Spatial analysis for *Piper* species distribution in India

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Summary
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Kerala State is the land of Black pepper, producing 97% of India's total output. There are about 16 species of pepper in Kerala, and it is essential to understand their genetic diversity. Surveys were conducted in various locations in Kerala and *Piper* species were collected. These were mapped using DIVA-GIS software for spatial analysis of plant genetic resource data, and the collected data were subjected to analysis for *Piper* species richness. Species richness is clearly not homogenously distributed within Districts. *Piper nigrum* and some of the related species originate in Kerala. DOMAIN and Bioclim models of DIVA-GIS were applied to map potential distribution sites of *Piper* species occurrence in Kerala. Based on the distribution and species richness, the areas where *Piper* species might be found have been predicted. DIVA-GIS was also used to predict the possible distribution of *Piper* species in other parts of India. Based on these prediction distribution maps, it is expected that most areas of north-east India, coastal Andhra Pradesh, Orissa and West Bengal are also likely to have many *Piper* species, while the chances of distribution of *Piper* species in other parts of the country are remote. The ideal annual rainfall distribution for these *Piper* species ranges between 2200 and 2700 mm and the frequency of the *Piper* species studied is very high in this range, though *Piper* species also occur in areas with 1500 to 3500 mm/yr. The distribution of *Piper* species at different altitudes was also studied and mapped using DIVA-GIS. Interestingly, all the species occur in the Silent Valley National Park in the Western Ghats, confirming earlier reports. The mapping exercise highlighted the joint effects of climate and soil on the distribution of wild *Piper* spp. The present study is the first report on the geographical distribution of *Piper* species using GIS.

Key words: GIS; plant exploration; wild relatives; *Piper* species.

Résumé
Analyse spatiale de la distribution d'espèces de *Piper* en Inde

L'État de Kerala est le pays du poivre noir, assurant 97 % de la production totale de l'Inde. Il existe environ 16 espèces de poivre au Kerala, dont il est essentiel de connaître la diversité génétique. Des études ont été réalisées dans diverses situations géographiques au Kerala et des espèces de *Piper* ont été collectées. Elles ont été cartographiées en utilisant le logiciel SIG DIVA pour l'analyse spatiale des données des ressources phytogénétiques et les données collectées ont été analysées pour déterminer la richesse en espèces de *Piper*. La richesse en espèces n'est manifestement pas distribuée de manière homogène dans les différents districts. *Piper nigrum* et certaines espèces apparentées sont originaires du Kerala. Les modèles DOMAIN et Bioclim de SIG DIVA ont été utilisés pour cartographier les sites de distribution où des espèces de *Piper* sont potentiellement présentes au Kerala. En se basant sur la distribution et la richesse en espèces, nous avons prédit les zones où des espèces de *Piper* peuvent être trouvées. Le SIG DIVA a également été utilisé pour prédire la distribution possible d'espèces de *Piper* dans d'autres parties de l'Inde. En se basant sur ces cartes de prédiction de la distribution, nous nous attendons à ce que la plupart des régions du nord-est de l'Inde, de la côte de l'Andhra Pradesh, l'Orissa et l'ouest du Bengale abritent également de nombreuses espèces de *Piper*, alors que la probabilité d'observer des espèces de *Piper* dans d'autres parties du pays est faible. Le régime annuel idéal des pluies pour ces espèces de *Piper* est compris entre 2200 et 2700 mm et la fréquence des espèces étudiées est très élevée dans cette fourchette, bien que des espèces de *Piper* soient également présentes dans les zones arrosées par 1500 à 3500 mm/an. La distribution d'espèces de *Piper* à différentes altitudes a également été étudiée et cartographiée en utilisant le SIG DIVA. Il est intéressant de constater que toutes les espèces se rencontrent dans le parc national de Silent Valley National dans les Ghats occidentaux, confirmant des observations antérieures. L'étude cartographique met en évidence les effets conjoints du climat et du sol sur la distribution de *Piper* spp. sauvages. Cet article est la première étude de la distribution d'espèces de *Piper* réalisée à l'aide d'un SIG.

