The Scientific Temper (2023) Vol. 14 (4): 1060-1065
E-ISSN: 2231-6396, ISSN: 0976-8653
Doi: 10.58414/SCIENTIFICTEMPER.2023.14.4.01
https://scientifictemper.com/

RESEARCH ARTICLE

Bioclimatic modeling of the species *Phlomoides canescens* (Lamiaceae)

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Abstract

The article analyzes the natural distribution area of the species *Phlomoides canescens* (Regel) Adylov, Kamelin and Makhmedov using the programs of type MaxEnt and ArcGis, the widespread of Central Asia (past, future). A methodological algorithm of bioclimatic modeling was developed. According to the results of the study, it is proved that the main distribution of the species coincides with the boundaries of the area Pomir-Alay mountain system (Uzbekistan, Tajikistan and Kyrgyzstan) as well as northern Afghanistan. Is noted that the climatic and topographic factors that are optimal for the species are the precipitation of the coldest quarter and elevation. According to the RCP 2.6 (2061-2080) climate scenario, an increase in temperature of 0.4 to 1.6°C will create many potentially suitable areas in the form of fragments in the regions of Afghanistan and Tajikistan. Under the RCP8.5_2070s climate scenario, an increase in temperature of 1.4 to 2.6°C has replaced scattered high-level suitable areas with medium-level suitable areas. Under both climate scenarios, temperature increases of 0.4 to1.6°C and 1.4 to 2.6°C did not adversely affect the species' main hotspots. Ecological features of the species and modeling results allow to creation of natural plantations in the foothills of Kashkadarya, Surkhandarya (Hisor Range) and Jizzakh (Turkestan Range) regions. This makes it possible to provide a sufficient amount of biomass for the development of drugs from the plant in the field of pharmaceuticals.

Keywords: Climate change, MaxEnt model, Hot spots, *Phlomoides canescens*, Potential geographical distribution, Pamir-Alay.

Introduction

Climate change has an important impact on ecological phenomena such as regional distribution and phenology of species' hot spots, resulting in changes of species distribution patterns on different temporal and spatial scales, thus accelerating the speed of species extinction or prosperity (Alan Pounds *et al*., 2006).

Climate change is one of the main factors affecting the range of the species, and international government experts have noted that the average global temperature will rise by 1.4 to 5.8˚C between 1900 and 2100 (IPCC, 2019). Today, climate change is having an impact on species adaptation and development. In the coming years, species modeling analysis will play an important role in current and future analysis. The developed models play a crucial role in predicting the risk of future biodiversity loss and in shifting strategies to reduce this risk.

Central Asia is a particularly vulnerable region due to its physical geography with temperate deserts and semi-deserts (Lioubimtseva and Henebry 2009, Gulomov, 2022). The environment is very sensitive to global climate change, and it is particularly vulnerable to changing weather patterns (Brooke 2014). Especially, water resources in this area are the main factors for the sustainable development of biodiversity. There is a low concentration of water vapor over this area and the distribution of water resources in Central Asia is very uneven. Meteorological data have shown that air temperatures are increasing across Central Asia, and regional climate change scenarios show that temperatures will rise by 1 to 3°C in the next 20 to 40 years. If global greenhouse gas emissions are not reduced, temperatures are projected to rise by 3 to 6°C above today's levels by the end of the century (Novikov *et al*., 2012). Despite the critical habitat for biodiversity, it is considered one of the main centers of plant

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How to cite this article: Gulomov, R., Rakhimova, K., Batoshov, A., Komilov, D. (2023). Bioclimatic modeling of the species *Phlomoides canescens* (Lamiaceae). The Scientific Temper, **14**(4):1060-1065.

Doi: 10.58414/SCIENTIFICTEMPER.2023.14.4.01

Source of support: Nil

Conflict of interest: None.

Received: 16/09/2023 **Accepted:** 06/11/2023 **Published:**27/12/2023

diversity (Nowak *et al*. 2020) and endemism in particular (Tojibaev *et al*. 2020), which represents nearly 10 thousand species of vascular plants (Khassanov 2015).

In recent years, the growing demand for natural medicinal plants and climate change has led to a reduction in plant stocks. For this reason, much attention is paid in the world to determining the species composition of medicinal plants, studying their biological properties (Sasha *et al*., 2013), identifying natural resources and bioclimatic modeling, and scientifically substantiating changes in populations as a result of external.

