ORIGINAL ARTICLE

UDC: 581.9:582.736

DOI: 10.30901/2658-3860-2022-1-3-22

High mountain perennial pea *Vavilovia formosa* (Steven) Fed. – a review of its study in Armenia

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The high mountain perennial pea *Vavilovia formosa* (Steven) Fed., commonly known as beautiful vavilovia, is a rare species of the high alpine flora of Armenia bound to scree habitats. Populations of *V. formosa* in Armenia, as well as in other regions of the world, are endangered and need to be studied and preserved both in natural and *ex situ* conditions. Studies of the relic alpine pea *V. formosa*, unique in its bioecological features and beauty, were initiated in Armenia in the 20-30s of the last century and continue at the present time. Thanks to numerous expeditions to the hard-to-reach habitats of *Vavilovia* in the Gegham and Syunik highlands, Zangezur ridge, many researchers of the Armenian flora collected herbarium material, conducted ecological and coenotic studies, analyzed karyology on the basis of local populations, repeatedly conducted experiments on growing *Vavilovia* in laboratory conditions and in botanical gardens of Armenia. As a result of field observations, information was obtained on the status of *Vavilovia* populations in different regions of the republic, in natural conditions, floristic and coenotic composition of habitats at the Aknasar and Sevkatar (Sevsar) mountain peaks, on slopes near the Aknalich lake, of the Mets Ishkhansar mountain, and near the Ughtasar mountain peak. One of the main natural threats leading to the change in and shrinking of *Vavilovia* populations is the overgrowth of mobile scree habitats with turf-forming grasses, which creates conditions for the development of mountain-meadow vegetation on screes. The *ex situ* conservation strategy for *V. formosa* is one of the possible ways to evaluate its adaptive capacity to environmental changes, as well as to conserve it and use in basic and applied research. An experiment on the introduction and cultivation of *Vavilovia* conducted by the Yerevan and Sevan Botanical Gardens of Armenia has yielded some data on biomorphological and ecophysiological features in *ex situ* conditions.

Keywords: Armenia, beautiful vavilovia, cultivation, ecology, field investigation, karyology, literature data, phytocoenology

For citation: Akopian J., Ghukasyan A., Gabrielyan I., Hovakimyan Zh., Martirosyan L. High mountain perennial pea *Vavilovia formosa* (Steven) Fed. – a review of its study in Armenia. *Vavilovia*. 2022;5(1):3-22 . DOI: 10.30901/2658-3860-2022-1-3-22

ОРИГИНАЛЬНАЯ СТАТЬЯ

УДК: 581.9:582.736

DOI: 10.30901/2658-3860-2022-1-3-22

Высокогорный многолетний горох *Vavilovia formosa* (Steven) Fed. – обзор исследований в Армении

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Высокогорный многолетний горох *Vavilovia formosa* (Steven) Fed. (вавиловия прекрасная) – редкий вид верхнеальпийской флоры Армении, специализированный к осыпным местообитаниям. Популяции *V. formosa* в Армении, как и в других регионах мира, находятся под угрозой исчезновения и нуждаются в изучении и сохранении в природе и в условиях *ex situ*. Исследования в Армении реликтового высокогорного гороха *V. formosa*, уникального по своим биоэкологическим особенностям и декоративности, были начаты в 20-30-е годы прошлого столетия и продолжаются в настоящее время. Благодаря многочисленным экспедициям в труднодоступные местообитания *Vavilovia* на Гегамском, Сюникском высокогорьях, Зангезурском хребте, многими исследователями флоры Армении был собран гербарный материал, проведены эколого-ценотические исследования, изучена кариология на материале местных популяций, неоднократно проводились опыты по выращиванию вавиловии в лабораторных условиях и в ботанических садах Армении. В результате полевых наблюдений получена информация о состоянии популяций вавиловии в разных регионах республики, о природных условиях, флористическом и ценотическом составе местообитаний на вершинах Акнасар, Севкатар (Севсар), на склонах близ оз. Акналич, горы Мец Ишхансар и близ вершины Ухтасар. Одной из основных природных угроз, приводящих к изменению и сокращению популяций вавиловии, является зарастание подвижных осыпных местообитаний дернообразующими травами, что создает условия для развития на осыпях горно-луговой растительности. Стратегия сохранения *V. formosa ex situ* является одним из возможных способов оценки ее способности адаптироваться к изменениям окружающей среды, а также ее сохранения и использования в фундаментальных и прикладных исследованиях. В Ереванском и Севанском ботанических садах Армении проводится эксперимент по интродукции и выращиванию вавиловии, получены некоторые данные о биоморфологических и эколого-физиологических особенностях в *ex situ* условиях.

Ключевые слова: Армения, вавиловия прекрасная, кариология, культивирование, литературные данные, полевые исследования, фитоценология, экология

Для цитирования: Акопян Ж.А., Гукасян А.Г., Габриэлян И.Г., Овакимян Ж.О., Мартиросян Л.Ю. Высокогорный многолетний горох *Vavilovia formosa* (Steven) Fed. – обзор исследований в Армении. Vavilovia. 2022;5(1):3-22. DOI: 10.30901/2658-3860-2022-1-3-22

«The authors dedicate this work to the memory of the outstanding Serbian scientist Alexandar Mikich, an innovator and tireless enthusiast in the exploration of beautiful vavilovia».

Introduction

Wild perennial pea *Vavilovia formosa* (Steven) Fed. (Fabaceae) is a relic and endangered pea species of the alpine flora of Armenia. *Vavilovia* Fed. is an independent branch in the tribe Fabeae of the Fabaceae family, which includes some of the most ancient and important crops like pea, lentil, vetch, and vetchling. The study of *Vavilovia* is of current importance because of its introduction into modern biotechnology and breeding as a source of perenniality for cultivated relatives. *V. formosa* has a high potential for breeding, due to its adaptive features: perennial life cycle, tolerance to frost, drought, pests and diseases, resistance to various biotic and abiotic stresses. Crosses of *V. formosa* with *Pisum* species, as well as with other species from the tribe Fabeae, are of significant theoretical and practical interest.

