for reintroduction into natural habitats.

Keywords: chromosome number; climate change impact; total water content; photosynthetic productivity; intensity of transpiration; reintroduction to nature.

Introduction

The conservation of plant species and ecosystems is a major focus of international environmental conventions (Giulietti et al., 2005; Khan et al., 2013). Armenia is a critical biodiversity hotspot and a key part of the Caucasus eco-corridor that connects the Caucasus and Iranian montane ecosystems. It lies at the junction of two biogeographical provinces: the Caucasus to the north and the Irano-Anatolian to the south. Conserving plant diversity both *in situ* and *ex situ* is a crucial task mandated by the Convention on Biological Diversity. Recently, Armenia's ecosystems and biodiversity have faced significant anthropogenic pressures, including deforestation, overexploitation of water and biological resources, and economic development. This has led to ecosystem degradation, destruction and loss of natural habitats, diminished species ranges, and changes in population structures (Giam et al., 2010; Fayvush et al., 2023).

Climate change also poses a potential threat to biodiversity, though it requires further research and analysis. Studies indicate that climate change will particularly impact rare species with narrow ecological ranges, pushing some endangered species towards extinction (Fayvush, 2010). Botanical gardens and arboretums play a crucial role in conserving rare and endangered plant species. The creation and maintenance of *ex situ* collections are key aspects of contemporary botanical garden activities.

Genus *Potentilla* L. is one of the largest genera in the Rosaceae family, comprising about 500 species predominantly found in the Northern Hemisphere, especially in temperate and boreal regions (Mabberley, 2017). The genus *Potentilla* is highly polymorphic due to its wide geographic distribution and significant ecological amplitude. In the third volume of the Flora of Armenia (Fedorov, 1958) lists 29 species of *Potentilla*. Through a critical revision of the *Potentilla* genus, Khanjyan (2009) identifies 3 new, rare species for the flora of Armenia: *P. erecta* (L.) Hampe, *P. cryptophyla* Bornm. and *P. holoceuca* Boiss., the latter being a new species for the flora of the Caucasus. Thus, according to the latest treatment, 32 species of the *Potentilla* genus grow in the flora of Armenia, of which 3 species are included in the second edition of the Red Book of Armenia: *P. porphyrantha* Juz., *P. erecta* and *P. cryptophyla* (Tamanyan et al., 2010).

Potentilla porphyrantha is an extremely rare and taxonomically significant plant species endemic to South Transcaucasia. Its distribution is confined to Armenia (where only five small populations were previously known), the Nakhichevan Republic (one population), and Northern Iran (three populations) (Noroozi et al., 2008; Tamanyan et al., 2010; Sadeghi et al., 2021). Due to its rarity, it is listed in the Critically Endangered category of the Red Book of Plants of Armenia (Tamanyan et al., 2010). This species grows in the alpine belt at elevations of 3,300–3,500 meters above sea level, on rocky and stony slopes, screes, and "chingils," flowering from July to August and fruiting from August to September. Most representatives of the genus *Potentilla* have yellow or white flowers. However, this species, along with 2–3 other closely related species from the section *Persicae*, has pink flowers (Fig. 1). It is a perennial herbaceous plant with a caudex. The aerial part consists of annual flowering shoots 6–15 cm in height. The basal leaves are digitate, with five thick obovate lobes and cuneate base, while the cauline leaves are tripartite. The inflorescence is loose, with 5–15 pentamerous, bright purple flowers that have distinct dark veins. The fruit a multinucula. It should be noted that Tamamshyan (1954) questioned the species status of *P. porphyrantha*, considering it a synonym of the previously described *P. cryptophyla*, however, Khanjyan (2009) confirms their differences, indicating that *P. porphyrantha* has a powerful, blackish, many-headed upper part of the rhizome developing very short stem shoots covered at the top with brown, almost black stipule remnants, whereas *P. cryptophyla* has a somewhat thick but not powerful, light brown upper part of the rhizome developing not such short stem shoots covered at the top with light brown stipule remnants. Besides these features, Khanjyan (2009) points out that *P. porphyrantha* has comparatively short leaf petioles, strongly shortened stems, and intensely colored petals. This species differs significantly from the closely related species *P. petraea* Willd. ex Schlect. and *P. cryptophila* Bornm. by the color of its petals, the height of its stems, and form of its leaves.