Today, research on the medicinal properties and chemical composition of *Phlomoides canescens* (Regel) Adylov, Kamelin and Machmedov (Lamiaceae Martinov) distributed (Figure 1) in Central Asia (Pamir-Alay) is increasing (Rakhimova *et al*., 2021). Currently, alcohol-soluble sugars, physical and chemical analysis of components of a complex of carbohydrates, water-soluble polysaccharides, highly esterified pectins and hemicelluloses have been isolated from the plant as well as their qualitative and quantitative characteristics are given (Rakhimova and Gulomov, 2021). The obtained results and the isolated amino acids, and vitamins in the food and pharmaceutical industry, the preparation of various nutritional products and vitamin preparations useful for human health, and their application in practice are of urgent scientific and practical importance.

For the first time, bioclimatic modeling of the future potential distribution areas of this plant species is being done using Maxent and ArcGIS programs. The obtained results allow to obtain enough biomass for the creation and production of plantations of the species in the areas of potential distribution.

The following tasks were defined as the research objective: (1) identify the hot spots of *P. canescens* plant in Pamir-Alay under past climatic conditions. (2) Explore the relationship between the distribution of hot spots and environmental factors, and explore the important environmental factors that limit the distribution of hot spots. (3) The hot spots of *P. canescens* plants in Pamir-Alay were predicted according to the global climate change scenarios of the future (2070s).

Material and Methods

Study Area

Pamir-Alay is a mountain system in the southeast of Central Asia. Located on the territory of Tajikistan, Kyrgyzstan (in the southwest), Uzbekistan (in the west) and Turkmenistan (in the southwest); the eastern and partially southern edge enters China and Afghanistan. Pamir-Alay stretches from west to east for 900 km, from north to south for 400 km. It consists of mountain ranges and highlands between the Fergana valley in the north and the headwaters of the Amu-Darya in the south.

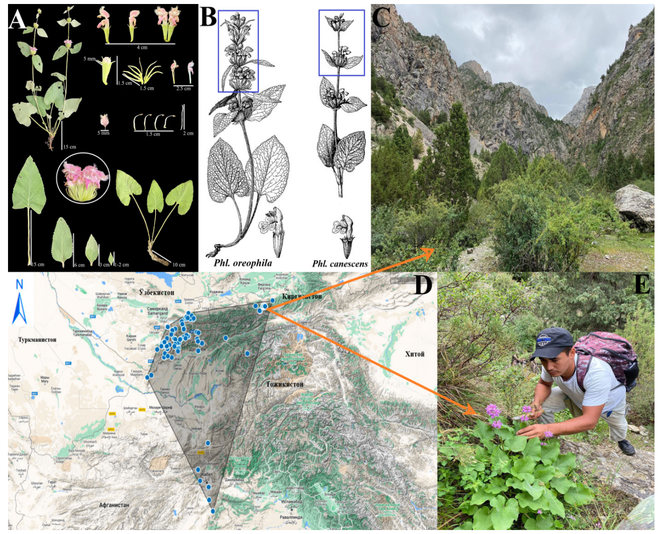

Figure 1: A) Illustrations of *P. canescens* (by photo Gulomov, 2023); **B)** *Phlomoides oreophila* and *P. canescens* species differences; **C-E)** Species ecology (Shahimardon, Fergana province, Uzbekistan); **D)** GeoCAT map of species distribution.

Species Presence Data

In total 130 species presence records of *P. canescens* were incorporated in this investigation. By searching the Global Biodiversity Information Facility (GBIF; https://www.gbif.org/), the Moscow Virtual Herbarium (MW; https://plant.depo.msu.ru/), Herbarium of Saint-Petersburg Botanical Institute (LE), National Herbarium of Uzbekistan (TASH), Kyrgyz National Herbarium (FRU) and the results of field research conducted in the Pamir-Alay regions in 2020-2023 were used. In determining the areas where the species is distributed in Afghanistan checklist of the flowering plants of Afghanistan was used (Podlech and München, 2012). The point record from each herbarium specimen was transformed into GPS geographical coordinates using Google Earth Pro 7.1 and ArcGIS (version 10.6.1) software. Natural illustration of the species is made using Photoshop CS6x64 software.

