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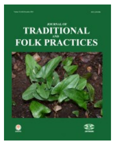

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Ecological niche modelling of *Trichopus zeylanicus* subsp. *travancoricus* (Bedd.) Burkill ex. K Narayanan (*Arogyapacha*) an ethnomedicinal herb

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Abstract

Trichopus zeylanicus subsp. *travancoricus* (Bedd.) Burkill ex. K Narayanan is an important ethnomedicinal plant. Restricted distributions were observed at southern Western Ghats, India and populations were growing as small, isolated patches. The purpose of this study was to predict the current and possible future distribution of *T. zeylanicus* subsp. *travancoricus* in India. The current distribution of the species depends on the availability of suitable habitats, capacity to disperse to other habitats and persist owe after establishment. The ecological niche modelling shows that a considerable number of suitable habitats could vanish in the coming years because of changing climatic conditions. The area mapped on both current and future space can help identify potential future habitats that could be valuable for eco-restoration and conservation efforts.

Keywords: Bioclimatic, Eco-tourism, Habitat, Perennial herb, Tribal communities

1. Introduction

The traditional knowledge of the tribal communities regarding the use medicinal and food plants were acquired through ages of experience usually passed by oral customarily, ethnomedical information are which guarded as secrets of certain individuals/families/communities. The ancient knowledge of various tribes and folklore systems of medicine provided a powerful and more effective strategy for the discovery of clinically useful compounds. *Trichopus zeylanicus* subsp. *travancoricus* (Bedd.) Burkill ex. K Narayanan is such a plant that was discovered, studied and developed as a product named 'Jeevani' from the lead obtained from the '*Kani*' tribes of the Agastyar hills of Kerala (Rajasekharan, 1996). It is a perennial rhizomatous herb under the family Dioscoreaceae commonly known as *'Arogyapacha'* for its ethnomedicinal usage (Fig. 1). In India, this sub-species is primarily dispersed in Agasthyamala Biosphere Reserve (ABR) of southern Western Ghats, particularly the Shendurney, Neyyar and Peppara Wildlife Sanctuaries of Kerala and Kalakkad Mundanthurai Tiger Reserve of Tamil Nadu states (Fig. 2). The species shows altitudinal and habitat specialization and is adapted to the high rainfall and humidity, and specific soil types prevalent in its natural habitat. The *Kani* tribes residing in the Agastyar hills of the southern Western Ghats traditionally use unripened fruits of the plant as health food for getting instant stamina and vitality. Phytochemical and pharmacological activities of this plant is resembling with the *Panax Ginseng,* a perennial plant whose root is the unique source of ginseng therefore the procumbent species is referred as 'Kerala Ginseng' (Pushpangadan *et a*l., 1988,Anilkumar *et al*., 2002).

Fig. 1. *Trichopus zeylanicus* subsp. *travancoricus* (Bedd.) Burkill ex. K Narayanan

In ecology, species distribution regulates both edaphological and environmental factors like soil types, soil and atmosphere moisture contents, sunlight exposure and elevation ranges. Also, climate change is forcing species to track suitable climatic conditions and shift their distribution ranges. Ecological niche models (ENM) have become a proactive tool to envisage and express the ecological niche of a species. One such tool is the Max-Ent (Maximum Entropy) model that can assess the climate change influences on *T. zeylanicus* subsp. *travancoricus* distribution. Due to climatic changes the structure and function of an ecosystem can alter by pathogen and insect outbreaks, exotic species, drought, landslides and windstorms (Dale *et al*., 2001). Rising temperatures and changing precipitation patterns will significantly affect the spatial distribution of species and some habitats may disappear completely (Anderegg *et al*., 2015). Many researchers predicted that the future bio-climate will harmfully affect the distributions of many species (Remya *et al*., 2015; Priti *et al*., 2016).

Due to its slow growth, restricted habitat and over harvesting for medicinal purposes, *Arogyapacha* is considered a vulnerable and rare species. Its conservation has become a matter of concern to protect this valuable plant from potential extinction. Understanding the habits of *Arogyapacha* is essential for its conservation and sustainable use in traditional medicine and other potential applications. Further research and conservation efforts are necessary to ensure the preservation of this unique and valuable plant species for future generations.