Resumen
Análisis espacial de la distribución de especies de *Piper* en la India

El Estado de Kerala es la tierra de la pimienta negra, de donde proviene el 97 % de la producción total de la India. En Kerala existen unas 16 especies de pimienta y resulta esencial comprender su diversidad genética. Se efectuaron relevamientos en diversas ubicaciones de Kerala, recogiéndose especies de *Piper*. Con el programa DIVA-GIS de análisis espacial de datos de recursos fitogenéticos se elaboraron mapas de esas ubicaciones, y se analizaron los datos recogidos para determinar la riqueza de especies de *Piper*. Es claro que dicha riqueza no se distribuye de manera homogénea entre los distritos. En Kerala tienen su origen *Piper nigrum* y algunas especies vinculadas. Para mapear la posible distribución de los sitios donde hay especies de *Piper* en Kerala se aplicaron los modelos DOMAIN y Bioclim de DIVA-GIS. Las zonas donde se podían hallar especies de *Piper* se predijeron sobre la base de la distribución y riqueza de especies. También se empleó DIVA-GIS para predecir la distribución posible de especies de *Piper* en otras partes de la India. Sobre la base de estos mapas de predicción de la distribución, se supone que en la mayoría de las zonas de la India nororiental, la zona costera de Andhra Pradesh, Orissa y Bengala Occidental haya también muchas especies de *Piper*, mientras que la posibilidad de que se encuentren especies de *Piper* en otras partes del país es remota. La distribución anual ideal de precipitaciones pluviales para estas especies de *Piper* va de 2200 a 2700 mm y en esta gama la frecuencia de las especies de *Piper* examinadas es muy elevada, aunque también hay especies de *Piper* en zonas con 1500 a 3500 mm/año. Empleando DIVA-GIS se relevó y mapeó también la distribución de especies de *Piper* a diferentes alturas. Es interesante notar que todas las especies presentes en el Silent Valley National Park de Gaths occidental confirmaron informes anteriores. El programa de mapeado puso de relieve el efecto conjunto del clima y los suelos en la distribución de especies silvestres de *Piper*. Este es el primer informe sobre la distribución geográfica de las especies de *Piper* en que se emplea GIS.

Introduction

Black pepper is native to Malabar, a region on the western coast of south India, and today this region forms part of the Indian union state of Kerala. Black pepper has been cultivated there for more than two thousand years. Though earlier cultivation was confined to Malabar, it reached South-east Asia more than two thousand years ago, and has been grown in Malaysia and Indonesia since about that time. In the last decades of the 20th century, pepper production increased dramatically as new plantations were founded in Thailand, Viet Nam, China and Sri Lanka. In the New World, Brazil is the only important producer; pepper plantations there go back to the 1930s. However, the most important producers are India and Indonesia, which together account for about 50% of global traded volume. In trade, the pepper grades are identified by their origin. The most important Indian grades are *Malabar* and *Tellicherry* (*Thalassery*). The Malabar grade is regular black pepper with a slightly greenish hue, while *Tellicherry* is a special product. Both Indian black peppers, but especially the *Tellicherry* grade, are very aromatic and pungent.

According to Ravindran (2000), most of the *Piper* species occur in the semi-evergreen and moist deciduous forests of the Western Ghats of India. The present study is an attempt to understand the patterns of genetic diversity of *Piper* species occurring in Kerala, a southern province of India, using Geographical Information System (GIS) technology. No reports could be found of any critical study of the effect of climatic components, nor attempts to classify the area of pepper cultivation according to their eco-climatic suitability (Sadanandan 2000).

In this present study, mapping of collection data of *Piper* spp. from Kerala has been done to understand where the species naturally occur or might successfully be introduced. Kerala supplies about 97% of the country's pepper production and 16 *Piper* spp. have been recorded from the various forest ranges of the state. This paper describes a geographical approach to identifying biodiversity hotspots, prioritizing regions for conservation action, and identifying gaps in collections and new cultivation areas. The methodology used for this study follows the approach of Guarino et al. (2001) for the application of GIS to the process of plant exploration, conservation and subsequent use.

Materials and methods

Collection data of 84 *Piper* spp. collections from 9 districts of Kerala were used. The *Piper* spp. collected are given in Table 1, together with geographical origins.

The collecting sites of these *Piper* spp. collected by the Indian Institute of Spices Research (IISR) were tabulated, together with the approximate longitude and latitude of the collection sites. Using DIVA-GIS software, species richness based on diversity analysis was mapped, as well as distribution patterns relative to various climatic parameters.

Table 1. Distribution by administrative district of *Piper* spp. collected in Kerala State, India.

