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Assessing the Potential Global Distribution of *Monolepta* spp. (Coleoptera: Chrysomelidae) using the MaxEnt Model

Muhammad Ramzan[1,*], Muhammad Umair Sial[2,*], Rashad Rasool Khan[2], Mahreen Hanif [3], Owusu Fordjour Aidoo[4], Muhammad Waqas[5], Mohammed Bourhia[6] and Khalid S. Almaary[7]

[1]State Key Laboratory for Biology of Plant Diseases and Insect Pests, Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing, 100193, China; [2]Department of Entomology, University of Agriculture Faisalabad, Pakistan; [3]Institute od Plant Protection, MNS-University of Agriculture Multan, Pakistan; [3]University of Environment and Sustainable Development, Department of Biological Sciences, PMB, Samanya, E/R, Ghana; [5]Department of Entomology, PMAS Arid Agriculture University, Rawalpindi, Pakistan; [6]Laboratory of Biotechnology and Natural Resources Valorization, Faculty of Sciences, Ibn Zohr University, 80060, Agadir, Morocco; [7]Department of Botany and Microbiology, College of Science, King Saud University, P. O. BOX 2455, Riyadh 11451, Saudi Arabia.
[*]Corresponding author's e-mail: omairsial@hotmail.com; and ramzan.mnsua@gmail.com

Monolepta species (*Monolepta quadriguttata*, *M. hieroglyphica*, *M. signata*) pose a significant threat to crop production in many regions. However, there is limited information on studies assessing the habitat suitability of these pests. This study evaluates the potential global distribution of these pests using the Maximum Entropy (MaxEnt) model and ArcMap GIS software. Our predictive maps show that East Asian countries, particularly North and South Korea, have high suitability, while Russia and South-Southeast Asian regions have low suitability for *M. quadriguttata*. The model predicts habitat suitability in parts of the United Kingdom, while Western Asia, Europe, and Africa are considered unsuitable for *M. quadriguttata*. East Asian regions have very high suitability (0.8-1.0) for *M. hieroglyphica*, and some Southeast Asian countries, including Indonesia, Myanmar, Cambodia, and the Philippines, have optimal suitability. Similarly, optimal habitat suitability for *M. signata* occurs in Southeast Asian countries, with marginal suitability in parts of Africa and Brazil. The niche analysis show that the *Monolepta* spp. share similar environment requirements. Our study provides a theoretical basis for developing proactive surveillance and management strategies to reduce the potential spread of *Monolepta* spp. and emphasizes the need for international cooperation in addressing the challenges that climate change poses to the spread of agricultural pests.

Keywords: Species distribution modelling, MaxEnt, *Monolepta quadriguttata*, *Monolepta hieroglyphica*, *Monolepta signata*, Climate change.

INTRODUCTION

Climate change is one of the most pressing issues confronting the world today (Sultan *et al.*, 2022). Climate change is the biggest environmental issue facing the world, and the most vulnerable industry is agriculture. The growing season, crop yield, and crop quality are all greatly impacted by extreme weather and climate events brought on by climate change, such as high global temperatures, droughts, rainstorms, floods, and hail. They also affect the reproduction and biological and morphological parameters of agricultural pests (Naeem-Ullah *et al.*, 2020). Consequently, climate change increases the instability of agricultural production, alters the agricultural production structure, and significantly raises agricultural costs and investments (Koundinya *et al.*, 2018; Guo, 2015). Climate change has a significant impact on the ecological traits of plant pests, including growth, reproduction, overwintering, and distribution (Skendžić *et al.*, 2021). Global climate change has profoundly altered the composition, structure, function, and succession of insect communities in agroforestry ecosystems, expanding insect ranges, increasing generations, and altering ecological adaptability. These changes affect the internal relationships between plants, pests, and natural enemies, leading to outbreaks of certain pests (Li *et al.*, 2010; Wang *et al.*, 2022). Corn (*Zea mays*) is the third most important grain in the world after rice and wheat (Soto-Gómez *et al.*, 2022). Its cultivation is widespread, with significant production in the United States, China, Brazil, and Argentina, among other countries (Erenstein *et al.*, 2022). Corn is critical to food security as it

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is a staple food for human consumption and a primary livestock feed source (Suganya *et al.*, 2020). Additionally, it is an important raw material for numerous industrial products, including biofuels, starch, and sweeteners, which are essential to the global food processing and energy sectors (Salakinkop *et al.*, 2024). Despite its global importance, corn production is directly or indirectly affected by various insect pests, resulting in crop yield losses and reduced quality. The genus *Monolepta* has emerged as a significant pest of corn crops worldwide, particularly in China (Zhang *et al.*, 2014; Gao *et al.*, 2021).