2. Materials and methods

The eco-physiological adaptations of *T. zeylanicus* subsp.*travancoricus* for both current and future potential distribution were assessed under different climate change scenarios. Located seven populations for the present study through a thorough review of the literature and frequent field visits where the species naturally occurs.These were Aryankavu, Kulathupuzha, Cheenikkala, Kallar, Bonacaud and Kottur in Kerala state and Poonkulam in Tamil Nadu state. In this study,

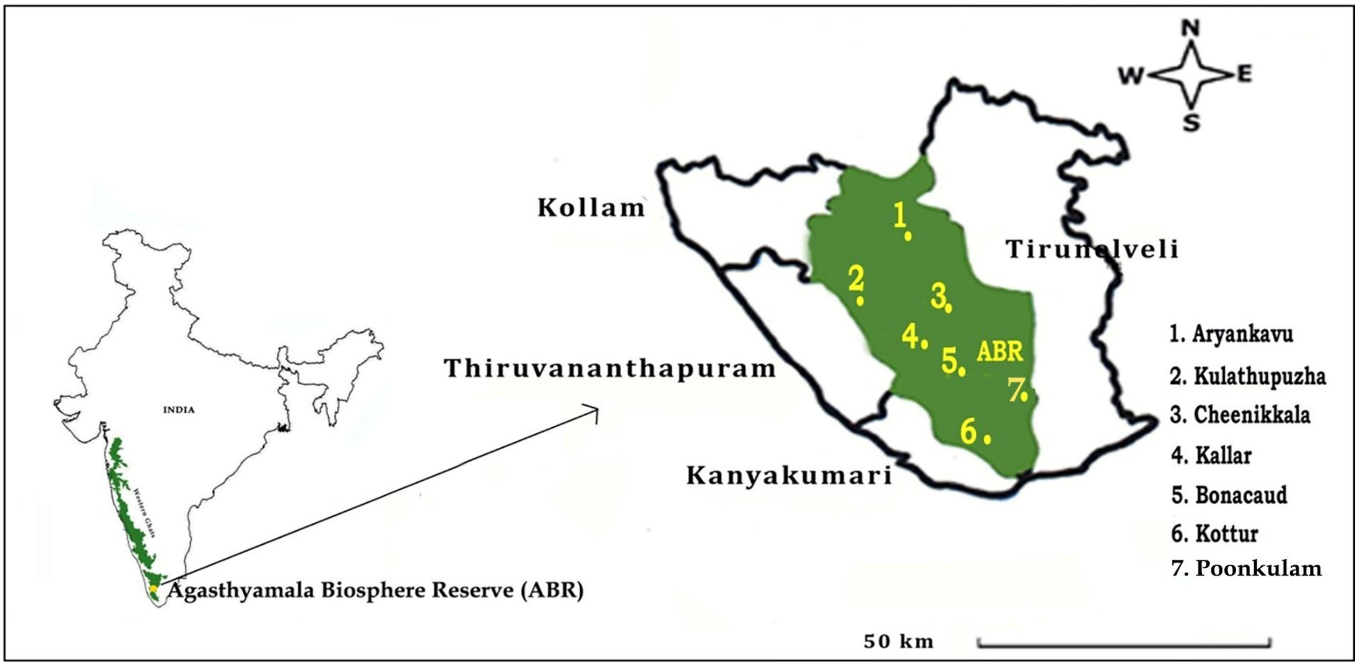

Fig. 2. Distribution map of *Trichopus zeylanicus* subsp. *travancoricus* (Bedd.) Burkill ex. K Narayanan

the coordinates of each candidate plant were marked using a global positioning system (GPS- Garmin eTrex 30). The current and future potential distributions of the species were identified using Max-Ent (version 3.4.1) and DIVA-GIS (version 7.5) software and were marked on the map. For this, the bioclimatic variables having spatial resolution of 30 arc seconds (~1 km^2) were derived from the observational data in WorldClim ver. 1.4. These variables contain information about monthly minimum, maximum, and mean temperatures from 1970 to 2000, as well as monthly mean areal precipitation.

A total of 19 bioclimatic variables as per the WorldClim database for the period 1970–2000 (Fick and Hijmans, 2017) (Table 1), among which eight are having higher percentage of contribution in our current study were used to predict the possible future climatic conditions of the candidate species. These were BIO14 (Precipitation of Driest Month), BIO1 (Annual Mean Temperature), BIO17 (Precipitation of Driest Quarter), BIO16 (Precipitation of Wettest Quarter), BIO6 (Min Temperature of Coldest Month), BIO12 (Annual Precipitation), BIO18 (Precipitation of Warmest Quarter) and BIO15 (Precipitation Seasonality).