Wild perennial pea was first described by Christian Steven and originally assigned to the genus *Orobus* L. (Steven, 1812). After that, this species was in turn associated with two other genera of the Fabaceae family, *Lathyrus* L. and *Pisum* L. A. Fedorov critically revised the taxonomy of the mountain pea (Fedorov, 1939). Based

on morphological characteristics, ecology and perennial habit, he separated the species into a monotypic genus *Vavilovia*. The genus was named to honor N. I. Vavilov, the prominent Russian scientist, who pioneered the study of cultivated plants and first recognized the importance of their wild relatives.

Vavilovia grows in high mountains of the Great and Lesser Caucasus, North and Northwestern Iran, Northern Iraq, Anatolia, Syria, and Lebanon. It belongs to representatives of cryophilic flora and Pliocene relics, and is included in the category of paleoendemics (Prima, 1974; Kharadze, 1960). It is a highly ornamental plant (Fig.1).

V. formosa is recognized as an endangered and protected plant species. The existing populations of *V. formosa* in Armenia, as well as in other sites of the world, are in danger of extinction (Akopian et al., 2008, 2010, 2018; Tamanyan et al., 2010; Mikic et al. 2013, 2014; Vishnyakova et al., 2016; Smykal et al., 2017). Due to the specificity of habitat requirements, *Vavilovia* distribution range is considered to be shrinking. Narrow ecological amplitude, isolation and fragmentation of populations are among the factors limiting expansion of the species. In the habitats where mountain slopes are not very steep and high, the main human-induced threat for *V. formosa* is grazing. Among the natural threats leading to the change and reduction of *Vavilovia* population is the overgrowing of mobile scree habitat with turf-forming grasses, which creates conditions for the development of mountain-meadow vegetation (Akopian et al., 2019). Another presumptive threat to *V. formosa* is the forecasted warming due to the influence of the global climate change, which can lead to redistribution of territories of different ecosystems. A new environmental niche modeling has predicted a further range reduction for *V. formosa* (Akopian, Gabrielyan, 2008; Smykal et al., 2017).

Fig. 1. Perennial pea *Vavilovia formosa* (Steven) Fed., Gegham mountains population, the first decade of July. Photo by J. Akopian

Рис. 1. Многолетний горох *Vavilovia formosa* (Steven) Fed., популяция в Гегамских горах, первая декада июля. Фото Ж. Акопян

Vavilovia ex situ conservation strategy is one of the possible ways to estimate its capacity to adapt to environment changes, as well as to save and use it in basic and applied researches. The most important goal in *Vavilovia* cultivation under *ex situ* conditions is to grow the plants that are capable of developing reproductive organs and produce seeds. In case of *V. formosa* flowering in culture, interspecific and *intergeneric* hybridization can be done (Mikich et al., 2014).

Many attempts to conserve *Vavilovia ex situ* have been made, however the majority of them were unsuccessful due to inadequate management of soil aeration and water flow (Zhukovskyi, 1971). Some success was achieved in the UK at the Official Seed Testing Station in Edinburgh and at Southampton University (Cooper, Cadger, 1990), but it did not result in the production of new seeds or multiplication of the plants. More promising results were obtained in 1974–1981 at the N.I. Vavilov Institute of Plant Industry (VIR) (the N.I. Vavilov Institute of Plant Genetic Resources, VIR, since 2015). Some plants survived for some years, bloomed and even formed fruits with seeds (Golubev, 1990). Some results of *V. formosa ex situ* growing was also obtained in laboratory conditions at the A.L. Takhtajan Institute of Botany of the National Academy of Sciences of the Republic of Armenia (NAS RA) (Akopian et al., 2014) and in 2008–2010 and 2018–2019 in the Yerevan Botanical Garden of NAS RA (Akopian et al., 2010, 2019).

Field study of *Vavilovia formosa* in Armenia

Field studies of *V. formosa* started in Armenia in the late twenties of the last century. For the first time, *V. formosa* was collected in 1929 in southern Armenia on the slopes of Kaputjugh mountain (3904 m) in the alpine zone of the Zangezur mountain range, at altitudes from 3.200 to 3500 m.a.s.l., during an expedition organized by the Nature and History Museum of Armenia and led by A. Schelkovnikov. In 1929, *Vavilovia* was collected by Y. Kazaryan, D. Sosnovskyi, and H. Maghakyan during several expeditions in central Armenia on the top of the Sevsar volcanic mountain in the Gegham highland (Fedorov, 1939). In 1936, the plant was found by A. Fedorov in the same area, and in 1937 it was collected by him on the slopes of Kaputjugh. Studies conducted by A. Fedorov played an important role in the critical revision of the taxonomy of high-mountain pea and for understanding its ecology. In his famous monograph «Wild mountain pea of the Caucasus» , A. Fedorov used his field observations to provide a detailed description of habitats of *V. formosa* in Armenia and the species' adaptive features of narrow specialization to areas with moving debris and screes of black or red volcanic slags (Fedorov, 1939). In the monograph he recognized two species of the genus *Vavilovia*, that is, *V. formosa* (Steven) Fed. and *V. aucheri* Fed. with different areas in the Great and Lesser Caucasus. However, when obvious transition plant forms were found in Armenia, both species were united by him again under the priority name of *V. formosa* (Fedorov, 1952). It should be noted that some current studies of the intraspecific variability of *Vavilovia* across the general range of its distribution showed that the most morphologically divergent group occurs in Armenia (Sinjushin, Belyakova, 2010).