Environmental Variables and Processing

The current climate data used in this study (1970-2000) come from the WorldClim database (http://www.worldclim.org/). The model contains four emission scenarios proposed by the sixth International Coupled Models Comparison Program (CMIP6). This scenario is developed on the basis of the typical concentration path (RCPs) scenario, with a spatial resolution of 2.5 arc minutes (~4.64 km^2 at the equator). The data contain 19 bioclimatic variables, which are obviously biologically significant and are usually used in species distribution and related ecological modeling (Table 1). The topographic data contain elevation variables.

Pearson correlation analysis of 19 environmental variables was performed *via* ArcGIS. When the correlation coefficient of two climate variables was less than 0.80, all the relevant climate variables were retained, and when the correlation coefficient of two climate variables was greater than 0.80, the climate variables with more important ecological significance were retained, we selected the climate variables that are important for the hot spots.

Ensemble of the MaxEnt Model

We used MaxEnt software (version 3.4.4) to model the habitat suitability of *P. canescens* plant in Pamir-Alay. This software is considered to build some of the best-performing models for forecasting species distribution with a limited number of records. Initially, 130 coordinates in Comma Separated Values (*CSV) format were stored and 19 bioclimatic variables and altitude values obtained from the WorldClim database were imported into the MaxEnt model. From the MaxEnt model, the output map values range from 0 to 1 (0 least and 1 most suitable species probability pixels) (Phillips *et al.*, 2006). In our models, 75% of the occurrence records were used for training whereas 25% of the records were used for testing the model (Figure 2). The background points and the number of iterations were set at no more than 10,000 and 1000, respectively. The algorithm ran either 1000 iterations of these processes or continued until convergence (threshold 0.00001). The ensemble processes were repeated in a ten-fold cross-validation to improve the performance of the model.

When receiving research results the scenarios RCP2.6_2070s (SSP1-2.6 (ssp126) minimum greenhouse gases) and RCP8.5_2070s (SSP5-8.5 (ssp585) maximum greenhouse gases) based on IPCC proposed greenhouse gas concentrations (RCP) were used. According to the IPCC (2019) sixth report (AR5), the annual average temperature is 0.4 to 1.6°C under the RCP 2.6 (2061–2080) scenario, and 1.4 to 2.6°C under the RCP 8.5 (2061–2080) scenario (Meinshausen *et al.*, 2011).

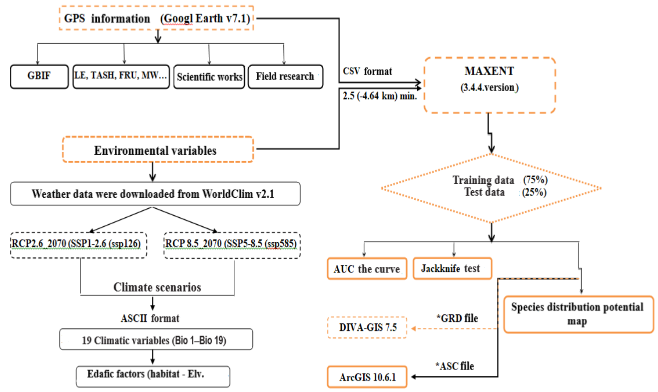

Figure 2: Methodological algorithm for bioclimatic modeling

The default output of Maxent is in the logistic form, indicating the environmental suitability for *P. canescens* in Pamir-Alay with values ranging from 0 to 1. For further analyses, the results of MaxEnt were imported into ArcGIS program potential habitats were reclassified as follows: In this appendix, the high range of the species is described in "Red", the areas with low distribution are described in

Table 1: Environmental variables

Variables	*Description*	*Source*	*Unit*
Bio1	Annual mean temperature	WorldClim	°C
Bio2	Mean diurnal range (mean of monthly (max temp - min temp))	WorldClim	°C
Bio3	Isothermality (bio2/bio7) (*100) ºC	WorldClim	%
Bio4	Temperature seasonality (standard deviation *100	WorldClim	-
Bio5	Max temperature of the warmest month	WorldClim	°C
Bio6	Min temperature of the coldest month	WorldClim	°C
Bio7	Temperature annual range (bio5-bio6)	WorldClim	°C
Bio8	Mean temperature of wettest quarter	WorldClim	°C
Bio9	Mean temperature of driest quarter	WorldClim	°C
Bio10	Mean temperature of warmest quarter	WorldClim	°C
Bio11	Mean temperature of coldest quarter	WorldClim	°C
Bio12	Annual precipitation	WorldClim	mm
Bio13	Precipitation of wettest month	WorldClim	mm
Bio14	Precipitation of driest month	WorldClim	mm
Bio15	Precipitation seasonality (coefficient of variation)	WorldClim	1
Bio16	Precipitation of wettest quarter	WorldClim	mm
Bio17	Precipitation of driest quarter	WorldClim	mm
Bio18	Precipitation of warmest quarter	WorldClim	mm
Bio19	Precipitation of coldest quarter	WorldClim	mm
Elv.	Elevation		m