Fig. 1. *Potentilla porphyrantha* in the alpine belt (Mt. Amulsar, Armenia)

Fig. 2. Map of distribution of *Potentilla porphyrantha*

The international mining company Lydian International (later Lydian Armenia), in collaboration with the staff of the Institute of Botany of the National Academy of Sciences of Armenia, conducted an Environmental Impact Assessment (EIA) on Mt. Amulsar (alpine belt) to obtain a license for developing a gold deposit. During the EIA, a population of *P. porphyrantha* was discovered. Researchers from the Institute of Botany organized comprehensive studies of this species to explore possibilities for its reproduction, preservation, and subsequent reintroduction. The results of these studies are presented in this article.

Material and methods

The material for the research (seeds and live plants) was collected in Armenia on Mt. Amulsar (39°44'25" N, 45°42'19" E). Live plants were collected for the herbarium (10 samples) and for cultivation in meadow-steppe and semi-desert belts (Sevan and Yerevan Botanical Gardens, approximately 2000 samples from the locality which will be destroyed during mining activity). The formal identification of the plant material used in our study was undertaken by Dr. G. Fayvush. Herbarium specimens are stored in the herbarium of the Institute of Botany named after A. Takhtajan (ERE). Voucher specimens are stored and deposited at the Herbarium of the Institute of Botany named after A. Takhtajan NAS RA (ERE: 193406, 193408): Armenia, Vayots Dzor region, Amulsar mnt., Artavazdes peak, cliffs. 39°43'37" N, 45°42'59" E, 2990 m a.s.l. 18 Jul 2016. Leg. G. Fayvush, K. Janjughasyan. Det. George Fayvush. Live plants are grown in meadow-steppe and semi-desert belts (Sevan and Yerevan Botanical gardens) in rock gardens and in green houses. The collected seeds and live plants were used for cultivation and reproduction in *ex situ* conditions in the Sevan and Yerevan botanical gardens, the seeds were also used in carrying out karyological studies. Live plants have also been used for eco-physiological research. According to the Decree of the Government of Armenia N-781 dated July 31, 2014, species included in the Red Book of Plants of Armenia can be collected only for scientific purposes by employees of specially authorized organizations (including the Institute of Botany named after A. Takhtajan NAS RA) for a herbarium or transplanted into the territory of botanical gardens or specially protected natural areas. The studies were carried out in accordance with this regulation. The Institute of Botany named after A. Takhtajan has permission of the Ministry of Environment RA for collecting plants on the whole territory of the Republic. Climatic diagrams of localities where *Potentilla porphyrantha* was prepared by Breckle Siegmar – Walter, mainly from "worldclimate.com"-data.

Research on *P. porphyrantha* was conducted in three localities: in a natural conditions in the alpine belt (Mt. Amulsar) and in *ex situ* conditions in meadow-steppe and semi-desert belts (Sevan and Yerevan Botanical Gardens). Table 1 shows data on average annual and seasonal temperatures and precipitation, and based on climate change scenarios in Armenia, forecasts are made for changes in these indicators until 2100.

Table 1
Forecasted changes in air temperature and precipitation in places where *Potentilla porphyrantha* grows (semi-desert, meadow-steppe and alpine belts)

Locality	1961–1990		2011–2040		2041–2070		2071–2100	
	T, °C	P, mm	T, °C	P, mm	T, °C	P, mm	T, °C	P, mm
Semi-desert belt	8.4	502	10.0	486	11.7	472	13.1	458
Meadow-steppe belt	3.3	660	4.9	640	6.6	621	8.0	603
Alpine belt	1.6	732	3.2	713	4.9	692	6.3	672

Climatic diagrams for three localities (alpine, meadow-steppe and semi-desert belts) are provided in Figure 3.

The study of the growth and development of *P. porphyrantha* was carried out on plants of different ages under natural conditions in the alpine belt (on Mt. Amulsar) and under *ex situ* conditions in meadow-steppe and semi-desert belts (Sevan and Yerevan Botanical Gardens), in rock gardens and as a potted plant in a greenhouse (Fig. 4a, 4b, 4c). The main attention was paid to the annual growth of plant shoots and the area they occupy. Measurements were carried out twice a year – in spring and autumn.