Monolepta spp. (*Monolepta hieroglyphica*, *M. signata*, and *M. quadriguttata*) are polyphagous pests that damage a variety of crops, including corn (Ramzan *et al.*, 2024). The adults feed on both the vegetative and reproductive parts of plants, causing skeletonization and leaf shedding, which reduces photosynthetic capacity (Dai *et al.*, 2016; Das, 2020). Severe attacks by both mature and immature stages significantly impact crop pollination and production, leading to an increase in empty pods and a reduction in grain number and mass (Li *et al.*, 2016; Liu *et al.*, 2016). In their immature stage, grubs primarily feed on roots, resulting in stunted growth and even plant death (Chen *et al.*, 2016). Additionally, excessive adult feeding can cause corn ear rot, further contributing to crop losses (Gyawali, 1986; Zhao and Zhao, 2013; Zhao *et al.*, 2021; Ge *et al.*, 2023).

Farmers resort to chemicals or insecticides (dimethoate, fipronil, endosulfan, thiamethoxam, acetamiprid, and imidacloprid) to control *Monolepta* spp. due to their accessibility in many countries and the lack of alternative or eco-friendly methods to manage these pests (Ramzan *et al.*, 2024). The most effective insecticides against *Monolepta* spp. are beta-cyfluthrin and methomyl, which showed >85% mortality (Tian *et al.*, 2014). Among the methods used to suppress beetle populations in China are manual adult collection or the use of modified cultivators fitted with sweep nets, deep plowing to disturb overwintering egg sites, and efficient weed control to eradicate substitute plant hosts (Zhang *et al.*, 2013; Borkakati *et al.*, 2019; Bian *et al.*, 2022). Additionally, enhancing plant stress tolerance through appropriate fertilization and irrigation can be beneficial in managing *M. hieroglyphica* (Wang *et al.*, 2006; Zhao *et al.*, 2011; Liu *et al.*, 2011; Ju *et al.*, 2022; He *et al.*, 2024). In Bangladesh, plant-based extracts (*Nicotiana tabacum*, *Azadirachta indica*) have been tested against *Monolepta* spp. with significant pest mortality rates (Farhana *et al.*, 2021). Yuan *et al*. (2014) found that the essential oil of wild mugwort (*Artemisia lavandulaefolia*) resulted in 80-100% *M. hieroglyphica* mortality. Stink bug, *Arma chinensis* is a potential predator of *M. hieroglyphica*, consuming 20.4 adults on average (Chen *et al.*, 2007), while the predation of the ladybird beetle, *Coccinella septempunctata*, has been investigated in China (Li, 2008). RNA interference (RNAi)-based genetically modified (GM) maize has been developed against *M. hieroglyphica* that suppresses the MhSnf7 gene, leading to *M. hieroglyphica* death (Zhang *et al.*, 2020). Nevertheless, *Monolepta* spp. continue to reduce agricultural yields and increase the production costs of controlling them (Ramzan *et al*., 2024).

Climate change can facilitate the establishment of beetles in new areas under climatic conditions, complicating management and control measures (Ramzan *et al.*, 2024). In response to changing climatic conditions, it is crucial to develop efficient pest control techniques to limit economic impacts (Hayat, 1999; Hazarika *et al.*, 2017; Ramzan *et al.*, 2024). Species distribution models (SDMs) use specific algorithms to predict the likely distribution areas of species based on actual distribution locations and environmental parameters (Gobeyn *et al.*, 2019; Van Eupen *et al.*, 2021; Wei *et al.*, 2024). The availability of computational modeling tools and algorithms integrated into ArcGIS has significantly improved our understanding of the spatial patterns of species distribution depending on climatic conditions (Melo-Merino *et al.*, 2020). Early predictions of pest distribution and abundance using predictive models enable better preparation and development of effective pest control strategies long before possible outbreaks (Ali, 1988; Fand *et al.*, 2014; Abdelaal *et al.*, 2019; Bekele *et al.*, 2024).

To the best of our knowledge, no previous studies have modeled the distribution of *Monolepta* spp. on a global scale. This study examines how changing environmental factors impact the ecological interactions of these pests. By achieving these goals, the research aims to improve the resilience of corn production systems to pest threats and ensure sustainable agricultural practices and food security in the context of climate change. Our predictions represent a significant advance in predictive pest control and agricultural adaptation strategies.