"Orange", the areas with a low probability of distribution and almost no chance of occurrence are described in "Green and White". The resulting model was validated on the basis of the area under the curve (AUC) calculated from the receptor operating characteristic and whose growth factor is set from 0 to 1. AUC values > 09 indicate high accuracy, values of 07–08 indicate good accuracy, < 07 indicate poor accuracy, and <05 indicate poor accuracy (Guo *et al*., 2017). The contribution of variable environmental factors is evaluated according to the results of the Jackknife test.

Results

By applying the MaxEnt model, the model predicted the potential distribution of *P. canescens* plant in Pamir-Alay, with a training AUC value of 0.996 and a test AUC value of 0.996, (under both climate scenarios) which indicates its high level of predictive performance (Figure 3).

Among the environmental data used for the prediction of the MaxEnt model, MaxEnt constantly modifies the single evaluation factor coefficient adjustment model through iterative algorithms to calculate the contribution rates of 5 environmental factors to the prediction (Table 2).

The results of the Jackknife (Figure 4) method show that when 18 environmental factors and elevation are used, the five environmental factors that have the greatest influence on the normalized training; precipitation of coldest quarter (Bio19), mean diurnal range (Bio2), precipitation of warmest quarter (Bio18), precipitation of driest month (Bio14), precipitation of driest quarter (Bio17) from environmental factors and elevation (Elv.) contain information. Generally speaking, the main influencing factors of *P. canescens* plants in Pamir-Alay are precipitation of coldest quarter and elevation.

Under two emission scenarios, MaxEnt model was used to identify the hot spots of *P. canescens* plant in Pamir-Alay.

As a result, the hot spot of the past distribution map of plants in Pamir-Alay (Figure 4) was brought.

The species are mainly distributed in southwestern Pamir-Alay, despite the fact that during the period of industrial development (1970–2000) the sharp anthropogenic climate change had a limiting effect on the range of the species, its ecological niche is Hisar, Zarafshan, Turkestan, Alay ridge and showed that it can spread in the eastern regions of Afghanistan. To date, the species have been recorded from these areas. During the period of industrial development, the regions of Uzbekistan (Kashkadarya, Surkhandarya, Samarkand and Jizzakh), Tajikistan (Sughd and districts subordinate to the republic) and Kyrgyzstan (Batkent) can be cited as regions of high potential for the growth and spread of the species. Western Tien-Shan and Afghanistan are cited as moderately suitable areas for the growth of the species.

Table 2: Environmental variables and their contributions

Variable	*Percent contribution (%)*	
	RCP_2.6	*RCP_8.5*
Bio19	53	58,7
Elevation	20,4	17,6
Bio2	12,9	12
Bio18	4,8	4,3
Bio14	2,7	2,6
Bio17	2,6	2,2