Karyological investigations were conducted using mitotic chromosome preparations from metaphase stages, obtained from meristematic cells in root tips. The seeds were germinated on damp filter paper within Petri dishes in a laboratory setting (19–21 °C). The root tips underwent a pretreatment in a 0.4% colchicine solution for a duration of 2 hours, followed by fixation in a mixture of alcohol and glacial acetic acid at a 3:1 ratio, held at room temperature for at least 2 hours. Following a hydrolysis step in 1 N HCl at 60 °C for 10–15 minutes, the root tips were subjected to staining with Schiff reagent for 1.5 hours. Subsequently, the root tips were gently squashed onto a glass slide along with 45% acetic acid. The prepared slides were sequentially immersed in butyl alcohol for 5 minutes, followed by xylene for another 5 minutes, before being embedded in Canadian balsam. For chromosome counting, a minimum of 10 plates of chromosome preparations were meticulously examined.

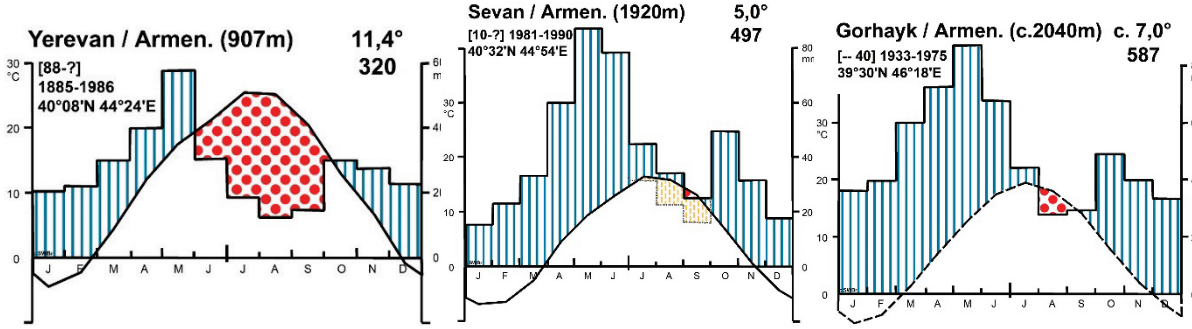

Fig. 3. Climatic diagrams of localities where *Potentilla porphyrantha* was investigated

Fig. 4. *Potentilla porphyrantha* in meadow-steppe belt (Sevan Botanical Garden): *a* and *b* – in rock garden, *c* – in green house

The determination of chromosome numbers and the characterization of species karyotypes were performed using a Photomicroscope (AmScope 2000xLED Lab Trinocular Compound Microscope SKU: T120B-5M, China, 2020) equipped with an oil immersion objective (×100). Photomicrographs were captured using the same microscope setup. We follow the scheme of chromosome morphology and terminology presented by (Agapova & Grif, 1982). The centromere index of chromosomes (Ic) was determined by a formula:

$$\mathbf{I}^c = \frac{\boldsymbol{S}}{\boldsymbol{S}+\boldsymbol{L}}$$

where: S – the short arm of the chromosome, L – the long arm of the chromosome.

The investigation of the eco-physiological characteristics of *P. porphyrantha* in Armenia has been carried out for the first time. The studies of total water content, the intensity of transpiration and photosynthetic productivity were conducted. All the measurements were taken in the period between 1100 and 1300. Each measurement was taken with 3 repetitions and in 3 variants (7–10 shoots were chosen for each sample). Physiological research was conducted by well-known methods (Ghukasyan et al., 2023; Akopian et al., 2023). The presented data represent statistically processed average results of the analysis.

Fresh samples were weighed immediately (KERN ABS220-4N, Kern & Sohn, Germany, 2022) and dried in a thermostat under (Binder BF-56, Binder GmbH, Germany, 2022) 105 ℃, to determine the whole water content in the leaves.

The water deficit was determined based on the principle of leaf water saturation. One gram of the received circles was weighed and then placed in a Petri dish filled with distilled water. After 2 hours, the circles were removed, dried with filter paper and weighed again. To ensure that the leaves were fully saturated with water, they were placed back in the Petri dish for an additional 30 minutes, then removed again, dried and weighed. This process was continued until the weight of the sample no longer changed and the leaves were considered to be fully saturated. The last weighing data was used as the final result. After that, these leaf circles were dried in a thermostat at 105 °C for 5 hours, weighed, and then dried again up to stable weight.

30% solution of sucrose was prepared and checked with a refractometer (HI96801, Hanna Instruments, Germany, 2021). 1.5 mL of 30% sucrose was poured into the pre-weighed weighing bottle, the lid tightly closed and weighed again. 20 leaves were cut from the four sides of the middle part of the tree, the circles removed with a cutter bunch, they were poured into the weighing bottle with the tip of a metal needle, without sticking to the sucrose solution, and the weighing bottle reweighed with its entire content. Subtracting the weight of weighing bottle and sucrose from this result (the result of the second weighing) gives the weight of the leaf circles. The plates remained in the solution for 2 hours, during which the free water of the leaf tissue passed into the sucrose solution and lowered its density. The solution was stirred with a glass rod, then 1–2 drops were transferred into the refractometer chamber, and the density after the experiment recorded.