Habitats of *V. formosa* in the Gegham highland were investigated by Y. Kazaryan in the summer of 1931 during a study of natural fodder lands. According to the classification developed by him, movable and fixed screes were observed in the Gegham ridge (Kazaryan, 1939). The movable scree is represented by large-gravel, fine-grained and sandy screes. *Vavilovia* does not grow on large-gravel slopes. *Vavilovia* plants were found by Y. Kazaryan in the top area of southeastern fine-grained movable slope of the Sevsar mountain and in the neighborhood of the Aknalich crater lake in 1931 and 1935. He mentioned that besides

Sevsar *Vavilovia* occurred at that period in vast numbers on other volcanic cones surrounding the Aknalich lake and was also recorded on sandy scree slopes (3000–3200 m.a.s.l.) 1.5 km east of the Vishapasar mountain in the Gegham ridge (Kazaryan, 1939). *Vavilovia* has periodically been transplanted from nature during the numerous expeditions led by A. Akhverdov and N. Mirzoeva and grown in the research plot «Flora and Vegetation of Armenia» in the Yerevan Botanical Garden since 1940 (Akhverdov, Mirzoeva, 1949). From the 1940s up to the present, *V. formosa* has been repeatedly collected at both sites in central and southern Armenia by A. Takhtajan, A. Akhverdov and N. Mirzoeva, S. Tamamschyan, Ya. Mulkijanyan, V. Avetisyan, E. Gabrielyan, V. Manakyan, V. Voskanyan, I. Arevshatyan, K. Tamanyan, G. Fayvush, M. Oganesian, E. Vitek, I. Gabrielyan and others. *Vavilovia* also occurs on another mountain of the Zangezur range near Kaputjukh, that is, the Parakan mountain, where it was collected at altitudes from 3200 to 3300 m.a.s.l. by S. Baloyan in 1986 (Baloyan, 1999). The collected materials are conserved in the Herbarium (ERE) of the A.L. Takhtajan Institute of Botany of NAS RA and the Yerevan State University (ERCB) (Akopian, 2018).

In 1972, *V. formosa* was found by VIR expeditions to the Gegham range when exploring two southern slopes (3300–3400 m.a.s.l.) southeast of Aknalich. Based on the studies of the material collected by the expeditions in the Stavropol Territory and in Armenia, the taxonomic status of *V. formosa* has been revised (Makasheva et al., 1973; Vishnyakova, 2020).

The third habitat of *V. formosa* was identified relatively recently in the Syunik upland region at an altitude of 3300–3400 m in the neighborhood of the Mets Ishkhanasar (3550 m) and Ughtasar (3296 m) mountains. *Vavilovia* was found on the eastern slope of the mountain Mets Ishkhanasar in 2003 by Heinz Parker and in the Ughtasar mountain neighborhood in 2006 by H. Kazaryan, where it was collected again in 2007 and 2009 by I. Gabrielyan (Gabrielyan, 2009). In 2006–2007, the Gegham highland and Syunik upland populations of *V. formosa* were studied within the framework of the UNEP/GEF funded Crop Wild Relatives projects, during an expedition led by I. Gabrielyan and A. Melikyan in 2006; some data on the species distribution in Armenia, population size and possibilities of *ex situ* conservation were obtained (Akopian et al., 2008).

Further field observations in the Gegham and Syunik mountains were carried out in July and August 2009. Three expeditions were organized: two to the Syunik upland region of the Ughtasar mountain and one to the Gegham mountains in the Aknalich lake area (Sarukhanyan et al., 2009; Akopian et al., 2010). The expeditions were undertaken by scientists and researchers from the A.L. Takhtajan Institute of Botany of NAS RA, Agricultural Reform Support Project Implementation Unit (ARSPIU) of the Ministry of Agriculture of Armenia, Syunik Agricultural Support Regional Center, and the Green Lane NGO. In the Syunik upland region, *Vavilovia* occurs near the Ughtasar mountain of the Tskhuk mountain range in the 3305–3453 m.a.s.l. range. From western, southern to eastern slopes, the population is spread over an area of about 800 m^2. The slopes of the Tskhuk Mountain Range are coated with reddish-yellow and reddish-black slag. On July 17, 2009, the expedition reached the highest area of the scree slopes near the Ughtasar mountain. The first plants of *V. formosa* were found at altitudes within the 3305–3315 m.a.s.l. range on the southeastern slope. The *Vavilovia* population was found at the budding–flowering onset phenophase, so sporadic plants with open flowers were found. On the explored slopes *Vavilovia* was accompanied by many other species of high mountain plants: *Anthriscus sylvestris* (L.) Hoffm. var. *nemorosa* (M. Bieb.) Trautv., *Tanacetum zangezuricum* Chadjian, *Taraxacum*

stevenii DC., *Coluteocarpus vesicaria* (L.) Holmboe, *Draba bruniifolia* Stev., *Pseudovesicaria digitata* (C.A. Mey.) Rupr., *Campanula aucheri* DC., *Campanula tridentate* Schreb. subsp. *tridentata*, *Corydalis alpestris* C.A. Mey., *Gentiana pontica* Soltok, *Primula algida* Adams, *Delphinium foetidum* Lomak., *Cruciata taurica* (Pall. ex Willd.) Ehrend., *Pedicularis crassirostris* Bunge, *Veronica gentianoides* Vahl, *Eunomia rotundifolia* C.A. Mey., and some others. During the observation time (14:00 to 18:00 h), the slope stayed sunlit and sun warmed. In the period between 16:30 and 17:30 h, the blooming process became more active and flowering *Vavilovia* plants started occurring more often on the slope. At an altitude of about 3350–3400 m, the density of plants in the population was higher than that observed at the foot of the slope. Probably, as a result of being permanently covered by detritus, the offshoots develop numerous extremely thin secondary roots that not only spread in topsoil (20–30 cm), but also go down into the soil layer underlying the detritus. Mechanically, the soil is light loamy, with humus content of 4.4 % and pH 7.7. Plantlets with 5–7 leaves, developed rootlets and remaining seed coats, have been occurring sporadically. In the Ughtasar mountain population, plants are from 4 up to 6 cm high, with 4–8 offshoots; leaves and flower-bearing stems are vivid green with violet spots. Both the vegetative organs of *Vavilovia* and its flowers are in close contact with substratum. The temperature on the slope, and in particular, at the surface of the sun-warmed scree near the plants, was +30…+32°C, while on the same slope fragment, the air temperature in the shade was about +16°C. After 19:00 h, the air temperature went down to +10…+12°C and the surface temperature of the sun-warmed stones was +12…+16°C. Strong winds about 7.7 to 15.0 m/sec in the region of the Ughtasar mountain were recorded.