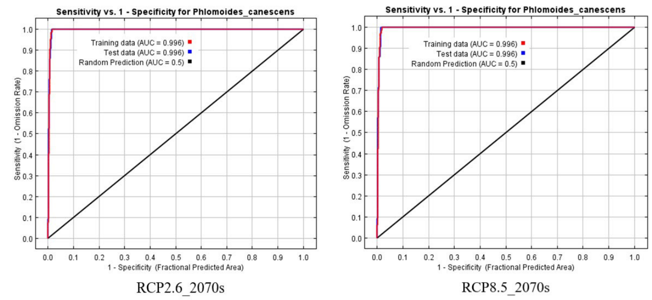

Figure 3: Receiver operating characteristic curve

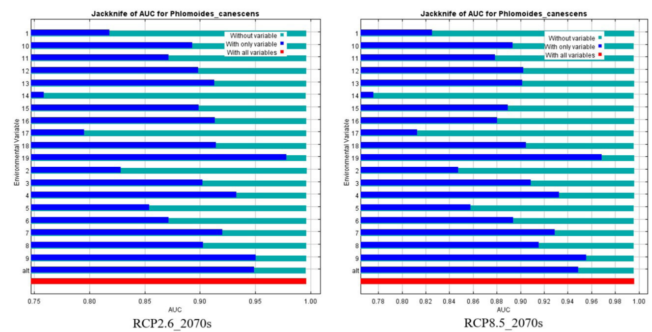

Figure 4: Jackknife test result of environmental factor

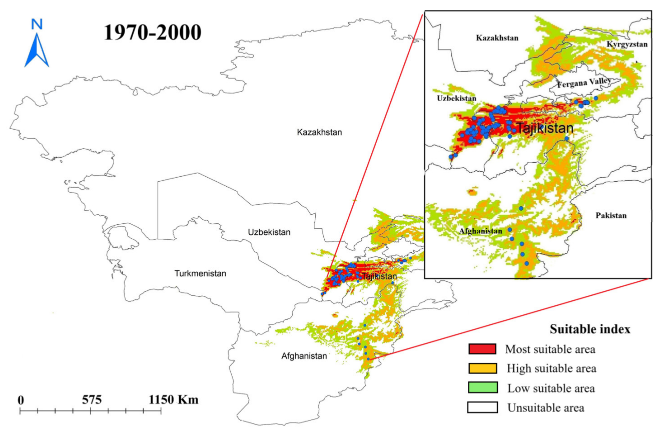

Figure 5: Hotspots of species under past climate change scenarios

As can be seen from Figure 5, the areas of different growth grades under the two emission scenarios in 2070 (2061–2080) will change by various degrees compared to those under current climate conditions.

The RCP 2.6 2070 climate scenario associated with an increase in minimum greenhouse gas concentrations showed that the species' high and medium suitable habitat

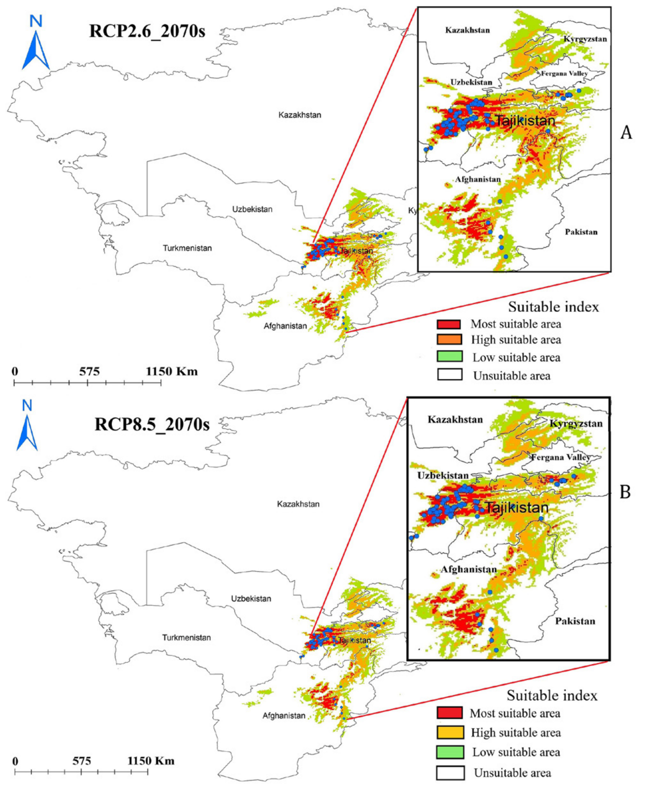

Figure 6: Hotspots of species under future climate change scenarios

will expand in the future. In particular, during the period of industrial development, the areas with a low brightness index and unsuitable for the growth of the species will become highly suitable areas under the RCP 2.6 2070 climate scenario (Bamian, Wardak provinces). According to the RCP 2.6 (2061–2080) climate scenario, an increase in temperature of 0.4 to 1.6°C will create many potentially suitable areas in the form of fragments in the regions of Afghanistan and Tajikistan. It is directly related to precipitation (Bio19) and elevation (Elv.) in the coldest quarter. Under the RCP8.5_2070s climate scenario, an increase in temperature of 1.4 to 2.6°C has replaced scattered high-level suitable areas with medium-level suitable areas. Under both climate scenarios, temperature increases of 0.4 to 1.6°C and 1.4 to 2.6°C did not adversely affect the species' main hotspots.

Discussion

Most of Central Asia shows an increase in drought frequency and duration by the end of the current century, mainly caused by the consistently enhanced evaporation that roughly balances the precipitation growth after 2030 (Hua *et al*., 2022).