The intensity of transpiration of the leaves was determined by rapid weighing with an analytical balance ABS 220-4N (Kern & Sohn, Germany, 2022). The leaf material was cut with scissors and quickly weighed with an analytical balance, after 5 minutes the weighing was repeated.

The photosynthetic productivity was also measured during this research by the method of leaf halves, the essence of which is the determination of the increase in the weight of the plant mass in per unit area as a result of photosynthesis in a certain time. For this purpose, leaves were selected from the 4 sides of the middle part of the trees, the number of which should not be less than 20. Half of the leaves were cut along the length of the main vein and placed in a bowl filled with water for 0.5 hours to saturate the tissue with water. Then, 100 circles of leaves were removed, divided into equal number of groups and dried in a thermostat for 4–6 hours at 105 ℃. This determines the initial dry weight per unit leaf area (mg/dm^2). The other half of the leaf with the petiole remained on the plant for several hours (4–5 h), after which the dry weight of their surface (mg/dm^2) was determined as described above. The amount of dry material accumulated during photosynthesis was determined by the difference between the dry weight of the last and the first determinations, which, divided by the time between the determinations, expresses the photosynthetic productivity in mg/dm^2, hour.

To determine the leaf surface area, the leaves were laid out on paper and their contours were outlined, cut out and weighed. A square of 100 sm^2 was cut out of the same paper and weighed.

To assess the threat to the existence of the *P. porphyrantha* population in Armenia, we used the climate change forecasts given in the National Communications under the UN Framework Convention on Climate Change (Fayvush, 2010, 2015; Melkonyan & Gevorkyan, 2020).

Results

In the course of scientific research on the rare stenotopic species *P. porphyrantha* at the Institute of Botany, the following results were obtained. The growing conditions of *P. porphyrantha* in three localities (in the natural conditions in the alpine belt (Mt. Amulsar) and in *ex situ* conditions in meadow-steppe and semi-desert belts (Sevan and Yerevan Botanical Gardens) differ significantly, especially conditions in the semi-desert belt. The main differences arise from the substantial variation in altitudes: semi-desert belt is at 1240 m, meadow-steppe belt at 1920 m, and alpine belt at 2450–3020 m a.s.l.

In the meadow-steppe belt, where the plants are in favorable climatic and edaphic conditions in the absence of competition from other plant species, the most intensive growth and high seed productivity were observed. At the same time, the seeds had a high degree of germination – in the first year up to 100%, then when the seeds were stored in different conditions, their germination naturally decreased. As a result of studies of degree of germination, it was shown that the main limiting factor for the growth and development of *P. porphyrantha* in natural conditions of the alpine belt is the insufficiency of edaphic conditions and competition from other plant species. In the semi-desert belt, the growth and development of plants was limited by high temperatures and very dry air. These factors were not mitigated even by regular watering and sprinkling. It turned out that the conditions of the meadow-steppe belt are optimal for growing this species and can serve as a place for their reproduction with subsequent return to nature.

During karyological examination of *P. porphyrantha*, it was determined that the diploid cytorace (2x), 2n = 14 of this species grows in alpine belt, on Mt. Amulsar (Fig. 5a). The karyotype is symmetric (Fig. 5b) with very small metacentric chromosomes. The size of chromosomes varies from 0.76 to 1.54 µm. TF Index = 49.67%, the karyotype's formula is 2n = 14 M, and length of all chromosomes is 13.85 µm.

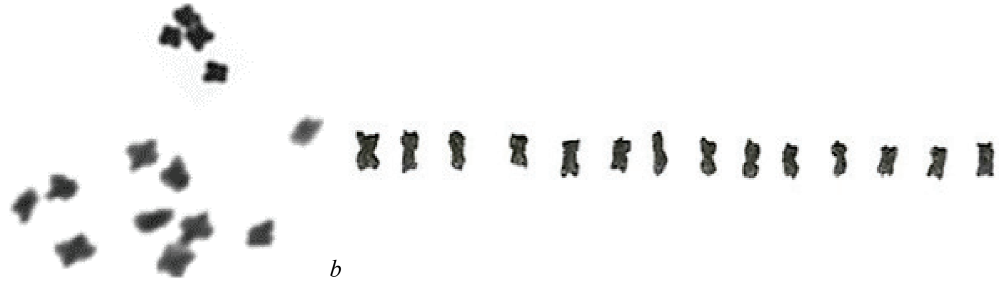

Fig. 5. Karyological peculiarity of *Potentilla porphyrantha*: *a* – metaphase plate (2n = 14), *b* – karyotype