Cones with Upper Quaternary slag deposits are most clearly visible in the Gegham highland, which is dominated by about 30 large volcanic cones. The population of *V. formosa* in the Gegham mountains is the largest in Armenia. During the field studies in the Gegham highland from 1929 to recent time, *Vavilovia* was recorded on southeastern and southwestern mobile scree slopes of mountain peaks of Aknasar (3258 m), Vishapasar (3157 m), Spitakasar (3555 m), and Sevkatar (Sevsar) (3225 m), in the neighborhood of the Aknalich lake (3032 m.a.s.l.), and on volcanic cones surrounding the lake (Kazaryan, 1939; Fedorov, 1939; Makasheva et al., 1973; Baloyan, 2004; Akopian et al., 2008, 2010, 2018; data on the ERE and ERCB Herbarium materials).

The *Vavilovia* population observed during the expedition of 2009 to the Sevsar mountain is situated 1 km north of the Aknalich lake (Fig. 2). The area occupied by the population about 700 m long and 100 m wide. On the western, southwestern and southern slopes it starts at the altitude of 3111 and continues up to 3203 m. The slopes of Sevsar are covered with an incoherent slag blanket of two colors: the western part is red and the eastern part is black.

V. formosa occurs in both areas, though on the slopes coated with reddish slag the number of plants is far larger. The expeditions within the framework of the UNEP/GEF Crop Wild Relatives projects were organized in 2007 in the vicinity of Aknalich on the adret slopes at the southern shore of the lake. Their participants A. Danelyan, I. Gabrielyan, and A. Melikyan found several hundreds of *Vavilovia* plants in an area of 0.5 ha. In the Red Book of Plants of RA (Tamanyanet al., 2010), the population of *Vavilovia* in the vicinity of Aknalich is defined as extinct. These contradictory data suggest extreme instability of the population that obviously is in serious danger of extinction. Besides *Vavilovia*, other rare species under protection occur in this area: *Eunomia rotundifolia, Potentilla porphyrantha, P. seidlitziana, Scilla rosenii,* etc. The second *Vavilovia* population spread over an area of about 4–4.5 ha to the northeast

Fig. 2. Aknalich lake
Рис. 2. Озеро Акналич

of Aknalich, on the northern slopes of a big hill at an altitude of 3045–3170 m, facing a small water-logged hollow. The slope angle was 45–55°. In that area, the plants and flowers were already touched by frost and the expedition found few flowers and dry pods, as the air temperature was -2… -3°C at night. In contrast to the Ughtasar population, the plants in the region of Aknalich were a little more inconspicuous and mostly deep green, without spots. The number of leaves on each plant varied from 6 to 22. So, the expeditions of 2009 resulted in studying *V. formosa* populations in two different localities of the Gegham and Syunik mountains, thus enriching our knowledge about natural habitats, climatic and geomorphological conditions.

Vavilovia research was continued in 2018–2019 as part of a project «Wild perennial pea *Vavilovia formosa* (Fabaceae) adaptive bio-ecological features evaluation in the Gegham mountain population and under *ex situ* conditions in the Botanical Gardens of Armenia», supported by the Armenian National Science and Education Fund (ANSEF). Scientific expeditions to the Aknasar mountain in the Gegham highland were carried out on July 11 and September 13, 2018 with the aim of conducting bio-ecological studies and botanical inventory of a *Vavilovia* population located on the southeastern moving scree slope of Aknasar. The population occupies an area of 0.12 ha at an altitude of 3135–3150 m (Fig. 3). The slope is sunlit and sun-warmed, covered by a layer (4–6 cm thick) of red and grey volcanic fine-grained slag particles of 0.5 to 2–3 cm in size and by larger tuff stones of up to 20–30 cm (Fig. 4). The base of the slope is composed of large rocks. The water that comes from the melting snow at the top of the mountain is absorbed by the slag under which the aquifer layer is formed. The habitat is characterized by precipitation during the spring and autumn-winter months, strong heating of the soil in the summer dry period, and winds that dry up the surface layer of slag and the adjacent layer of soil. These conditions lead to the xerophytization of the plants growing here.

The climatic and soil conditions at Aknasar are as follows: daytime air temperature is 26.5°C, the air temperature in the sun is 32.1°C, and relative air humidity is 37–40 %. Sandy loam soil moisture content under the gravel at a depth of about 40–50 cm is 1.0–1.2 %. The high percentage of sand (72.2 %) in the soil promotes water infiltration to deeper

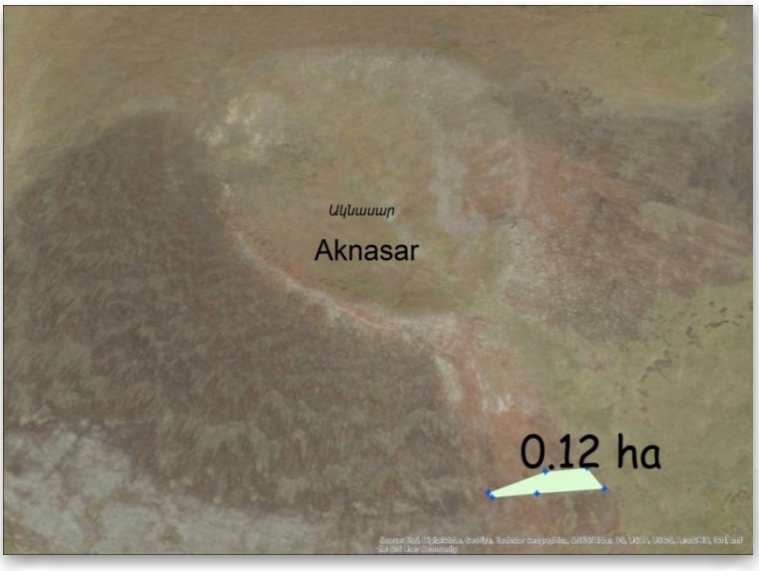

Fig. 3. *Vavilovia formosa* (Steven) Fed. population with an area of 0.12 ha on the southeastern scree slope of the Aknasar mountain (Gegham highland), 3135–3150 m.a.s.l. Source: GPS imported to GIS

Рис. 3. Популяция *Vavilovia formosa* (Steven) Fed. на площади 0,12 га на осыпях юго-восточного склона горы Акнасар (Гегамское плато), 3135–3150 м н.у.м.