District	*Piper* species collected
Idukki	P. argyrophyllum
	P. argyrophyllum
	P. attenuatum
	P. galeatum
	P. hymenophyllum
	P. longum
	P. mullesua
	P. nigrum
	P. schmidtii
	P. sugandhi
	P. trichostachyon
	P. wightii
Kollam	P. argyrophyllum
	P. attenuatum
	P. hapinum
	P. longum
	P. nigrum
	P. hymenophyllum
Kottayam	P. argyrophyllum
	P. attenuatum
	P. betle
	P. hapinum
	P. longum
	P. nigrum
Palaghat	P. attenuatum
	P. galeatum
	P. hymenophyllum
	P. mullesua
	P. nigrum
	P. silentvalleyensis
	P. sugandhi
	P. tricostachyan
Malapuram	P. argyrophyllum
	P. attenuatum
	P. nigrum
Pathanamthitta	P. attenuatum
	P. galeatum
	P. hymenophyllum
	P. longum
	P. nigrum
	P. sugandhi
	P. trichstachyon
Trissur	P. argyrophyllum
	P. attenuatum
	P. hymenophyllum
	P. nigrum
	P. sugandhi
Trivandrum	P. attenuatum
	P. barberi
	P. betle
	P. longum
	P. nigrum
Wynad	P. attenuatum
	P. galeatum
	P. hymenophyllum
	P. longum
	P. mullesua
	P. nigrum
	P. sugandhi
	P. tricostachyan

Results and discussion

Mapping and locating *Piper* spp. distribution

The data were subjected to spatial analysis for species richness of *Piper* (Figure 1) and showed that there was a high level of diversity in Wayanad District, with moderately high diversity in areas bordering Kozhikode and Wayanad, Palghat District (where Silent Valley National Park is situated), and in Kollam district bordering Tamil Nadu. Species richness is clearly not homogenously distributed across districts. There are a few areas with many species and many areas with only a few species. *Piper nigrum* and some of the related species originated in the Western Ghats.
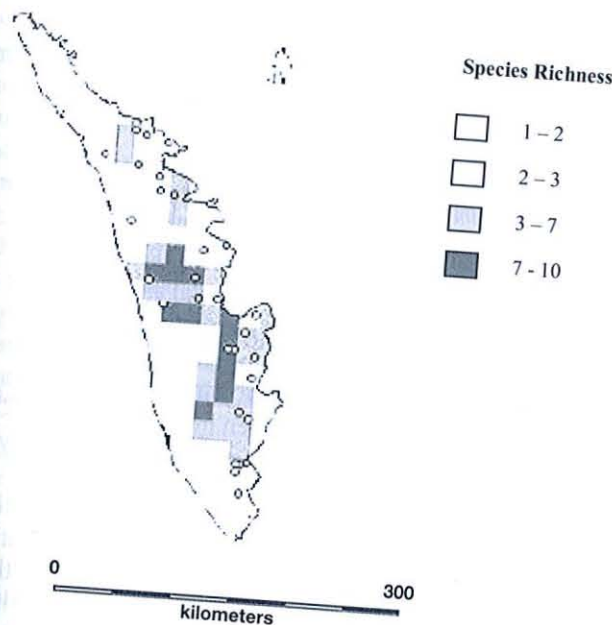
Species richness and diversity analysis

Applying the Shannon diversity index (Figure 2) revealed that, while there is a high diversity index in Wayanad district (Sugandhagiri), moderately high diversity occurs in Kozhikode and Palghat. There are many areas in Idukki and Kollam where moderate diversity exists, which could be surveyed for further collecting.

Prediction of high potential areas of habitat

Using DIVA-GIS, a Geographical Information System for the analysis of biodiversity data (see http://research.cip.cgiar.org/confluence/display/divagis/Home), the DOMAIN model was applied to map potential distribution of *Piper* spp. in Kerala. Ten BIOCLIM climatic parameters were used to study the predicted distribution of *Piper* species, using the BIOCLIM and DOMAIN models provided with DIVA-GIS. Based on the distribution and species richness, the areas where *Piper* species may be available for further survey has been predicted using DOMAIN and BIOCLIM models (Figure 3). The entire Kerala State still abounds in rich *Piper* spp. diversity, but the BIOCLIM model (not illustrated) indicates that Kasaragod and Kannur have a limited distribution of *Piper* spp. Only limited distribution of *Piper* spp. was identified in Kollam along the coast and in Allepey District.

Using the collecting data from Kerala state, DIVA-GIS was used to predict the distribution of *Piper* spp. in other parts of India (Figure 4). From the figure it is evident that, besides Kerala, parts of Karnataka and many areas in

Figure 1. Richness analysis of *Piper* species in Kerala.