The examination of the biostructural characteristics of high-altitude plants holds significance in elucidating their adaptation mechanisms and ensuring their reproductive success. The altitude factor plays a pivotal role in determining plant vitality, growth, and the intensity and efficiency of developmental processes. This is explained by the fact that with height the tension of the abiotic factors of the environment changes, as well as the edaphic conditions. Under conditions of constant changes in environmental factors, certain changes occur both in the photosynthetic apparatus and its functional activity, as well as in the water regime of plants, which are self-regulating in nature and aimed at ensuring the normal life activity of plants. Consequently, investigations into the water regulation, transpiration rates, and photosynthetic activities of plants across diverse microclimatic conditions represent a crucial ecophysiological problem.

A study was conducted on the ecophysiological parameters of the species *P. porphyrantha*, including water regulation (free and bound water, water deficiency), transpiration rates, and photosynthetic efficiency, both in their natural habitat and when introduction to semi-desert and meadow-steppe belt (Yerevan and Sevan Botanical Gardens). This study was conducted on the principle of preserving the integrity of the plant organism (Table 2).

Table 2
The average values of the eco-physiological indicators of *Potentilla porphyrantha* in 2021–2023 (mean ± standard deviation, n = 9)

Locality and elevation, m a.s.l.	Water content, %	Free water, %	Bound water, %	Ration of free and bound water	Water deficit, %	Intensity of transpiration, mg CO_2 dm^2/ hour	Photosynthetic productivity, mg/g wet weight, hour
2900 m, alpine belt	75.11 ± 0.55^a	51.41 ± 0.43^a	23.70 ± 0.18^a	2.163 ± 0.017^a	14.51 ± 0.44^a	387.12 ± 0.10^a	3.62 ± 0.17^a
1900 m, meadow-steppe belt	69.90 ± 1.25^b	40.92 ± 0.70^b	28.98 ± 0.55^b	1.408 ± 0.004^b	21.23 ± 0.61^b	433.23 ± 0.56^b	3.11 ± 0.11^b
1250 m, semi-desert belt	67.53 ± 0.82^b	37.72 ± 0.36^c	29.81 ± 0.47^b	1.260 ± 0.011^c	24.34 ± 0.74^c	419.42 ± 0.67^c	2.21 ± 0.11^c

Discussion

The Amulsar mountain massif is located in the Vayots Dzor region of Armenia at an altitude of slightly more than 3000 m above sea level. The mining company Lydian Armenia has received permission for its plans to open an open pit gold mine there. *Potentilla porphyrantha* is a stenotopic species that grows here in cracks in volcanic rocks at an altitude of 2450 to 3200 m above sea level. As studies have shown, the subpopulation on Mt. Amulsar is obviously the largest in Armenia – more than 7,500 specimens of different ages were counted. The studies on growth and reproduction of *P. porphyrantha* were carried out in the alpine belt (on Mt. Amulsar), in the meadow-steppe belt (Sevan Botanical Garden in a greenhouse and on a specially created rockery) and in the semi-desert belt (Yerevan Botanical Garden). It was shown that this species perfectly adapted to the conditions of the meadow-steppe belt, grows superbly and reproduces by seeds in rockery conditions. In the greenhouse conditions, the plants also adapted well, bloomed and gave full-fledged seeds with high germination (more than 95%), however, some violations in the growth patterns were noted. In the semi-desert belt, the species apparently did not adapt well to climatic conditions, grew and developed for 2–3 years, after which the plants died, and seed reproduction was suppressed. Thus, it was found that in the conditions of the meadow-steppe belt it is possible to preserve and even increase the number of cultivated plants in order to return them to nature after the mining is completed, as well as for use in the flower decoration of Armenian settlements with similar climatic conditions.