Источник: данные GPS импортированные в GIS

layers, which creates dryness both at the top of the scree slag layer and under it. Vegetation in the scree habitat is low, with surface coverage of about 20–25 %. The density of *Vavilovia* population is from 40 to 150 plants per 1 m^2. *Vavilovia* occupies 30 to 85 % of the total number of plants per 1 m^2.

Fig. 4. Aknasar mountain. Climbing up during the expedition

Рис. 4. Гора Акнасар. Подъем по склону в ходе экспедиции

Vegetation is represented by annual, biennial and perennial herbs, with the leading role in the vegetation cover of Aknasar slopes belonging to low-growing perennial ones. Mass flowering of *Vavilovia* was observed in early July (Fig. 5), on an average ten days earlier than usual. Flowers fallen from night cold were not recorded. During the autumn expedition in early September 2018, a large number of seedlings and juvenile *Vavilovia* plants were observed, which indicates the activation of reproduction by seed (Fig. 6) along with the vegetative propagation. The present state of the Aknasar mountain population can be estimated as satisfactory. No facts of grazing were noted at the altitude of the explored site. The floristic composition of studied vegetation is represented by the following plant species, which were recorded in July-September aspects: *Alchemilla sericea* Willd., *A. grossheimii* Juz., *A. retinervis* Buser, *Alopecurus tuscheticus* Trautv., *A. laguroides* Balansa, *A. textilis* Boiss. subsp. *textilis*, *Allium schoenoprasum* L., *Arenaria dianthoides* Sm., *Asperula glomerate* (M. Bieb.) Griseb., *Astragalus incertus* Ledeb., *Bromopsis variegata* (M. Bieb.) Holub, *Campanula glomerata* L., *C. saxifraga* subsp. *aucheri* (A. DC.) Ogan., *C. tridentata* Schreb., *Centaurea fischeri* Willd., *Cerastium araraticum* Rupr., *C. szowitsii* Boiss., *Chamaesciadium acaule* (M. Bieb.) Boiss., *Cirsium rhizochephalum* C.A. Mey., *Coluteocarpus vesicaria* (L.) Holmboe, *Dianthus raddeanus* Vierh., *Doronicum oblongifolium* DC., *Draba araratica* Rupr., *D. siliquosa* M. Bieb., *Erysimum gelidum* Bunge, *Festuca woronowii* Hack. subsp. *caucasica* (St.-Yves) E.B. Alexeev, *Galium sosnovskyi* Manden., *Gentiana pontica* Solt., *Leontodon hispidus* L., *Luzula pseudosudetica* V.I. Krecz., *Minuartia oreina* Schischk., *Nepeta lamiifolia* Benth., *Papaver fugax* Poir., *P. caucasicum* M. Bieb., *Pedicularis sibthorpii* Boiss., *Rumex acetosa* L. subsp. *acetosa*, *Ranunculus oreophilus* M. Bieb., *Saxifraga sibirica* Pall. ex Ledeb., *Scrophularia olympica* Boiss., *Senecio vernalis* subsp. *sosnovskyi* (Sof.) V.E. Avet., *Sibbaldia procumbens* L., *Silene ruprechtii* Schischk., *S. saxatilis* Sims, *Thymus kotschyanus* Boiss. & Hohen., *Trifolium ambiguum* M. Bieb., *T. canescens* Willd., *T. trichocephalum* M. Bieb., *Tripleurospermum caucasicum* (Willd.) Hayek, *Veronica orientalis* Mill., *Ziziphora raddei* Juz., *Z. clinopodioides* Lam. and some others. Saxicolous lichens develop on many stones of Aknasar, which belong to the first settlers on stones, involved in the formation of a scree. They give the stones a bright orange or grayish color. Scree plants specialization is aimed at fixing the underground organs in a moving substrate and at adapting the above-ground parts to the conditions of continuous slag coating. In *Vavilovia*, this is achieved by the rapid formation of numerous thin, long, branched roots and above-ground sprouts, which, when covered by the substrate, continue to grow under its surface, take root and produce new shoots with leaves. Roots and the rooting above-ground shoots spread in all directions, consolidate the scree and, thus, reach the state of their relative immobility. *Vavilovia* plants are often found in small groups together with other species, such as *Galium sosnovskyi, Astragalus insertus, Campanula saxifraga* subsp. *aucheri*, *Cerastium araraticum, Thymus kotschyanus*, *Trifolium ambiguum* and *Tripleurospermum caucasicum*. Intertwined by roots, these plants fix the scree in the place where they grow.

Fig. 5. Moving scree habitat of *Vavilovia formosa* (Steven) Fed. on Mt. Aknasar, July 2018, mass flowering. Photo by J. Akopian

Рис. 5. Местообитания *Vavilovia formosa* (Steven) Fed. на подвижной каменистой осыпи, гора Акнасар, июль 2018 г. Фото Ж. Акопян

Fig. 6. *Vavilovia formosa* (Steven) Fed. fruitification, Aknasar population, September 13, 2018. Photo by G. Zaroyan

Рис. 6. Плоды *Vavilovia formosa* (Steven) Fed., популяция на горе Акнасар, 13 сентября 2018 г. Фото Г. Зарояна