Species Richness
- 1 – 2
- 2 – 3
- 3 – 7
- 7 – 10
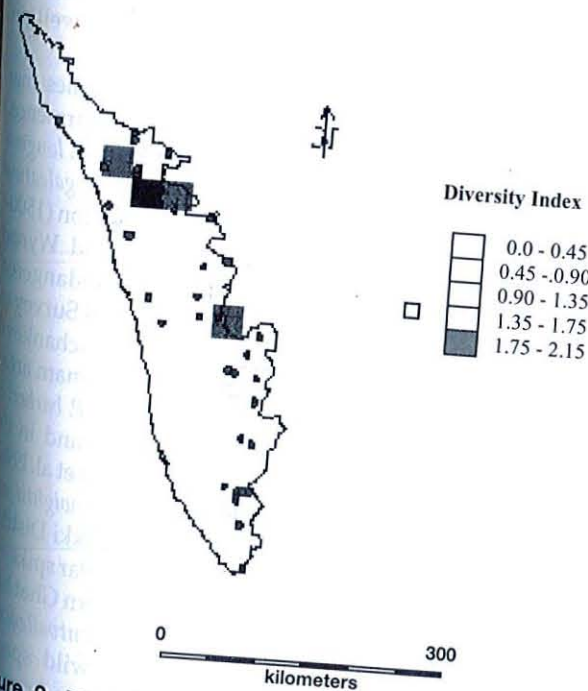
Figure 2. Diversity analysis of *Piper* species in Kerala (Shannon Diversity Index).

Diversity Index
- 0.0 - 0.45
- 0.45 - 0.90
- 0.90 - 1.35
- 1.35 - 1.75
- 1.75 - 2.15
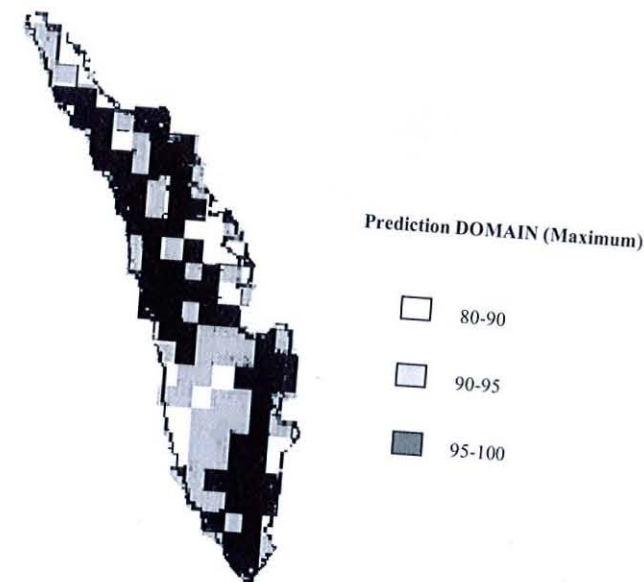
Figure 3. Prediction of *Piper* species distribution or suitable sites for cultivation in Kerala, based on DOMAIN (Maximum) prediction model.

Prediction DOMAIN (Maximum)
- 80-90
- 90-95
- 95-100

Tamil Nadu and Srikakulam District of Andhra Pradesh are also suitable for *Piper* spp. Most areas of north-east India, coastal Andhra Pradesh, Orissa and West Bengal are also likely to have many *Piper* spp. A subsequent survey in north-East India indicated the presence of several species, namely *P. peepuloides, P. thomsoni, P. sylvaticum* and others. The likelihood of *Piper* species in other parts of the country are remote. It is clear that species occurrence is highly correlated with climatic conditions. The ideal
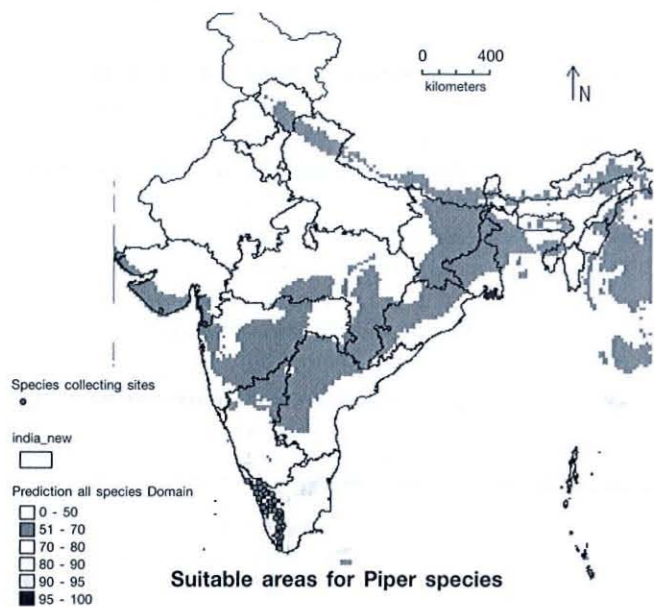