MATERIALS AND METHODS

Data on the occurrence of Monolepta species**:** Occurrence records of *Monolepta* spp. were obtained from various official sources, including the Global Biodiversity Information Facility (GBIF, 2024a, b, c), Centre for Agriculture and Bioscience International , European and Mediterranean Plant Protection Organization (EPPO, https://www.eppo.int/), and supplemented by many published articles and reports (Table S1). In case of missing coordinates, the distribution records of *Monolepta* spp. were obtained using Google Earth (https://earth.google.com/) and the method of Rashid *et al*. (2021). A total of 501 records were collected, including 172 for *M. hieroglyphica*, 102 for *M. quadriguttata*, and 227 for *M. signata*. Next, we removed duplicate records and enforced a 1 km distance between the occurrence records. After the thinning process (*spthin* package in R), 168, 82, and 176 records for *M. hieroglyphica*, *M. quadriguttata*, and *M. signata* were obtained, respectively. The datasets were processed in Microsoft Excel, converted into comma-separated values (CSV) format (Wei *et al.*, 2024; Wang *et al.*, 2020), and further used to assess habitat suitability for *Monolepta* spp. worldwide. ArcGIS (Version 10.7.1, 380 New York Street, Redlands, CA, USA) was used for the initial data processing and image extraction (clipping) of our study area.

Climatic data**:** Bioclimatic data, including 11 temperature and eight precipitation variables with a spatial resolution of 2.5 arc min (~5 km), were obtained from the official World Climate database (http://www.worldclim.org). We addressed multicollinearity in the datasets using variance inflation and the pearson correlation approach (*Vifcor*: Pearson < 0.7). The selected variables for the simulation are presented in Table 1. Lastly, ArcGIS v 10.7.1 was used to convert the selected variables into ASCII format to evaluate the key variables biologically related to the current model of *Monolepta* spp.

Model calibration and evaluation**:** For this study, the MaxEnt software (Version 3.4.1) was used (accessed in January 2024), which is available from http://biodiversityinformatics.amnh.org/open_source/maxent (Rashid *et al.*, 2021). The study extent was defined using a minimum convex polygon at 4 degrees around the occurrence records. Simultaneously, 10,000 background points were selected and used to fine-tune the MaxEnt model. The feature classes for *M. hieroglyphica* (hinge, regularization multiplier 2.5), *M. signata* (quadratic, hinge, product, regularization multiplier 1), and *M. quadriguttata* (linear, quadratic, hinge, regularization multiplier 0.5) were selected based on 171 model combinations in a grid search, followed by a genetic algorithm for optimization using the optimizeModel function in the SDMtune package (Vignali *et al.* 2022). We used a 30% testing with 5000 maximum number of iterations (Phillips and Dudık, 2008). A convergence threshold of 0.00001 was applied, and subsample replicates were used. The jackknife test was used to evaluate the effects of various environmental variables. To avoid random errors, MaxEnt was performed with 10-fold cross-validation using species occurrence data and environmental variables (Wang *et al.*, 2019). The rest were set to default. The MaxEnt model's file output is in ASCII format, which cannot be presented graphically on the map. ArcGIS' "Conversion Tools" converted the file from 'ASCII' to 'Raster' format, and the "Extraction" tool extracted the probability distribution map of *Monolepta* spp. In the globe. One useful tool for assessing the species distribution model's accuracy is the receiver operating characteristic curve (ROC). When assessing species distribution models, ROC curves are frequently employed (Franklin *et al*. (2013). The accuracy is measured using the area under the curve (AUC) as an index. The model's prediction accuracy increases with the AUC value's proximity to 1, which goes from 0 to 1 in theory. The potential distribution areas of the appropriate map were determined based on the value of the "10th". The Percentile Training Presence Threshold is divided into four levels for each species. Unsuitable, low suitability, medium suitability, and high suitability range for *M. signata* were 0-0.2475, 0.2475-0.4, 0.4-0.6, and >0.6, respectively, unsuitable, low suitability, medium suitability and high suitability range for *M. hieroglyphica* was 0-0.2125, 0.2125-0.4, 0.4-0.6 and >0.6, while for *M. quadriguttata* was 0-0.1025, 0.1025-0.4, 0.4-0.6 and >0.6, respectively. These layers were displayed in different colors (Zhang *et al.*, 2016). Lastly, we compared the environment requirements of the *Monolepta* spp. populations using NicheA (Qiao et al. 2016).