Over the past decades, an increase in air temperature has been observed in Armenia (an average of 5.5°C) (Fourth National …, 2020). With the increasing altitude, a recession in the temperature increase is observed: the temperature gradient up to 800 m.a.s.l. is 1.7°C, and at an altitude of 3000 m it is 0.7°C. Precipitation for the period from 1935 to 2016 decreased in Armenia by 9 %. Above 2500 m.a.s.l., there is a significant decrease in precipitation. As environmental niche modeling predicts, species may respond to the increasing temperature by moving to higher altitudes, which is difficult for the high mountain *V. formosa*, as it already occupies habitats at 3000–3500 m.a.s.l. in Armenia. The observations that we carried out in natural habitats showed that the scenario of *Vavilovia* range boundary moving higher is not feasible: this is prevented by the constant movement from above and slag shedding from the mountaintop. At the bottom, plants are limited by large stones, which cover the slope base. As a result, *Vavilovia* populations always occupy the middle part of a slope, which was also observed on the scree slopes near the Ughtasar mountain in the Syunik district (Akopian et al., 2010). Being a highly specialized species, *Vavilovia* belongs to the biological group of high-altitude xerophytes (Akhverdov, Mirzoeva, 1964). In this regard, it can be assumed that the observed increase in temperature and a decrease in precipitation in the high-mountainous zone of Armenia cannot appreciably affect *Vavilovia*. A possible threat factor leading to the reduction of *Vavilovia* habitats can be the overgrowing of mobile scree with such turf-forming grasses as *Alopecurus tuscheticus*, *A. laguroides*, *A. textilis* ssp. *textilis*, *Bromopsis variegatus*, and *Festuca woronowii* ssp. *caucasica*, which create conditions for the development of mountain-meadow vegetation. The overgrowing of mobile screes in the Gegham ridge was observed earlier by E. Kazaryan (1939) and it continues to the present. As a result of the expansion, grass vegetation can be seen not far from the Aknasar mountain on gentle slopes around the Aknalich lake (3090 m.a.s.l.). It led to vanishing of *Vavilovia* near the Aknalich lake, which used to grow there in abundance in the first half of the past century. The grazing and using this area as pastures is a secondary negative factor accompanying the natural degradation of screes.

Karyological studies of *Vavilovia formosa*

Karyological studies of the *Vavilovia* seed material collected during the expedition to the Gegham and Ughtasar mountains were also carried out. The karyology of the tribe Fabeae, represented by genera *Lathyrus* L., *Lens* Mill., *Pisum* L., *Vicia* L. and *Vavilovia* Fed., has been studied fairly well. Primary basic chromosome number is x=7. The chromosome number of *V. formosa* was first reported by Abramova (1971) for the material from the Stavropol Territory of Russia. She noted that the diploid set for this species consists of 7 chromosome pairs (2n=14): 6 pairs of submetacentric and 1 pair of metacentric chromosomes. The chromosome number 2n=14 was recorded by E. A. Nazarova for the Armenian material from the Sevsar population (Nazarova, 2004) and by Atlagic et al. for the Ughtasar population of this species (Atlagic et al., 2010). The chromosome number of *V. formosa* from the Sevsar population (Armenia, Gegham highland) obtained by A. G. Ghukasyan (Fig. 7) confirmed the previous data (Ghukasyan, Akopian, 2018). The karyotype formula is $2n=14=8SM+4SM^{S}+2M$. Karyotype of this species is asymmetric. The diploid set of chromosomes consists of 12 submetacentric and 2 metacentric chromosomes. Two pairs of submetacentric chromosomes have satellites (marked with arrows in Fig. 7). The chromosomes have an apparent size that varies between 2.30 and 4.61 µm. The largest are submetacentric chromosomes. The total length of the diploid set is 46.45 µm. The centromere

index (I) of submetacentric chromosomes varies between 33.0–30.0. The centromere index (I) of metacentric chromosomes is 50.0. The index of symmetry TF % is 34 %. The karyotype description, centromere index and symmetry index of this species from the Sevsar population (Armenia, Gegham Highland) are presented for the first time.

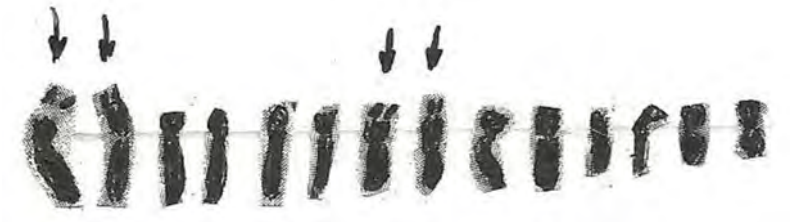

Fig. 7. *Vavilovia formosa* (Steven) Fed. karyogram. Scale bar = 10 µm (Ghukasyan, Akopian, 2018)

Рис. 7. Кариограмма *Vavilovia formosa* (Steven) Fed. Масштаб 10 µm (Гукасян, Акопян, 2018)

On the History of *Vavilovia formosa* cultivation in the Yerevan Botanical Garden

According to the definition of Botanical Gardens Conservation International (BGCI) in the framework of the International Agenda for Botanical Gardens in Conservation (IABGC), an important role in *ex situ* conservation of rare and endangered plants is given to botanical gardens. In Armenia, the first steps towards the cultivation and *ex situ* conservation of native flora were taken in 1935–1940 by famous Armenian botanists, founders of the Yerevan Botanical Garden H. Maghakyan, A. Akhverdov, and N. Mirzoeva. In 1954, Flora and Vegetation of Armenia Plot with a collection of live plants was established in the Yerevan Botanical Garden (Akhverdov, Mirzoeva, 1961). In 1960, an Alpinarium (alpine garden) (Fig. 8) with rocky hills for alpine plants was also created on the Plot at 1200 m.a.s.l. in the dry, continental stony semi-desert zone in which the Yerevan Botanical Garden is situated. It was preceded by a period of a long-term research on the biology and ecology of alpine plants, which facilitated their introduction into relatively low-altitude cultivation from their native alpine habitats at 2900–3500 m.a.s.l. (Akhverdov, Mirzoeva, 1964). Stony hills with slopes of different steepness and orientation were constructed in order to reproduce the Armenian highlands. Different landscape conditions replicating those in the Aragats, Gegam and Kaputjugh mountains have been modeled. These include rocks, screes, and plateau-like or gorge-like landscapes.

