Prediction of potential geographic distribution of exotic nematode, *Aphelenchoides fragariae* in India based on MaxEnt ecological niche modelling

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Abstract

Strawberry crimp nematode, Aphelenchoides fragariae *is an important ecto- and endoparasite affecting several plant species including ornamental plants. This nematode is polyphagous and invasive in nature, not reported to occur in India and has been listed as a quarantine pest in India. Understanding suitable habitat and potential geographic distribution of* A. fragariae *in India would greatly help to know its establishment and the extent of spread. The maximum entropy (MaxEnt) model was used in this study to identify potential geographic distribution in India under current climatic conditions. The MaxEnt model provided the reliable prediction of climate suitability for* A. fragariae *in India as measured by AUC values of 0.972 for training data and 0.942 for test data. The model identified highly suitable regions for A. fragariae that are mainly located in Northern and Eastern parts of India, such as Himachal Pradesh, Uttarakhand, Arunachal Pradesh and few places in Jammu and Kashmir. Among the bioclimatic variables, isothermality (Bio3) and precipitation of driest month (Bio14) have more influence on geographic suitability for* A. fragariae *as indicated with highest gain value in Jackknife test.*

Keywords: *Aphelenchoides fragariae,* prediction, distribution, MaxEnt, modelling

Introduction

Strawberry crimp nematode, *Aphelenchoides fragariae* is an ecto- and endoparasite of the above-ground parts of plants and associated with at least 621 plant species and varieties from 287 genera (Khan *et al.,* 2007; 2008; Sanchez-Monge *et al*., 2015) including strawberries, ferns, foliage and flowering plants, bedding plants, and herbaceous perennials such as *Stachy riederi*, *Helianthus tuberosus* and *Weigela subsessilis*. *A. fragariae* is an important quarantine pest for India and is regulated as per Plant Quarantine (Regulation of Import into India) Order, 2003. This potentially economically important nematode having morphological variations and redescribed with additional characteristics (Khan *et al.,* 2007b), intercepted on strawberry, *Fragaria* sp. and orchids imported from Australia, The Netherlands and USA at ICAR-National Bureau of Plant genetic Resources (ICAR-NBPGR), New Delhi (Lal and Rajan, 2005). The unidentified species of *Aphelenchoides* spp. were also intercepted on several horticultural crops (Lal and Rajan, 2005). *A. fragariae* is reported to cause losses of about millions dollars each year in the ornamental nursery industry (Jagdale and Grewal, 2006).

The *A. fragariae* is a polyphagous pest, mainly attacks on aerial parts of plants and has wide host range. It causes chlorotic blotches or vein-delimited lesions that turn necrotic over time on leaves (Chizhov *et al.,* 2006; Khan *et al.,* 2007; 2008; Kohl *et al.,* 2010) necrosis, distortion, deformation and dwarfing of the leaves, stems, flowers or bulbs, leaf tattering and defoliation (McCuiston *et al.,* 2007) on several plant species. The nematode is an invasive species and complete life cycle in 10-11 days at 18°C. Mode of reproduction is bisexual and amphimictic. Feeding habit is migratory ecto- and endoparasite. The nematode can survive under unfavourable conditions in a quiescent stage (anhydrobiosis) and disperse through bulbs, cut flowers and other propagative materials (Singh *et al.,* 2013).

Maximum entropy (MaxEnt) is widely used for prediction of suitable climate area for pathogens, insect pests and cultivation of crop plants under current and future climate in several countries (Sivaraj *et al.,* 2016, 2016a; Wang *et al.,* 2018; Fand *et al.,* 2020) but not much used to assess or predict suitable climatic areas for plant parasitic nematodes. The reason could be due to the fact that most of the plant parasitic nematodes are soil inhabiting and mainly attack on below ground parts. However, many economically important plant parasitic nematodes can infect above ground parts of plants such as leaves, flowers, stems, ear heads, buds etc. and MaxEnt can be used to predict the potential risk of these nematodes. The atmospheric temperature, relative humidity and other environmental factors greatly influence the infection and development of aerial feeding nematodes (Jagdale and Grewal, 2006; Khan and Ghosh, 2011; Tang *et al.,* 2021). MaxEnt model is one of the reliable methods for predicting *Bursaphelenchus xylophilus* which causes pine wilt diseases (Tang *et al.,* 2021) and burrowing nematode, *Radopholus similis* in China (Yun-sheng *et al.,* 2007). *A. fragariae* has a wide host range and high dispersal ability; forty-seven countries have a legislation mechanism for regulating the movement of *A. fragariae* in international trade (Lehman, 2004). Therefore, the purpose of this study was to determine the potential geographic distribution of this exotic nematode, *A. fragariae* in India under current climatic conditions through MaxEnt ecological niche modeling.