In the polymorphic genus *Potentilla*, a polyploid series was recorded: 2n = 14, 28, 35, 42, 56, 63, 70 with a base number of chromosomes x = 7, moreover, among the species of the genus, di-, tetra- and hexaploid cytoraces are more common (Goswami & Matfield, 1974; Delgado et al., 2000) and pentaploid and octaploid cytoraces are somewhat less common (Měsíček & Soják, 1992; Delgado et al., 2000; Ilnicki & Kolodziejek, 2008). During karyological examination of *P. porphyrantha* growing on Mt. Amulsar (Armenia) we identified a diploid cytorace (2x), 2n = 14, the number of chromosomes was given earlier by Ghukasyan & Janjughazyan (2015). The karyotype is symmetrical with very small metacentric chromosomes, 0.76–1.54 µm in size.

The formula of the karyotype is 2n = 14 M.

Symmetry index TF = 49.67%, total chromosome length is 13.85 µm. Unfortunately, we did not have the opportunity to compare the obtained data with the karyological data of other species of the section *Persicae*. On the other hand, the basic chromosome number x = 7 and the diploid cytorace (2n = 14) are very characteristic of many species of the genus *Potentilla* from other sections (Elkington, 1969; Smith, 1971; Rani et al., 2012). That is, the chromosome number of the studied species, established in the course of our research, undoubtedly confirms its belonging to the genus *Potentilla*, despite the color of the flowers, which is uncharacteristic for the genus.

After the transplantation of *P. porphyrantha* plants from alpine belt to the semi-desert (1230 m a.s.l.) and meadow-steppe belts (1940 m a.s.l.) (Yerevan and Sevan Botanical Gardens), along with observations of the growth and development of plants in the new conditions, palynological studies to clarify the viability of plants in new conditions were conducted. Namely, morphological changes and pollen fertility were determined. It was shown that pollen grains in *in-situ* conditions in the alpine belt are slightly larger than in the meadow-steppe belt, while in the semi-desert belt they are much smaller. It was also shown that in plants from the alpine belt and the meadow-steppe belt, pollen grains are distinguished by high fertility – more than 96%, and in the semi-desert belt, fertility is much lower (78%) (Janjughazyan, 2018). That is, from a palinological point of view, the conditions of the meadow-steppe belt had little effect on the pollen of the studied species, while the much hotter and drier conditions of the semi-desert belt largely inhibited the processes of pollen formation.

In most investigations devoted to the study of eco-physiological characteristics of plants, special attention is usually paid to the peculiarities of the total water content, because water availability and the state of water primarily determine the physiological activity of plants and their adaptability in various growing conditions. Not less important for assessing the physiological activity and the success of plant adaptation to new growing conditions are indicators of the intensity of transpiration and photosynthesis. The indicators of the total water content and the intensity of transpiration and photosynthetic productivity of the studied species in the conditions of the alpine belt and in the semi-desert and meadow-steppe belts were studied. It is shown that under the conditions of the semi-desert belt, plants are in a state of stress, while the indicators of plants in the meadow-steppe belt are close to those of plants from *in situ* conditions. We have conducted similar eco-physiological studies in the alpine belt on the Geghama Mountains of Armenia (Akopian et al., 2022). The findings from these studies align quite closely with our data regarding *P. porphyrantha*. Despite the artificial irrigation conditions in the semi-desert and meadow-steppe belts, plants from the natural habitat on alpine belt exhibited higher levels of total water content and photosynthetic productivity.

Furthermore, indicators of water deficit and transpiration intensity displayed an inverse relationship. As the altitude of the area increased, the values of these indicators decreased. This pattern was also observed in many other plant species examined in the alpine zone of the Geghama Mountains and in the semi-desert belt, despite the significant 1740-meter altitude difference between the two locations. The correlation between transpiration intensity and elevation appears to be influenced by a combination of factors, including disparities in soil composition, climatic conditions, and weather patterns (including variations in light intensity, atmospheric humidity, atmospheric pressure, and temperature). Additionally, structural modifications within the plants themselves, such as the quantity and density of stomata on the leaves and the leaves' diffusion permeability, likely play a role in this relationship (Sanchez-Martinez et al., 1999). In any case, both changes in the structural elements of plants and their functional changes should be considered as a complex of adaptation to climatic changes in the broad sense, aimed at maintaining homeostasis and dynamic equilibrium of plants.