Figure 4. Prediction of distribution of *Piper* spp. in India or suitable sites for their cultivation.
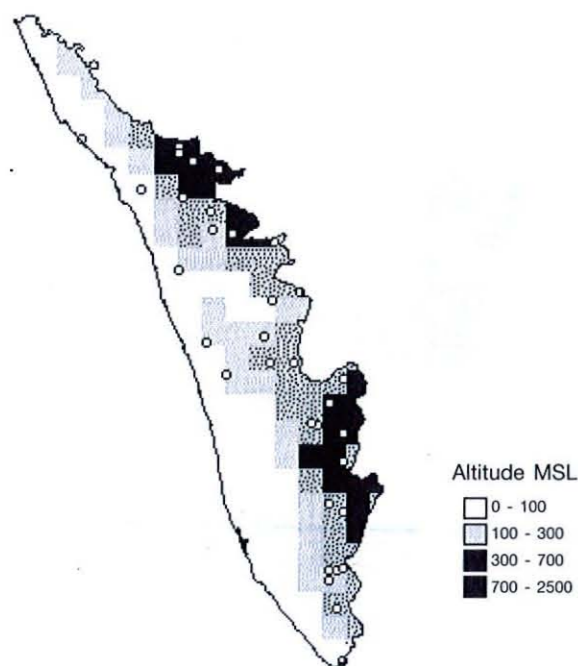

Figure 5. Piper species distribution in Kerala State, India, with respect to elevation.

temperature for *Piper* spp. is between 22° and 27.5°C, with the greatest occurrence between 26° and 28°C. Another climatic parameter that has significant influence on the distribution of *Piper* spp. is rainfall. The ideal annual rainfall is between 2200 and 2700 mm, even though *Piper* spp. are found in areas with 1500 to 3500 mm/yr precipitation. According to Sadanandan (2000), well distributed rainfall in the range of 1000 to 3000 mm/yr is best suited for proper growth and development of pepper.

The distribution of *Piper* species at different altitudes was also studied (Figure 5). It is clear from the figure that the distribution of species is very poor at altitudes below 100 m, with maximum distribution occurring at altitudes between 100 and 250 m and between 750 and 1000 m. *P. nigrum* occurs in all these altitudinal ranges. *P. longum, P. attenuatum, P. hapinum* and *P. hymenophyllum* occur up to 300 m, while *P. sugandhi, P. silentvalleyensis, P. mullesua, P. argyropyllum, P. barberi, P. trichostachyon* and *P. wightii* occur above 700 m. Interestingly, all these species occur in Silent Valley of the Western Ghats. Ravindran (2000) reported that most *Piper* species occur at an elevation of up to 1500 m. They also indicated the distribution of various species at different altitudes. Though the original home of pepper is the Western Ghats and adjoining plains of India, no effort is so far known to have been made to study critically the effects of components of climate and to then classify the areas according to their suitability (Sadanandan 2000).

Among the soil types of Kerala, Ultisols constitute 54% of the land area, with Inceptisols (30%), Entisols (6%), Mollisols (1%) and Alfisols (1%). Among these, Inseptisols are best for pepper growth, followed by Alfisols and Ultisols. The collection areas have these soil types. However, Entisols are also good for pepper cultivation and all the low-lying coastal area and the river banks are considered Entisols, and pepper cultivation does well on them.

The map with species and collection sites implies that climate and soil have an impact on wild *Piper* spp. presence. *P. attenuatum, P. hymenophyllum, P. argyrophyllum, P. longum* and *P. nigrum* are found in almost all the districts. *P. galeatum* and *P. trichostachyon* were found at medium elevation (1500–2500 m) in Idukki, Pathanamthitta, Palaghat and Wynad Districts (Ravindran 2000). *P. hapnium*—an endangered species listed in the red data book of the Botanical Survey of India—was collected from the Sabari hills and Achankovil forests of Pathanamthita District, and the Kuttikanam areas of Kottayam District at between 300 and 600 m. *P. barberi* is considered an endangered species, and was found in the Agasthimala area, and re-described (Nirmal Babu et al. 1998). High-elevation species like *P. schmidtii* and *P. wightii* are distributed on the tops of the Munnar hills, Idukki District, while *P. mullesua*—a medium climber with globular spike—is found at between 2500 and 4500 m on the Western Ghat hills of Idukki Wynad and Palaghat Districts. *P. silentvalleyensis* (Ravindran et al. 1987), the only bisexual wild species reported from south India, was found in the deep forests of Silent Valley, Palaghat District.

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