Table 1. Environmental variables collected and used for modelling.

Species	*M. signata*	*M. quadriguttata*	*M. hieroglyphica*
bio01			
bio02	√	√	√
bio03	√	√	√
bio04			
bio05			√
bio06			
bio07		√	
bio08	√	√	√
bio09		√	
bio10			
bio11			
bio12			
bio13	√		
bio14			
bio15	√	√	√
bio16			
bio17			
bio18	√	√	√
bio19	√	√	√

Niche analysis: To assess niche similarity within a three-dimensional space, a cross-platform, open-source program called Niche Analyst (NicheA; http://biodiversity-informatics-training. org/software-data-sources/nichea/), which is licensed under the GNU Public License (GPL), has proven helpful in this regard (Qiao *et al.*, 2016). Here, we compared the climate space occupied by the *Monolepta quadriguttata*, *M. hieroglyphica*, *M. signata*, *by* developing a minimum volume ellipsoid (MVE) using occurrences records of each species.

RESULTS

MaxEnt generated two ROC curves, displaying AUC values for each species based on training and test data (Table 2). The AUC values based on training and test data were 0.9579 and 0.9371 (SD = 0.0162) for *M. signata*, 0.9691 and 0.9602 (SD = 0.0098) for *M. hieroglyphica*, and 0.9770 and 0.9550 (SD = 0.0164) for *M. quadriguttata*. The MaxEnt model performed well in predicting the habitat suitability of *Monolepta* spp. in both training and test locations. The binomial omission test and test omission rate for each species were significant (<2%), with the lowest presence threshold (Table 2).

Table 2. Evaluation statistics of the MaxEnt model using threshold-dependent and threshold-independent evaluations.

Data partition	Training AUC	Test AUC	SD	Test omission rate	*p*-value
M. signata	0.9579	0.9371	0.0162	0.014	<0.01
M. hieroglyphica	0.9691	0.9602	0.0098	0.012	<0.01
M. quadriguttata	0.9770	0.9550	0.0164	0.082	<0.01

Percentage contribution of predictor variables: The main variables used to predict the potential distribution of *Monolepta* species were bio2 (Mean diurnal range), bio3 (Isothermality), bio5 (Max temperature of warmest month), bio8 (Mean temperature of wettest quarter), bio9 (Mean temperature of driest quarter), bio13 (precipitation of wettest month), bio15 (precipitation seasonality), bio18 (precipitation of warmest quarter) and bio19 (precipitation of coldest quarter). Among these potential distribution variables, bio18 was the main variable for predicting the potential distribution of *M. hieroglyphica*, *M. signata* and *M. quadriguttata* with contributions of 62.38%, 64.92% and 34.31%, respectively (Table 3).

Model performance evaluation based on AUC values: The area under the receiver operating characteristic curve (AUC) test for the current prediction and future projection was 0.988 (Fielding and Bell, 1997; Van-der-Putten *et al.*, 2010). AUC values for *M. hieroglyphica*, *M. signata*, and *M. quadriguttata* were 0.960, 0.937, and 0.955, respectively (Fig. 2D-F). Our AUC values were significant based on previous studies (Wani *et al.*, 2021; Gull *et al.*, 2022). The average omission and predicted areas for *M. signata*, *M. hieroglyphica*, and *M. quadriguttata* from the final model's 10-fold cross-validation (Fig. 2A-F). The response function of the cumulative threshold was observed in both the predicted area and the omission rate. We found that the omission rate was near the expected omission rate because of the definition of the cumulative threshold (Fig. 2A-C).

Table 3. Percentage contribution of each climatic variable to MaxEnt model.

Variables	Percentage contribution		
	M. hieroglyphica	***M. signata***	***M. quadriguttata***
bio2	2.168	11.885	5.308
bio3	19.204	6.314	31.120
bio5	1.551	-	-
bio8	0.192	2.015	2.1620
bio9	-	-	2.718
bio13	-	27.448	-
bio15	13.084	10.404	19.392
bio18	62.804	44.925	34.313
bio19	0.997	3.032	4.987

The results of the Jackknife test after running Maxent revealed a relative contribution of each bioclimatic variable to the prediction of *Monolepta* species (Fig. 1).