According to the latest data (Melkonyan & Gevorkyan, 2020) in Armenia, the average air temperature for the period from 1929 to 1996 increased by 0.40 °C, in the period 1929–2007 by 0.85 °C, in the period 1929–2012 by 1.03 °C, and in the period 1929–2016 by 1.23 °C. In general, in Armenia in the period 1935–2016 the annual amount of precipitation decreased by 9%, but if the regions of Central Armenia became much more arid, then in the north, southeast and in the southeastern part of the Lake Sevan basin their amount even slightly increased. Based on the data provided by the National Communication (Melkonyan & Gevorkyan, 2020), forecasts of changes in temperature and precipitation were made for the alpine belt and other volcanic highlands of Armenia, where *P. porphyrantha* grows, as well as for the Yerevan and meadow-steppe belt. If we assume that the current climatic conditions in the alpine belt are optimal for the growth of *P. porphyrantha*, and considering that in the conditions of the meadow-steppe belt this species has perfectly adapted, grows, is not oppressed and multiplies, then at least until 2100 the conditions in the alpine belt and, respectively, in other places of its natural growth will remain. That is, climate change should not be considered a threat to the existence of this species. Also this confirms our opinion that the reintroduction of the studied species to its former habitat in the alpine belt after the completion of mining operations will not have natural obstacles.

Conclusion

As a result of a multilateral study of the rare stenotopic species *P. porphyrantha* (Rosaceae), its ecological and biological features were revealed. In particular, the taxonomic independence of the species was clarified: it differs significantly in morphology from close related species in the section *Persicae*. The chromosome number and features of the karyotype of this species were identified. Based on the study of its physiology (total water content, intensity of transpiration and productivity of photosynthesis), the adaptive capabilities of the species in different environmental conditions were evaluated.

In the course of studying the growth and development of plants in *ex situ* conditions in meadow-steppe and semi-desert belts (Sevan and Yerevan Botanical Gardens), it was shown that in the conditions of Sevan (at an altitude of about 1000 m lower than the natural population), the species adapted well, exhibited good growth, and had high seed productivity with high seed viability, easily colonizing new territories. In the semi-desert belt (1240 m a.s.l.) the main limiting factors are high temperatures during the vegetation period and very low air humidity. In its natural population in the alpine belt, pure edaphic conditions and competition from other plant species are the limiting factors for distribution and intensive growth of *P. porphyrantha*.

An assessment of current climatic conditions and comparison with those predicted due to climate change led to the conclusion that global climate change does not pose a serious threat to the natural populations of this species. In general, it can be concluded that the reintroduction of the species from the meadow-steppe belt to restore the natural population, part of which may be destroyed during mining operations, is quite feasible and should be successful.

All data generated or analyzed during this study are included in this article.

This work was partly supported by the Higher Education and Science Committee of Ministry of Education, Science, Culture and Sport RA under the framework of research project N°21AG-1F004.

References

Agapova, N. D., & Grif, V. G. (1982). K khromosomnoy terminologii [On chromosome terminology]. Botanicheskii Zhurnal, 67(9), 1280–1284 (in Russian).

Akopian, J., Elbakyan, A., Martirosyan, L., Hovakimyan, Z., & Ghukasyan, A. (2023). Biological aspects of threatened *Psephellus erivanensis* (Asteraceae) in the context of *ex-situ* conservation. Iranian Journal of Botany, 29(2), 165–174.

Akopian, J., Ghukasyan, A., Hovakimyan, J., Gabrielyan, I., & Martirosyan, L. (2022). High mountain perennial pia *Vavilovia formosa* (Steven) Fed. – a review on the investigation in Armenia. Vavilovia, 5(1), 3–22.

Delgado, L., Gallego, F., & Rico, E. (2000). Karyosystematic study of *Potentilla* L. subsp. *potentilla* (Rosaceae) in Iberian Peninsula. Botanical Journal of the Linnean Society, 132(3), 263–280.

Elkington, T. T. (1969). Cytotaxonomic variation in *Potentilla fruticosa* L. New Phytologist, 68(1), 151–160.

Fayvush, G. (Ed.). (2010). Climate change impacts, vulnerability assessment and adaptation. In: Second National Communication on Climate Change under the United Nations Framework Convention on Climate Change. Yerevan. Pp. 47–77.

Fayvush, G., Hambaryan, L., Shahazizyan, I., Gasparyan, A., Poghosyan, A., Nanagulyan, S., Ghukasyan, A., Aleksanyan, A., Koopman, J., & Więcław, H. (2023). Biodiversity of Armenia. Springer, Switzerland.

Fayvush, G. (Ed.). (2015). Climate change impacts: Vulnerability assessment and adaptation. In: Third National Communication on Climate Change under the United Nations Framework Convention on Climate Change. Pp. 51–87.