In order to predict the future habitat aptness and related potential geographical distribution, bioclimatic layers for the period Representative Concentration Pathways (RCPs) 4.5 2070 obtained from WorldClim (http://www.worldclim.org/CMIP5, accessed on: 21.06.2023) was used. In future scenarios, the bioclimatic data for 2050 encompasses the mean values spanning from 2041 to 2060, whereas the data for 2070 encompasses the mean values from 2061 to 2080 (CESM, accessed on: 21.06.2023). RCPs are employed in climate modelling studies and research to depict potential climate scenarios that are believed to be contingent on greenhouse emissions in the upcoming years (CCSM4.0, accessed on: 21.06.2023). To determine the contribution of the bioclimatic variables, Jackknife test was also used.

3. Results and discussion

T. zeylanicus subsp. *travancoricus* distributions were observed at ABR of southern Western Ghats, India. Populations were restricted to montane forest of Peppara, Shendurney and Neyyar Wildlife Sanctuaries of Kerala and Kalakkad Mundanthurai Tiger Reserve of Tamil Nadu (Fig. 2). Seven distinct populations were identified in the area in between 100-1000 m above sea level and they are growing as small, isolated patches, with even within the same population showing fragmentation. Those populations are influenced and isolated by geographical barriers such as river, continuous rocks, roads, human settlements, plantations, barren soils, big canopy gaps, soil

Table 1. Description of bioclimatic variables used for Max-Ent model prediction

Sl. No.	Bioclimatic variable code	Bioclimatic variables
1	**BIO1**	**Annual Mean Temperature**
2	BIO2	Mean Diurnal Range (Mean of monthly (max temp – min temp)
3	**BIO3**	**Isothermality (BIO2/BIO7) (×100)**
4	BIO4	Temperature Seasonality (standard deviation ×100)
5	BIO5	Max Temperature of Warmest Month
6	**BIO6**	**Min Temperature of Coldest Month**
7	**BIO7**	**Temperature Annual Range (BIO5-BIO6)**
8	BIO8	Mean Temperature of Wettest Quarter
9	BIO9	Mean Temperature of Driest Quarter
10	BIO10	Mean Temperature of Warmest Quarter
11	**BIO11**	**Mean Temperature of Coldest Quarter**
12	**BIO12**	**Annual Precipitation**
13	**BIO13**	**Precipitation of Wettest Month**
14	**BIO14**	**Precipitation of Driest Month**
15	**BIO15**	**Precipitation Seasonality (Coefficient of Variation)**
16	**BIO16**	**Precipitation of Wettest Quarter**
17	**BIO17**	**Precipitation of Driest Quarter**
18	**BIO18**	**Precipitation of Warmest Quarter**
19	BIO19	Precipitation of Coldest Quarter

** Bold text indicates the fittest bioclimatic variables used for model construction after screening.*

characters, allelopathic effects of allied species and varied climates.

Climate changes, especially temperatures and altered precipitation patterns are altering the natural habitat and geographic range of plants, leading to a reduction in distribution areas. Camacho *et al*., (2010) reported that increased global temperature and changes in precipitation pattern alter the habitat and distribution of plant species, which may lead to extinction. These changes elevate the risk of extinction, especially for species characterized by small population sizes, habitat specialization, micro endemic distributions, and those already confined to limited geographical areas (Santiz *et al*., 2016). One of the main factors that controls and limits the spatial spread of a species is its ecological niche (Grinnell, 1917). The current study indicated that, *T. zeylanicus* subsp. *travancoricus* population is steadily declining due to climate change, habitat dwindling and human interference. The augmented global temperatures and variations in the precipitation severely affect the specific niche leads to changes in geographical distribution (Wani *et al*., 2021). Several factors also affect the distribution patterns which includes habitat degradation, human exploitation or inadequate conservation efforts (Barnosky *et al*., 2011). Despite extensive research in phytopharmacology, there is a lack of conservation reports addressing the shift in distribution patterns due to current climate changes of *Arogyapacha*. Urgent attention needs to be paid to the conservation of the species wild population and its ecological niche. The current study is valuable to know the future habitat aptness of this rare-endemic species in a conservation manner.