From the 40th to the 80th of the last century, *V. formosa* was periodically cultivated on alpine rocks in the mentioned Plot. It was observed (Akhverdov, Mirzoeva, 1949, 1961, 1962) that *V. formosa* adapted to new conditions more successfully than some of other transplanted alpine plants, and in some years produced mature fruits and seeds. Some alpine plants, which are alpine mesophytes as a rule, do not grow quite well in the dry continental conditions of the Yerevan Botanical Garden despite good care. However, the same conditions are fit for the successful cultivation of the upper alpine plant species belonging to the high-mountain xerophytes of the upper alpine and subnival zones, which in wild grow on well warmed lighted southern or eastern stony or scree slopes. *V. formosa* belongs to such plants (Akhverdov, Mirzoeva, 1964). Some information

on phenology and bio-morphology of *Vavilovia* seed germination, flowering and fruiting in culture was recorded in Plot observation notebooks and published (Akhverdov, Mirzoeva, 1961, 1962, 1964). According to the obtained data, the *Vavilovia* seeds sown in autumn germinate in the following spring under the influence of winter cold stratification. The duration of *Vavilovia* virginal period under cultivation is two years. First leaves of definitive plants appear at the beginning of April. Usually, all the alpine plants introduced at the Yerevan Botanical Garden, finish flowering by the end of May. Since *Vavilovia* flowers in the wild quite late, in July-August, the flowering period becomes extended under cultivation and continues from the first decade of May to the end of August. The fruiting is observed in June-August (beginning of September). The results achieved by Armenian botanists in the past century indicate the possibility of *V. formosa* cultivation and conservation under the conditions of the Yerevan Botanical Garden of NAS RA.

Fig. 8. View of the Alpinarium at the «Flora and Vegetation of Armenia» Plot of the Yerevan Botanical Garden, 1975. Photo of archive data of the «Flora and Vegetation of Armenia» Plot

Рис. 8. Вид альпинария на участке «Флора и растительность Армении» Ереванского ботанического сада, 1975 г. Фото из архива участка «Флора и растительность Армении»

Current Experience of *Vavilovia formosa* Cultivation in the Yerevan and Sevan Botanical Gardens

Growing of *Vavilovia ex situ* is very complicated. According to the observations of *Vavilovia* in natural scree habitats, its growing requires meeting a complex of ecological factors, which are difficult to replicate *ex situ*. Moderate air temperature and a lower ground temperature, continuous hydration (from melting glaciers) together with sufficient aeration of the substrate, dryness of the upper layers of the scree and a low concentration of mineral salts in the soil with pH 6.5–7.0 are important for the successful growing of this plant (Fedorov, 1939; Makasheva et al., 1973). Nevertheless, attempts to grow and study *V. formosa* in other conditions continue. During the period of 2010–2019, observations of *V. formosa* samples grown from seeds in laboratory conditions (Fig. 9a) at the A.L. Takhtajan Institute of Botany and under

cultivation in the Botanical Gardens (Fig. 9b) were conducted (Akopian et al., 2010, 2014, 2019). Seeds were germinated in laboratory conditions in Petri dishes on humid filter paper (Akopian et al., 2014). After 5 days, the swollen seeds were scarified for their germination 10-12 days after sowing. The seedlings were transplanted into small containers with soil and gravel, with holes on the bottom and on the entire surface to ensure proper aeration of the root system. Four cataphylls (scaly leaves) were observed at the base of the seedling. Seed germination of *V. formosa* is hypogeal. Naturally, the epicotyl, three next internodes and 3 (4) cataphylls remain under the moving scree layer. They lack chlorophyll, unlike the seedlings obtained in laboratory conditions. Buds form in all cataphyll axils, from which the shoots of the following orders develop in laboratory conditions. The assumption that the border between cataphylls and true leaves of perennial Fabeae coincides with the border between the wintering and annual plant parts, is confirmed by observations on *V. formosa*. In autumn, under a layer of scree in natural habitats, wintering hypogeal shoots develop from the buds in axils of cataphylls.

а **б**

Fig. 9. Germination of *Vavilovia formosa* (Steven) Fed. from seeds in laboratory conditions (a) and spring renewal of sprouts (b) in open ground conditions in the Yerevan Botanical Garden

Рис. 9. Проращивание *Vavilovia formosa* (Steven) Fed. из семян в лабораторных условиях (а) и весеннее обновление ростков (б) в открытом грунте в Ереванском ботаническом саду

To evaluation the adaptive bio-ecological features of *V. formosa* under *ex situ* conditions in the botanical gardens of Armenia, experimental cultivation of *Vavilovia* was undertaken in the Yerevan and Sevan Botanical Gardens. *V. formosa* and some other alpine plant samples from the Aknasar mountain were transplanted on July 12 and September 14, 2018 to the stony semi-desert zone of the Yerevan Botanical Garden and to the high mountain steppe zone of the Sevan Botanical Garden. Climate condition average characteristics in July-September at the Aknasar mountain and in Botanical Gardens are presented in Table 1.

Table 1. Climate conditions at Mt. Aknasar, Yerevan and Sevan Botanical Gardens in July-September

Таблица 1. Климатические условия на горе Акнасар, в Ереванском и Севанском ботанических садах в июле-сентябре

Altitude (m.a.s.l.)/ Высота (м н.у.м)	AirTemp (°C)/ Температура воздуха, (°C)	Relative air humidity (%)/ Относительная влажность воздуха, (%)	Soil moisture (%) / Влажность почвы (%)	Soil Ph (%)/ Ph почвы (%)	Light *(Klux)/ Освещение (Klux)*
***In situ*: Mt. Aknasar, 3150 m**	32	29	1,1	6,8-7	40
***Ex situ*: Sevan, 1950 m (partially shaded)**	20	56	8,5	6,9	33
***Ex situ*: Yerevan, 1250 m (partially shaded)**	30	47	7,5	6,8-7	22

Table 2. Soil chemical and mechanical composition of *Vavilovia formosa* (Steven) Fed. habitat on Mt. Aknasar

Таблица 2. Химический и механический состав почвы из места обитания *Vavilovia formosa* (Steven) Fed. на горе Акнасар