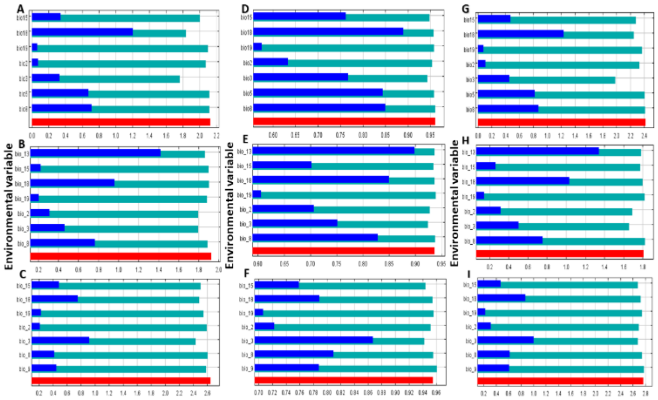

Figure 1. Jackknife of regularized training gain: A, B and C for *M. hieroglyphica*, *M. signata* and *M. quadriguttata*; AUC: D, E and F for *M. hieroglyphica*, *M. signata* and *M. quadriguttata*; test gain: G, H and I for *M. hieroglyphica*, *M. signata* and *M. quadriguttata*.

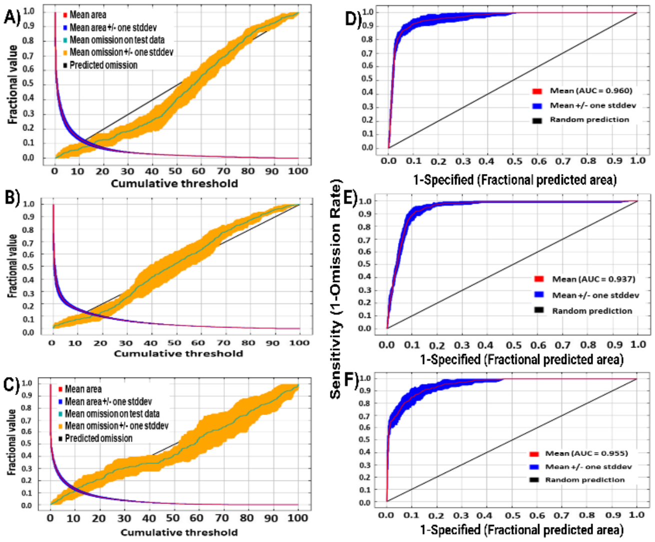

Figure 2. Model evaluations, (A-C) Average omission and predicted area: *M. hieroglyphica*, *M. signata* and *M.* quadriguttata*;* ROC curve (D-F): *M. hieroglyphica*, *M. signata* and *M. quadriguttata*.

Current climatic suitability for the growth and establishment of Monolepta species: The occurrence records, and habitat suitability of *M. signata* worldwide are shown in Fig. 3C. The results show that Southeast Asian countries are the highly suitable regions (>0.6). In contrast, some parts of African and Brazilian regions are only medium-suitable (0.4-0.6) for *M. hieroglyphica* (Fig. 3B) and *M. quadriguttata*. Predicted habitat suitability for *M. quadriguttata* around the world is shown in Fig. 3D. The results show that East Asian countries, especially North and South Korea, are highly suitable (>0.6) regions for the growth and development of *M. quadriguttata*. Russian and Southeast Asian areas also have low suitability (0.1025–0.4) for the growth and establishment of *M. quadriguttata* due to the provision of favorable abiotic factors such as temperature and precipitation (humidity). *M. quadriguttata* is predicted to occur in some areas of the United Kingdom (UK). The remaining regions of the world, including Western Asia, Europe, and Africa, are not suitable for *M. quadriguttata* invasion. The niche analysis showed that the *Monolepta* species share similar environmental conditions (Fig. 4). However, *M. signata* occupies a larger climate space than *M. hieroglyphica* and *M. quadriguttata.*