3.1. Ecological niche modelling of *T. zeylanicus* subsp. *travancoricus* under both current and future climate

In the current study, the (ecological niche modelling) Max-Ent model indicates that the present distribution of the *Arogyapacha* in India is restricted to the southernmost part of the Western Ghats and is exclusive to the ABR. All populations are located at montane areas in between 100-1000 m elevations with significant distributional variations. Topography plays a pivotal role in influencing species distribution, primarily through its impact on the microclimate (Coban *et al*., 2020). A crucial strategy for managing and protecting endangered and endemic species is predicting suitable ecological niches under current and future climatic situations. Different environmental, biotic and edaphic factors play the key role for species distribution in its habitat. On other hand, it is crucial to note that climate is typically viewed as the most important driver of species occurrence when niche modelling is done for larger geographical areas (Marino *et al*., 2011). In view of the current ecological niche modelling of *T. zeylanicus* subsp. *travancoricus* temperature and precipitation influenced the specific niche and enhanced the regeneration and adaptability.

3.2. Main climatic factors

The analysis indicated eight bioclimatic variables, which are known to influence the distribution and physiological performance of *T. zeylanicus* subsp. *travancoricus* (Table 2). Those climatic factors are Precipitation of Driest Month, Annual Mean Temperature, Precipitation of Driest Quarter, Precipitation of Wettest Quarter, Minimum Temperature of Coldest Month, Annual Precipitation, Precipitation of Warmest Quarter and Precipitation Seasonality. Based on the results of the Jack -knife test, the Precipitation of Driest Month (Bio14) was ranked as the top contributor (61.3 %) for *T. zeylanicus* subsp. *travancoricus* growth in its niche. In addition, Annual Mean Temperature (Bio1), Precipitation of Driest Quarter (Bio17) and Precipitation of Wettest Quarter (Bio16) constitute more than six percentage of the total environmental contribution (Table 2). *T. zeylanicus* subsp. *travancoricus* is highly sensitive to alterations in ecophysiological parameters and necessitates a specific ecological niche characterized by precise precipitation levels and suitable temperatures. Results from the Jack-knife test indicated that the precipitation was the most influential factor for this species (Bio15, Bio14, and Bio17) compared to other bioclimatic variables (Fig. 3). Receiver Operating Characteristic curve (ROC) showed maximum accuracy for the prediction (Fig. 4).

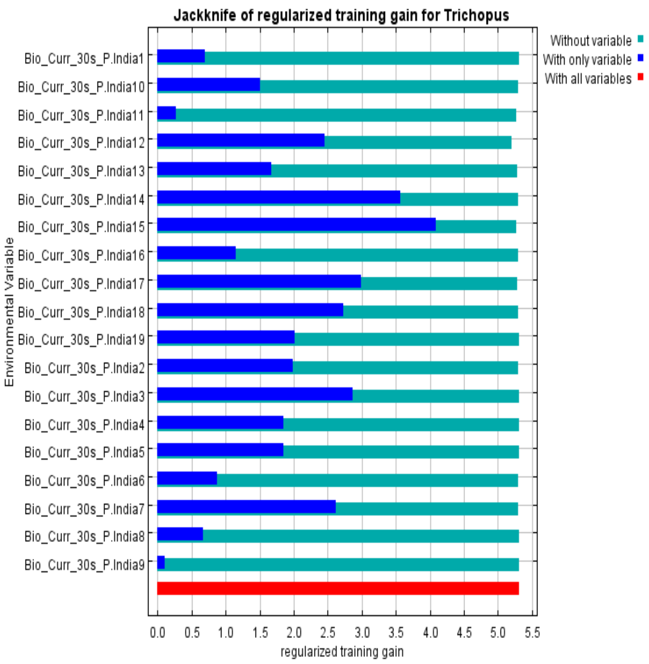

Fig. 3. Jackknife test results of the variables in the model.

Table 2. Major bioclimatic variables contribute the distribution of *T. zeylanicus* subsp.