Materials and methods

The *A. fragariae* is of quarantine significance to India was selected for the study. The data on current distribution of *A. fragariae* in various geographical regions of the world obtained from invasive species compendium, CABI database (www.cabi.org/isc/datasheet/6381). The places of occurrence of nematodes were used as presence-only data to predict its potential geographic distribution in India. For mapping potential distribution at current climatic conditions, reference data for the year 1950 to 2000 with 2.5 arc-minutes resolution (~5 km at the equator) were used. MaxEnt software (Version 3.4.4) was used for geographic distribution modelling (Steven et al., http://biodiversityinformatics.amnh.org/open_source/maxent/). DIVA-GIS open source software version 7.5 was used to generate gridmaps (http://www.diva-gis.org). MaxEnt model was run with the following settings: auto-features (feature types selected automatically based on the training sample size), 64 presence records used for training, 7 for testing, 10064 points used to determine the MaxEnt distribution, output format: logistic, environmental layers used: 19 (all continuous), algorithm terminated after 500 iterations (5 seconds), regularisation multiplier = 1 and replicates = 10.

Results and discussion

The MaxEnt model provided the reliable prediction of climate suitability for *A. fragariae* in India as measured by AUC values of 0.972 for training data and 0.942 for test data (Fig 1.). The predicted existence probabilities between 0 and 1 used for geographic suitability were categorized as highly suitable (0.8–1.0), optimally suitable (0.6-0.8), moderately suitable (0.4–0.6), marginally suitable (0.2-0.4) and unsuitable (0–0.2) by Fand *et al.,* (2020). Based on this, current suitable habitats for potential geographic occurrences of *A. fragariae* in India in present climatic conditions are presented on a map (Fig 3). The highly suitable regions are mainly confined to Northern and Eastern parts of India such as Himachal Pradesh, Uttarakhand, Arunachal Pradesh and few places in Jammu and Kashmir with probability threshold value of 0.79 to 1.0. The optimally suitable regions are also located in Northern and Eastern parts of India including Meghalaya, Mizoram, and few locations in high altitude regions of Central and Southern India with probability threshold value of 0.59 to 0.79. The regions with probability threshold values of 0.39-0.59 and 0.19 to 0.39 shown on the map were classified as moderately and marginally suitable regions respectively, for the establishment of *A. fragariae*.

The Jackknife test for importance of bioclimatic variables indicated that isothermality (ratio of diurnal variation to annual variation in temperatures, Bio3) and precipitation of driest month (Bio14) have more influence on geographic suitability for *A. fragariae* as indicated with highest gain value in Jackknife test (Fig. 2). The cumulative percent contribution of these two bioclimatic variables is 66.9. Other temperature and precipitation related bioclimatic variable influence the geographic suitability of *A. fragariae* are annual mean temperature (Bio1), mean diurnal range (Mean of monthly (max temp - min temp)) (Bio02), precipitation of wettest month (Bio13) and precipitation seasonality (Bio15) (Fig. 3). Similarly, Jagdale and Grewal (2006) observed that temperature and relative humidity influence behavior of *A. fragariae* on *Hosta* spp. Similarly, bioclimatic variables related to precipitation play an important role in the spatial distribution of *B. xylophilus* affecting pine trees (Tang *et al.,* 2021). The large fluctuation of foliar nematode population *A. besseyi* infecting the aerial part of tuberose is also greatly influenced by relative humidity (RH), rainfall and air-temperature (Khan and Ghosh, 2011).