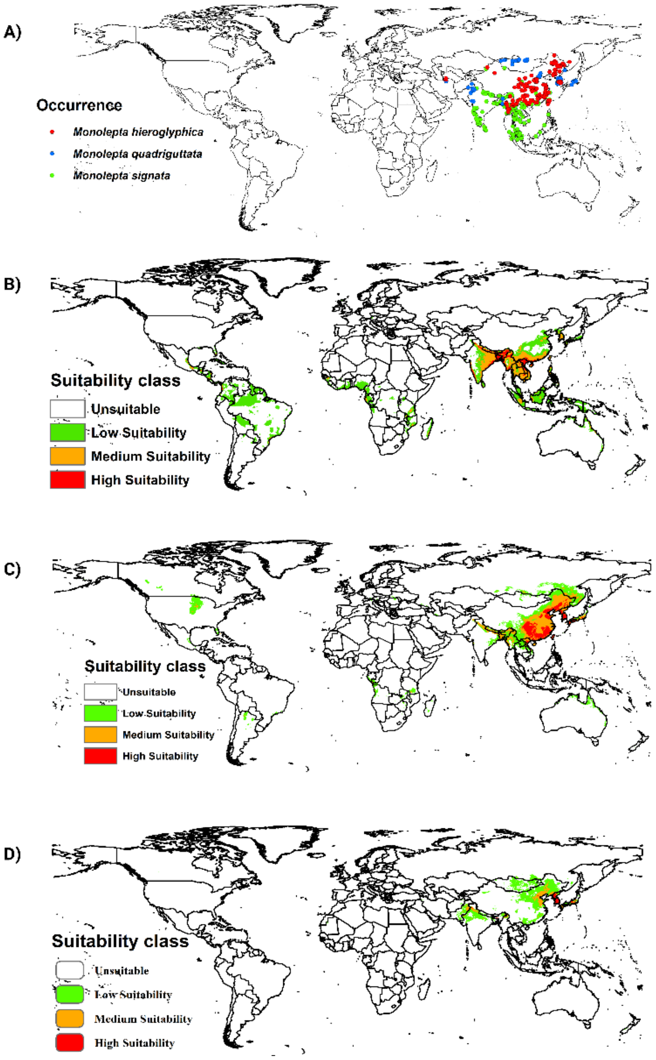

Figure 3. Occurrence and potential global distribution. (A: Occurrence records; B: *M. hieroglyphica*; C: *M. signata* and D: *M. quadriguttata*) with the MaxEnt model. Different colours show suitability of *Monolepta* spp. in the globe.

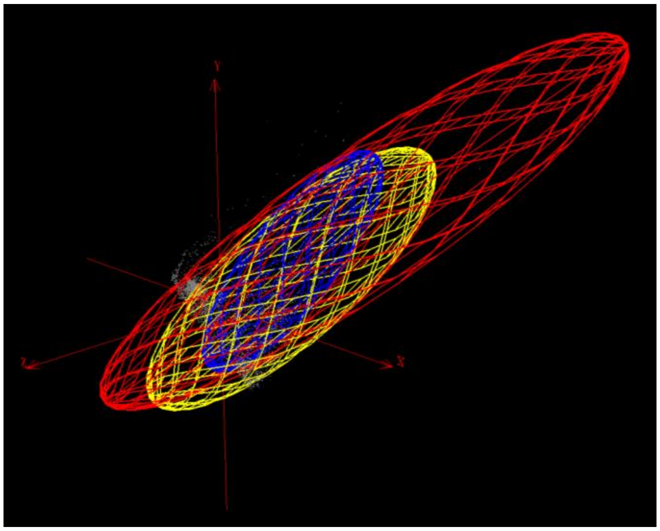

Figure 4. Comparison of climate space occupied by *Monolepta* spp. Note: red (*M. signata*), yellow (*M.* quadriguttata), and blue (*M. hieroglyphica*), and grey (background cloud). The X, Y, and Z axes represent different dimensions that define the ecological niche of a species.

***Effect of environmental factors on the distribution of Monolepta species*:** The areas with moderate temperature uniformity throughout the year have a higher probability of *M. signata*, *M. hieroglyphica* and *M. quadriguttata*. Even those regions where the temperature remains constant throughout the year with minimal seasonal fluctuations have a high probability of pests. The areas with irregular rainfall patterns have a higher risk of *Monolepta* spp. The probability of *M. signata* and *M. hieroglyphica* occurs at a temperature of 0.30 ˚C and 0.37 ˚C, respectively, when the minimum temperature of the coldest month is below -3.13 ˚C and -4.22 ˚C, respectively. The probability of *M. signata* and *M. hieroglyphica* increases with the increase in the minimum temperature of the coldest month, reaching the highest point at 30.0 °C and 28.33 °C, respectively. The change in the response curve of the precipitation of the wettest month and precipitation of the warmest quarter for *Monolepta* species are almost similar. The most suitable temperature for the occurrence of *Monolpeta* species is between 25-30 °C. When the probability of *M. quadriguttata* dispersal reaches its maximum, the precipitation in the warmest quarter and the wettest month is 3000 and 1600 mm, respectively.