Fedorov, A. A. (1958). Rod *Potentilla* L. [Genus *Potentilla* L.]. In: Takhtajyan, A. L. (Ed.). Flora Armenii [Flora of Armenia]. Izdatel'stvo Akademii Nauk Armianskoy SSR, Yerevan. Vol. 3. Pp. 79–131 (in Russian).

Ghukasyan, A., Elbakyan, A., Martirosyan, L., Hovakimyan, Z., & Akopian, J. (2023). Studies of the halophytic *Sphaerophysa salsula* (Fabaceae) in Armenia. Flora Mediterranea, 33, 157–165.

Ghukasyan, A., & Janjughazyan, K. (2015). Chromosome numbers of some rare flowering plants of Armenian flora. Electronic Journal of Natural Sciences NAS RA, 24, 23–26.

Giam, X., Bradshaw, C. J. A., Tan, H. T.-W., & Sodhi, N. S. (2010). Future habitat loss and the conservation of plant biodiversity. Biological Conservation, 143(7), 1594–1602.

Giulietti, A. M., Harley, R. M., De Queiroz, L. P., Wanderley, M. D. G. L., & Van Den Berg, C. (2005). Biodiversity and conservation of plants in Brazil. Conservation Biology, 19(3), 632–639.

Goswami, D. A., & Matfield, B. (1974). Cytogenetic studies in the genus *Potentilla* L. The New Phytologist, 75(1), 135–146.

Holdridge, L. R. (1966). The life zone system. Adansonia, 6, 199–203.

Ilnicki, T., & Kolodziejek, J. (2008). Chromosome numbers of *Potentilla* subsect. *collinae* (Rosaceae) from Poland. Caryologia, 61(2), 170–175.

Janjughazyan, K. (2018). Palynological pecularities of *Potentilla porphyrantha* (Rosaceae). Biological Journal of Armenia, 70(1), 48–52.

Tamamshyan, S. G. (1954). Rod Potentilla L. [Genus Potentilla L.]. In: Karyagin, I. I. (Ed.) Flora Azerbaijana [Flora of Azerbaijan]. Izdatel'stvo Akademii Nauk Azerbaijanskoy SSR, Baku. Vol. 5. Pp. 93–114 (in Russian).

Tamanyan, K., Fayvush, G., Nanagjulyan, S., & Danielyan, T. (Eds.). (2010). The Red Data Book of Plants of Armenia. Zangak, Yerevan.

Khanjyan, N. S. (2009). Novye redkie dlia Kavkaza i Armenii widy *Potentilla* (Rosaceae) [New rare species of *Potentilla* (Rosaceae) for the Caucasus and Armenia]. In: Flora, rastitel'nost' i rastitel'nye resursy Armenii. Yerevan. Vol. 17(1). Pp. 33–35 (in Russian).

Khan, S. M., Page, S. E., Ahmad, H., & Harper, D. M. (2013). Sustainable utilization and conservation of plant biodiversity in montane ecosystems: The Western Himalayas as a case study. Annals of Botany, 112(3), 479–501.

Mabberley, D. J. (2017). The plant-book. Cambridge University Press, Oxford.

Melkonyan, H., & Gevorkyan, A. (2020). Climate change scenarios. In: Fourth National Communication on Climate Change. Yerevan. Pp. 72–80.

Měsíček, J., & Soják, J. (1992). Chromosome counts of some Mongolian *Potentilla* species. Folia Geobotanica and Phytotaxonomica, 27(2), 167–176.

Müntzing, A. (1928). Pseudogamie in der Gattung *Potentilla*. Hereditas, 11(2), 267–283.

Noroozi, J., Akhani, H., & Breckle, S.-W. (2008). Biodiversity and phytogeography of the Alpine flora of Iran. Biodiversity and Conservation, 17, 493–521.

Rani, S., Kumar, S., Jeelani, S., Gupta, R., & Kumari, S. (2012). Additions to the cytologically investigated species of *Pottentilla* L. (Rosaceae) from India. Plant Systematics and Evolution, 298(2), 485–497.

Sadeghi, S., Beygom Faghir, M., Attar, F., & Alaami, A. (2021). Achene micromorphology of the genus *Potentilla* L. (Rosaceae) in Iran and its systematic application. Turkish Journal of Botany, 45(1), 15–42.

Sanchez-Martinez, P., & Oliveira-Filho, A. (1999). Changes in forest with altitude in the Brazilian Coastal Atlantic rain forest. In: Abstracts of XVI International Botanical Congress. St. Louis, Missouri.

Smith, G. L. (1971). Studies in *Potentilla* L. New Phytologist, 70(3), 607–618.