A. fragariae is adapted to tropical and temperature climatic conditions. In India, this nematode species has suitable hosts, including strawberries and several ornamental plants that are available throughout the year. *A. fragariae* nematodes can survive in propagating materials and potential to enter/spread through nursery stocks/trades in ornamentals. *A. fragariae* can cause economic damage to several crop plants and also reduce the aesthetic value of ornamental plants. Based on the present study, *A. fragariae* if introduced to India, may propagate, establish, multiply and assume a status of an economically important nematode pest, mainly in Himachal Pradesh, Uttarakhand, Arunachal Pradesh and a few places in Jammu and Kashmir warranting strict quarantine vigilance.

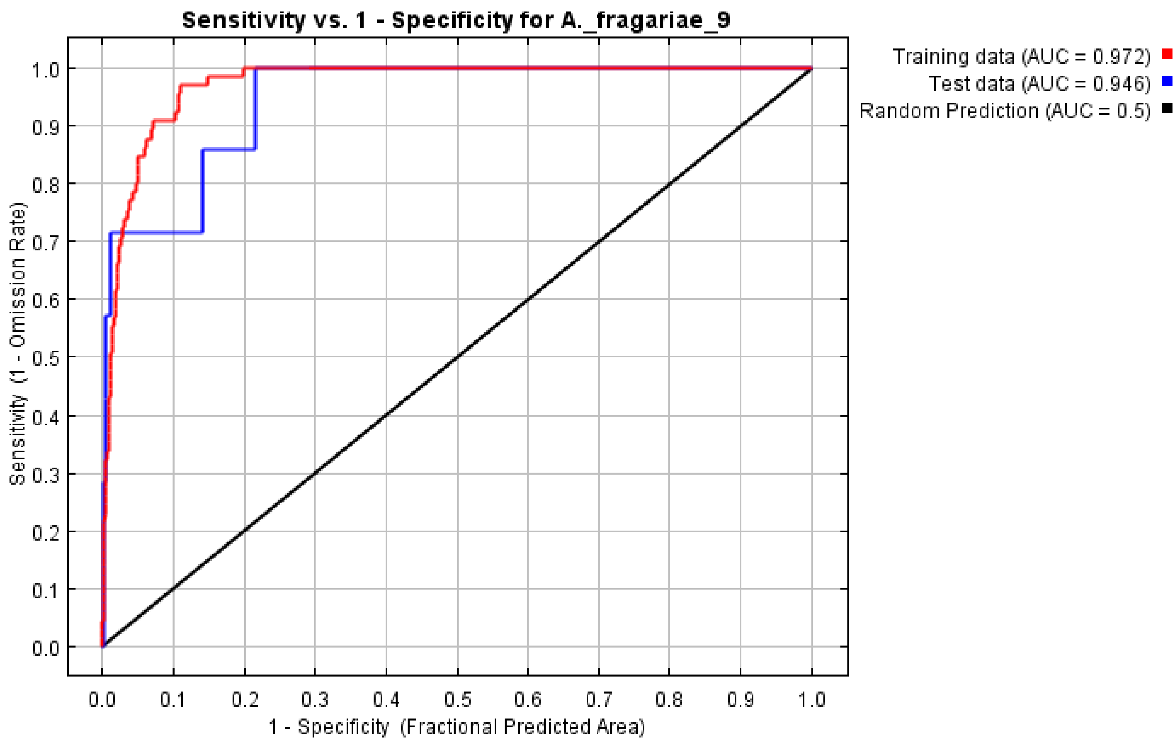

Figure 1. Receiver operating curve (ROC) for *Aphelenchoides fragariae* habitat suitability model.