DISCUSSION

The feature classes for *M. hieroglyphica* (hinge, regularization multiplier 2.5), *M. signata* (quadratic, hinge, product, regularization multiplier 1), and *M. quadriguttata* (linear, quadratic, hinge, regularization multiplier 0.5) were selected based on 171 model combinations in a grid search, followed by a genetic algorithm for optimization using the optimizeModel function in the SDMtune package (Vignali *et al*. 2022). We used a 30% testing with 5000 maximum number of iterations (Phillips and Dudık, 2008). A convergence threshold of 0.00001 was applied, and subsample replicates were used. The jackknife test was used to evaluate the effects of various environmental variables. To avoid random errors, MaxEnt was performed with 10-fold cross-validation using species occurrence data and environmental variables (Wang *et al.,* 2019). The rest were set to default.

MaxEnt is a species distribution modeling (SDM) method that predicts potential species distribution based on environmental variables and occurrence data (Zhang *et al.,* 2018; Kaky *et al.,* 2020; Ab Lah *et al.,* 2021; Mafuwe *et al.,* 2022). The current study used MaxEnt modeling to predict the global distribution and habitat suitability of three species within the genus *Monolepta* (*M. signata*, *M. hieroglyphica*, and *M. quadriguttata*). The AUC (Area Under the Curve) values derived from the ROC (Receiver Operating Characteristic) curves are an important indicator of the model's performance. For *M. signata*, the AUC values were 0.9579 (training data) and 0.9371 (testing data), with a standard deviation (SD) of 0.0162. Likewise, *M. hieroglyphica* had AUC values of 0.9691 (training data) and 0.9602 (test data) with a standard deviation of 0.0098, while *M. quadriguttata* AUC values of 0.9770 (training data) and 0.9550 (test data) with a standard deviation of 0.0164. These high AUC values, all above 0.95, reflect the model's strong discriminatory power and reliability in predicting suitable habitats for these species. The niche analysis suggests that *Monolepta* spp. share similar habitats, and the combined effects of the three species could pose a serious threat to the host plants wherever they occur together. The binomial omission test and test omission rates for each species were found to be significant and were less than 2% at the lowest presence threshold, further confirming the robustness of the model. These results suggest that the MaxEnt model has a low false negative rate, suggesting that the species' presence in suitable habitats is rarely missed. ROC analysis has been documented as the best measure of model performance with broader applicability in species dispersal modeling (Fand *et al.,* 2014; Duan *et al.,* 2014; Valavi *et al.,* 2022).

The results presented in Fig. 3B-D provide important insights into the potential spread and establishment of these species in different regions of the world. The modeling results suggest Southeast Asian countries with suitability values between >0.6 have a high suitability for *M. signata*. This suggests that the climatic and ecological conditions in this region are highly favorable to the growth and spread of *M. signata*. These conditions are likely to include optimal temperature ranges, rainfall patterns, and vegetation types that support the species' life cycle and reproductive success. In contrast, parts of Africa and Brazil show low suitability, with values between 0.2475-0.4. This lower suitability may be due to suboptimal environmental factors such as inadequate temperature, humidity, or vegetation that do not fully support the establishment and spread of *M. signata*. Despite the low suitability, these regions could still be subject to periodic invasions or local outbreaks under favorable conditions (Liu *et al*., 2024).

Predicted habitat suitability for *M. hieroglyphica* highlights East Asian regions as highly suitable, with values ranging from >0.6. These regions provide an ideal climate for *M. hieroglyphica*, likely including the necessary temperature, humidity, and food resources for optimal growth of the species. In addition, certain regions within Southeast Asia, particularly Indonesia, Myanmar, Cambodia, and the Philippines, are classified as medium-suitable with values between 0.4 and 0.6. This suggests that while these areas offer favorable conditions, they may not be as ideal as those in East Asia. The ecological flexibility of *M. hieroglyphica* allows it to thrive in diverse environmental conditions, making these regions potential hotspots for future invasions.