Sl. No.	Variable	Percent contribution	Permutation importance
1	Bio_Curr_30s_P.India14	61.3	0
2	Bio_Curr_30s_P.India1	13.1	0
3	Bio_Curr_30s_P.India17	6.4	4.8
4	Bio_Curr_30s_P.India16	6.1	9.8
5	Bio_Curr_30s_P.India6	3.8	0
6	Bio_Curr_30s_P.India12	2.3	32.4
7	Bio_Curr_30s_P.India18	2.3	0
8	Bio_Curr_30s_P.India15	2	36
9	Bio_Curr_30s_P.India11	1.1	0.3
10	Bio_Curr_30s_P.India13	0.8	12
11	Bio_Curr_30s_P.India7	0.7	4.6
12	Bio_Curr_30s_P.India3	0.1	0
13	Bio_Curr_30s_P.India10	0	0.1
14	Bio_Curr_30s_P.India9	0	0
15	Bio_Curr_30s_P.India19	0	0
16	Bio_Curr_30s_P.India8	0	0
17	Bio_Curr_30s_P.India2	0	0
18	Bio_Curr_30s_P.India4	0	0
19	Bio_Curr_30s_P.India5	0	0

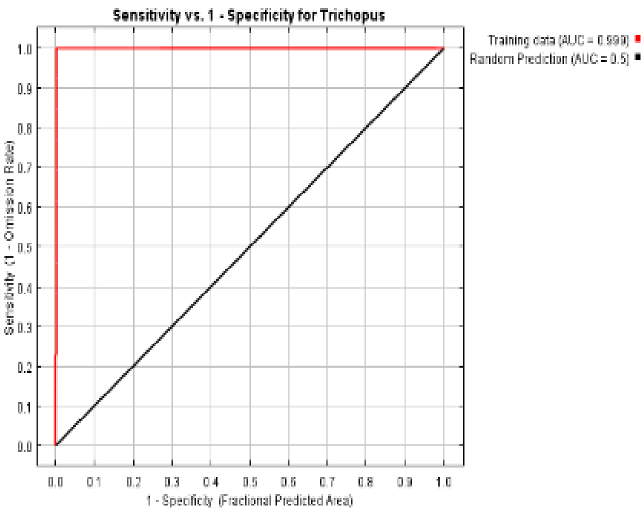

Fig. 4. Receiver Operating Characteristic curve (ROC)

The variability of the precipitation is another important factor that affects the distribution of species. Ecology and evolution experts agree that it is crucial to understand how various topographic and environmental factors shape and maintain the distribution range of a species (Wani *et al*., 2021). In order to determine whether a species is suitable or not for a particular niche, these variables offer logical classifications on the involvement of environmental agents (Sanchez-Cordero *et al*., 2005). The spatial and temporal variations of different vegetation indices, such as Enhanced Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) are clear indications of the plausible influence that environmental gradients like climate, soil, and geology have on different vegetation indices in a certain area (Wani *et al*., 2021).

Field observations and ecological niche modelling revealed that currently the potential distribution of *T. zeylanicus* subsp. *travancoricus* in India is being restricted to ABR as illustrated in Plate 1a. The distribution depends on the availability of suitable habitats, capacity to disperse to other habitats and persist owe after establishment and also showing the population dwindling nature. The changes in the future potential distribution of the candidate species were assessed by the difference among the current and future spatial distribution maps. Based on our research findings, the potential current distribution of *T. zeylanicus* subsp. *travancoricus is* expected to experience a substantial decline by 2070 due to ongoing global warming, resulting in a significant reduction in habitat suitability (under the RCP 4.5 2070 scenario) as illustrated in Plate 1b.

Several researchers said that decline in the appropriateness of different plant species' habitats due to a rise in greenhouse gases concentration under RCP's 4.5 (Dullinger *et al.,* 2012; Molloy *et al.,* 2013; Barrett *et al.,* 2013). In the case of *Myristica dactyloides* Gaertn., Max-Ent projection for the years