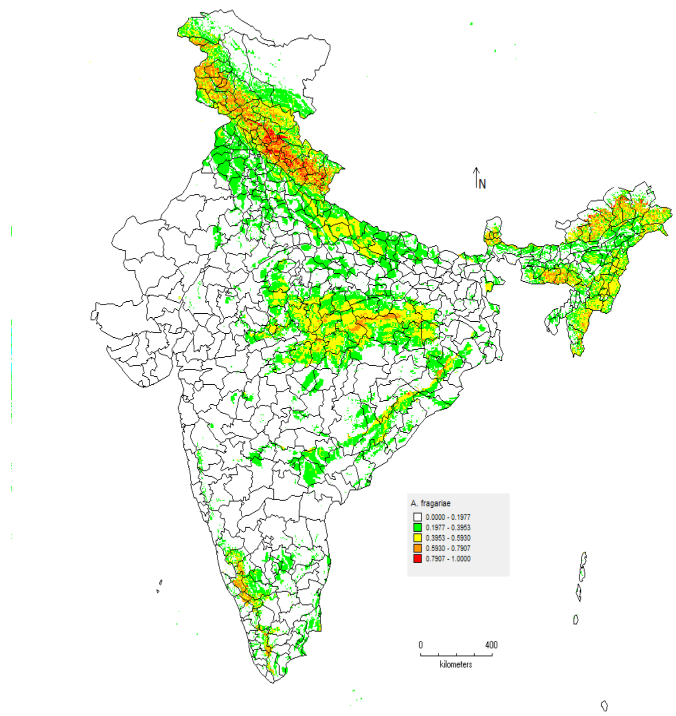

Figure 2. Potential suitable habitat for geographic distribution of *Aphelenchoides fragariae* in India under current climatic scenario

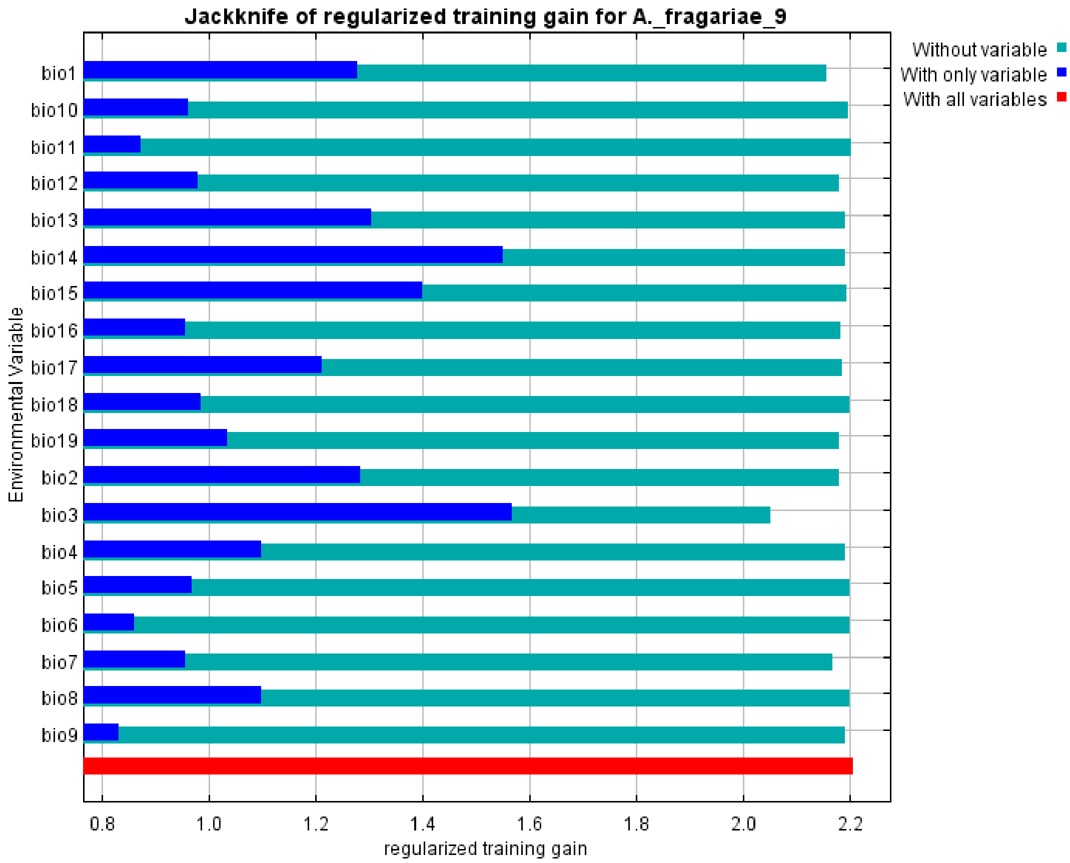

Figure 3. Jackknife test for relative importance of environmental variables in the development of *Aphelenchoides fragariae* in India

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