For *M. quadriguttata*, the results suggest that East Asian countries, particularly North and South Korea, are high suitable, with values between >0.6. The favorable abiotic factors in these regions, such as temperature and precipitation (humidity), contribute significantly to the growth and development of the species. Russian and Southeast Asian areas show low suitability with values between 0.1025-0.4. While these regions offer some of the necessary environmental conditions, they are not as favorable as those in East Asia. Interestingly, *M. quadriguttata* is also predicted to occur in certain areas of the United Kingdom (UK), suggesting that microclimatic conditions or localized habitats within the UK may favor its establishment. Conversely, Western Asia, Europe, and Africa are unsuitable for *M. quadriguttata* invasion. This unsuitability is likely due to the lack of essential environmental factors that the species requires, such as certain temperature and humidity values that are not maintained in these regions.

The climatic conditions of North Asia (Siberia) are also suitable for establishing *Monolepta* spp**.** The climate in Southeast Asia is favorable for the successful establishment of *Monolepta* species due to the wide host range and changes in land use and agricultural practices (Liu *et al*., 2024). The regions of East Asia will continue to support high populations due to optimal climatic conditions and the availability of host plants. *Monolepta* spp. have the potential to penetrate neighboring countries with favorable conditions, globalization, and trade. The potential spread of *Monolepta* spp. into new regions could have severe consequences for agriculture. These beetles are notorious for their polyphagous feeding habits, which can lead to significant crop damage and yield loss. Areas projected to become more suitable for *Monolepta* spp. include major agricultural zones, raising concerns over future food security. Adaptation strategies, such as the development of resistant crop varieties, improved pest monitoring, and integrated pest management (IPM) practices, will be crucial in mitigating the impact of these beetles. The common environmental variables for each *Monolepta* sp. are bio2, bio3, bio8, bio15, bio18, and bio19. The bio5, bio13, and bio9 variables also play key roles in species distribution. *Monolepta* spp. are highly susceptible to temperature variations, just like a lot of other insects, which can have an immediate impact on their physiological, morphological, and biological functions. To survive in a variety of climates, *Monolepta* spp. need to be able to maintain their body temperatures and metabolic rates, which can be made easier by the higher isothermality. The temperature during the wettest quarter is significant because it frequently corresponds with periods of increased plant growth and availability of food resources. These times of ideal temperature and moisture content can greatly increase the survival and success of reproduction, for *Monolepta* spp., whose larvae and adults feed on plant matter. Seasonality of precipitation impacts water and humidity availability, which in turn impacts host plant growth and the microhabitats that are accessible for *Monolepta* spp.

Based on the findings from the MaxEnt modeling of *Monolepta* spp., the following management implications can be made; Monitoring efforts should be focused on Southeast Asia and East Asia due to the high habitat suitability of *M. signata*, *M. hieroglyphica*, and *M. quadriguttata*. Early discovery can aid in controlling initial incursions and averting widespread establishment. To identify any early indicators of infestation, monitoring systems should be put in place in regions that are deemed moderately suitable, such as parts of Southeast Asia for *M. hieroglyphica* and parts of Russia for *M. quadriguttata*. It is possible to prevent *Monolepta* spp. from entering new areas and spreading by tightening phytosanitary and quarantine regulations. through travel and trade on a global scale. To combat *Monolepta* spp., neighboring nations with similar climates should work together on pest management strategies by exchanging information, research findings, and efficient practices. The distribution of suitable habitats for *Monolepta* spp. may change due to climate change. Implementing climate-resilient farming techniques will be crucial. This entails choosing crops that are climate-adapted, modifying planting dates, and enhancing water management. By updating and improving risk assessments regularly, predictive models such as MaxEnt enable proactive management and adaptable strategies to change environmental conditions. These bioclimatic factors directly affect the suitability of the insects' habitats, the availability of resources, and the environmental conditions required for their life cycles, which is why the distribution of *Monolepta* species is closely related to them. Through comprehension and examination of these factors, scientists can enhance their forecasting abilities regarding the dispersion trends and probable relocations of *Monolepta* species in reaction to variations in climate.

***Conclusions*:** The projected distributions of these *Monolepta* species highlight the need for continued monitoring and management strategies in regions identified as particularly suitable or optimally suitable. Southeast Asia and East Asia should prepare for a possible increase in *Monolepta* populations, which could impact local agriculture and biodiversity. Additionally, understanding the specific environmental variables that contribute to habitat suitability can assist in developing targeted mitigation measures. These include adopting agricultural practices, improving pest monitoring, and implementing biological control methods to manage *Monolepta* populations effectively. Future research should focus on refining this model with more precise climate data and investigating the adaptability of *Monolepta* species to different environmental conditions. This will provide deeper insights into their potential spread and inform more informed pest management strategies.

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