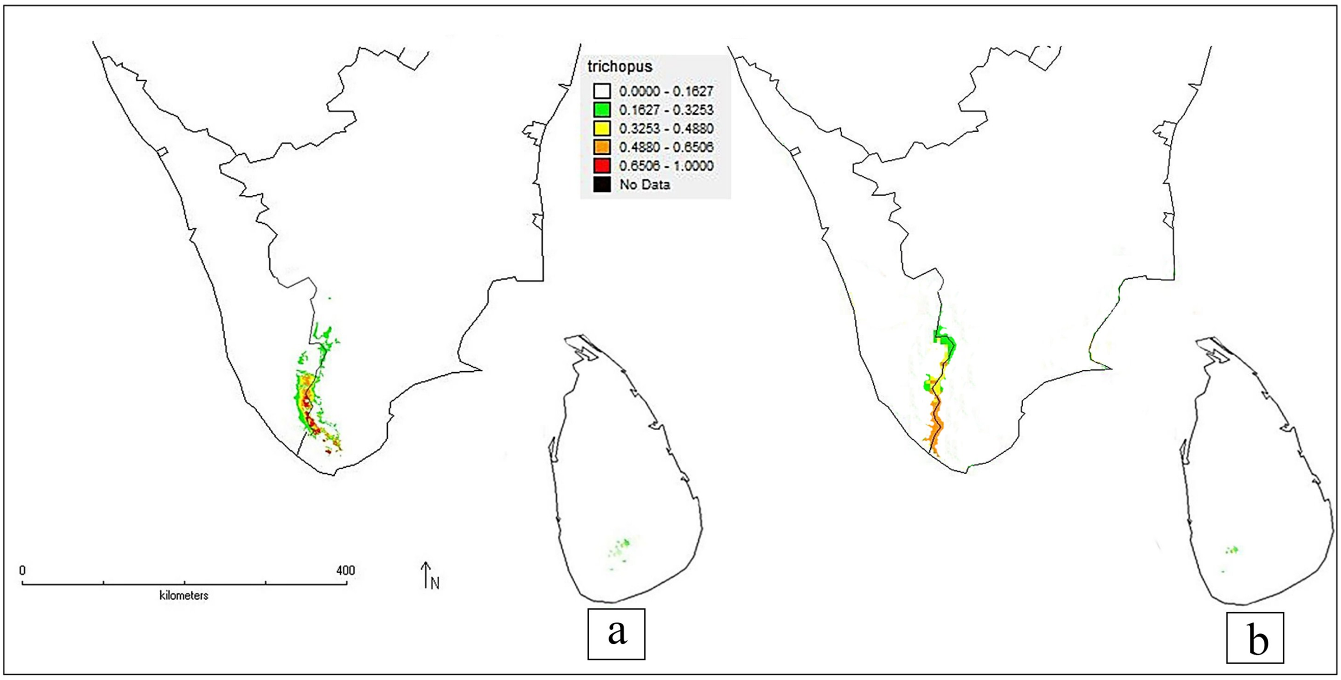

Plate 1. a. Suitable climate spaces in India for potential distribution of *Trichopus zeylanicus* subsp. *travancoricus*; b. Suitable climate spaces in the future India for potential distribution of *Trichopus zeylanicus* subsp. *travancoricus*

2050 and 2070 revealed that, there will be a considerable decrease in suitable habitats (Remya *et al.,* 2015). The climate change also affected the future distribution of *Hypsipyla robusta* Moore, favourable areas will decrease enormously within 2055 (Djotan *et al*., 2018). Climate change is contributing significantly to the spatial distribution of *Garcinia imbertii* Bourd., a critically endangered plant species, and some habitats are predicted to disappear completely in the coming years (Anto *et al*., 2023). Wani *et al*. (2021) reported that, *Rheum webbianum* Royle is a herbaceous perennial plant belonging to the Polygonaceae family and under the future climatic conditions, there is a significant reduction in the habitat suitability (RCP 8.5 for 2070).

4. Conclusion

This study utilizes ENM and population attributes to identify both current and future suitable habitats for *T. zeylanicus* subsp. *travancoricus*. It employs high-resolution spatial data, occurrence data and environmental variables to create the first predicted potential habitat distribution map for the species in the southern Western Ghats of India. This map can be valuable for discovering new populations, predict the future habitat aptness and utilized for the re-introduction of the '*Arogyapacha'*. However, under future climate scenarios, this species is projected to experience a significant reduction in habitat suitability. Considering the small size of wild populations, their fragmented distribution and human disturbances, we propose the following suggestions in the context of conservation: (1) Prioritize the *in-situ* conservation of the existing populations while minimizing human interference. (2) Invest in strengthening research efforts concerning the biological characteristics of the species, developing methods for artificial cultivation and genetic improvement. (3) Eco-restoration practices can be implemented in potential future areas with minimal human activity to maximize the size of wild populations. (4) Encourage *Kani* tribal community to cultivate the species in and around the tribal hamlets for conservation and ensuring sustainable utilisation of cultivated plants. The insights provided by the current study are invaluable for understanding the future habitat suitability of this rare ethnomedicinal species in the context of conservation.

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