Determined indicators/ Определяемые показатели	K	K_2O	Na	Cu	Pb	P_2O_5	Soil type/ Тип почвы
Outcomes, %	0.00085	0.00102	0.00075	$2.66 \cdot 10^{-5}$	$3.2 \cdot 10^{-4}$	0.95	Sandy loam
Determined indicators	**Ca**	**Mg**	**Cl^-**	**HCO_3^-**	**SO_4**	**N total**	
Outcomes, %	0.008	0.004	0.0084	0.0183	0.0082	0.52	
Determined indicators	**CaO**	**Humus**	**pH**	**Sand**	**Clay**	**Silt**	
Outcomes, %	1.68	37.0	6.38	72.2	5	22.2	

Alpine hillocks were prepared in the Yerevan and Sevan Botanical Gardens, using slag and soil from scree natural habitats (Table 2), as well as tuff stones and mixture (with pH 6.8-7.0) of black soil, peat, and red sand. *Vavilovia* samples were planted on hillock slopes of various exposure. Alpine hillocks were arranged to be semi-shaded, which is necessary to protect plants from direct sunlight, especially in summer. Some related high mountain plant species, such as *Alchimilla grossheimii, Astragalus incertus, Aster alpinum, Campanula saxifraga* ssp. *aucheri*, *C. tridentata*, *Centaurea fisheri, Cerastium araraticum, Chamaesciadium acaule, Coluteocarpus vesicaria, Dianthus raddeanus, Doronicum oblongifolium, Erigeron caucasicum, Galium sosnovskyi, Minuartia oreina, Pedicularis sibthorpii, Thymus kotschyanus* ssp. *kotschianus*, *Trifolium ambiguum*, *Tripleurospermum caucasicum* and others have been transplanted from the Aknasar mountain into a living collection created on alpine hillocks. The planting of *Vavilovia* specimens was done to mimic *in situ* plant growing habit, in particular, by orienting rhizomes almost horizontally to the ground or at a small angle but never vertically downwards (Fig. 10). Roots and the rooting underground shoots were oriented to the center of a hillock. The plants were developing better in the vicinity of large stones (Fig. 11) and

required only moderate watering. Permanent care of the plants was taken, peculiarities of growth and development under *ex situ* conditions were monitored. After 7–12 days of *Vavilovia* planting, there were noticeable signs of rooting. Plant survival in the Sevan Botanical Garden in the conditions of high mountain steppe zone was at first about 80–85 % and about 60 % in the Yerevan Botanical Garden. Further on, in the summer-autumn period, the growth and vegetative propagation of plants in the Yerevan Botanical Garden became more active, especially on the southeastern and southwestern slopes of the artificial hillocks. The shoots became 11–15 cm long and had 14–17 leaves, and 2–3 lateral branches with 5–6 leaves developed. The growing period of the plants in the Yerevan Botanical Garden continued almost until the end of October – middle of November, they were green, and new sprouts were appearing permanently.

In the Sevan Botanic Garden, plants developed more slowly, their shoots remained short, 5–8 cm in length, as those in natural habitats.

To determine the adaptive capacity of *Vavilovia* in nature and in the Yerevan Botanical Garden, such eco-physiological parameters as plastid pigments (chlorophyll, carotenoids), the intensity of photosynthesis, water regime (free and bound water, water deficiency) and transpiration, were calculated (Akopian et al., 2019). A comparative study of some parameters of *Vavilovia* fresh leaves was carried out two months after transplantation from nature, when plants under *ex situ* conditions multiplied and the possibility of sampling appeared.

Fig. 10. *Vavilovia formosa* (Steven) Fed. planting technique under *ex situ* condition
Рис. 10. Схема посадки *Vavilovia formosa* (Steven) Fed. в условиях *ex situ*

The observed quantitative decrease in the chlorophyll content in *Vavilovia* leaves in the mountains can be explained by a biological feature considered as a plant response to high light intensity; more chlorophyll accumulates at a lower light intensity in the Yerevan Botanical Garden. An increase in the content of carotenoids noticed in the conditions of the botanical garden indicates the adaptive and protective effect of these substances on the photosynthetic apparatus in the altered *ex situ* growing conditions. A comparison of water regime indicators has shown that despite regular watering of the rocky hillocks and soil moisture of 7.5 % in the arid conditions of the Yerevan Botanical Garden, the water deficit in *Vavilovia* was 20.6 %. It is not very different from that at Aknasar (23.3 %), where the soil moisture was 1.1 %. It is known that the

Fig. 11. *Vavilovi formosa* (Steven) Fed. cultivated in the Yerevan Botanical Garden
Рис. 11. *Vavilovia formosa* (Steven) Fed., выращенная в Ереванском ботаническом саду

intensification of transpiration leads to an increase in water deficiency. In *Vavilovia*, water deficit is compensated by the well-developed root system, which increases water absorption. Some other parameters recorded under *in situ* and *ex situ* conditions did not differ significantly and were within statistical deviations.

As can be seen from the review on *Vavilovia formosa* studies in Armenia from the late 1920s to the present, they have yielded new scientific data on natural conditions of the species, on flora composition, ecological and coenotic characteristic of habitats. Thanks to the observations of *Vavilovia* in its natural habitats made by many researchers of the Armenian flora, the species taxonomy has been clarified, some significant peculiarities of its morphology, phenology, biology, eco-physiology, and karyology were revealed. The data from these studies can contribute to the protection of this relic and endangered species and its *ex situ* conservation. The accumulated experience contributes to the development of *V. formosa* cultivation techniques and creation of a live collections in the Yerevan and Sevan Botanical Gardens. Some data on *Vavilovia* bio-morphological peculiarities under *ex situ* conditions were obtained. In case of subsequent success of the experiment, the species samples from the hard-to-reach high-mountain habitats will become available for researchers, enabling them to perform further comparative studies and issue recommendations concerning *Vavilovia ex situ* conservation.

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Вклад авторов: все авторы сделали эквивалентный вклад в подготовку публикации.
Contribution of the authors: the authors contributed equally to this article.
Конфликт интересов: авторы заявляют об отсутствии конфликта интересов.
Conflict of interests: The authors declare no conflicts of interests.

Статья поступила в редакцию 03.02.2022; принята к публикации 18.03.2022.
The article was submitted on 03.02.2022; accepted for publication on 18.03.2022.