Precipitation of the coldest quarter plays a major role in the formation of potential hotspots of the species under both climate scenarios. Also, in terms of seasonal variability, precipitation in Central Asia shows strong spatial heterogeneity, characterized by the peak rainfall amount occurring in spring and winter over southwestern Central Asia, but in summer over northern and southeastern parts (Song, Bai, 2016; Zhong *et al*., 2022). Moreover, the region is sensitive and vulnerable to rapid climate change, due to its scarcity of water resources and complex terrain (Tucker *et al*., 2015; De Beurs *et al*., 2018). In recent decades, Central Asia has experienced a significant increase in temperature but an unobvious decrease in precipitation (De Beurs *et al*., 2018).

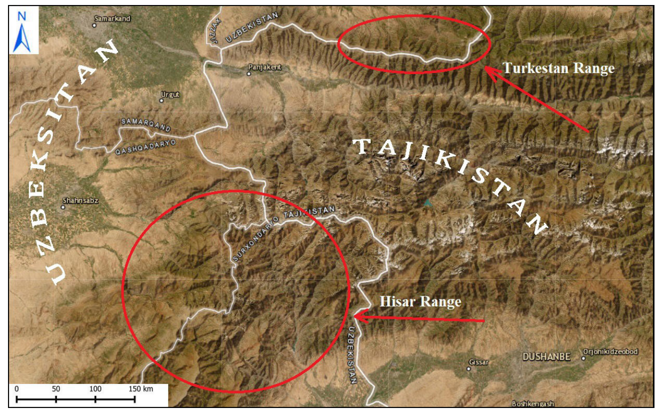

Figure 7: Recommended areas for creating natural plantations of the species (Uzbekistan)

The second main topographic factor is the importance of the height gradient. The ecology of the species is formed in relation to the altitudinal gradient. For example, the species is a whole-leaved mesophyte plant with a preference for forest landscapes, retaining more primitive characteristics. Including, Juniper thickets, alpine subalpine meadows, thorny grass associations, middle and upper mountain belts, 1.600 to 2.800 m a.s.l. These indicators allow to creation of natural plantations in the foothills of Kashkadarya, Surkhandarya (Hisor Range) and Jizzakh (Turkestan Range) regions (Figures 6 and 7).

This species is closely related to *P. oreophila* being different in its leaves with stellate hairs above. In the southern part of the distribution area *P. oreophila* (Fergana, Alay and Turkestan Ranges) the forms transitional to *P. canescens* occur. Unlike the typical *P. canescens*, these forms do not have filament appendages (Lazkov, 2011).

No measures are currently being taken to protect the species. It was assessed by the Least Concern-LC (EOO km^2; 184491, AOO km^2; 392) category according to the International Union for Conservation of Nature (IUCN) methodology (Gulomov, 2022). *P. canescens*, like the plant *P. oreophila*, has a short-term hypotensive effect and induces tremors in some animals (Khudoiberdiev, 1995). For this reason, domestic animals hardly eat it. This situation means that the species are free from the main anthropogenic factor.

Based on the predictions of the MaxEnt model, our study showed that the species' high habitats were gradually differentiated but not drastically reduced. Further research on its biological and ecological adaptation should be done in the future depending on different habitats and the response of the plant to climate change. This makes it possible to determine the ecological optimality of the species and its successful introduction in the near future.

Conclusion

According to the RCP 2.6 (2061–2080) climate scenario, an increase in temperature of 0.4 to 1.6°C will create many potentially suitable areas in the form of fragments in the regions of Afghanistan and Tajikistan. It is directly related to precipitation (Bio19) and elevation (Elv.) in the coldest quarter. Under the RCP8.5_2070s climate scenario, an increase in temperature of 1.4 to 2.6°C has replaced scattered high-level suitable areas with medium-level suitable areas. Under both climate scenarios, temperature increases of 0.4 to 1.6°C and 1.4 to 2.6°C did not adversely affect the species' main hotspots. The species are a whole-leaved mesophyte plant with a preference for forest landscapes, retaining more primitive characteristics. These indicators allow to creation of natural plantations in the foothills of Kashkadarya, Surkhandarya (Hisor Range), and Jizzakh (Turkestan Range) regions.

Acknowledgment

We express our gratitude to the scientific staff of the Institute of Botany of the Academy of Sciences of the Republic of Uzbekistan, who provided practical assistance in using the samples stored in the National Herbarium of Uzbekistan (TASH).

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