POTENTIAL DISTRIBUTION AND CLIMATIC SUITABILITY OF *KADSURA COCCINEA* (MAGNOLIACEAE) IN CHINA

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Abstract. *Kadsura coccinea*, a traditional Chinese medicine, is widely used in folk medicine for the treatment of stomach disorders, rheumatoid arthritis, bruises and contusions, and gynecological disorders. We used 132 *K. coccinea* loci and 19 climatic variables, maximum entropy model (Maxent), and geographic information system (ArcGIS) technique to screen the dominant climatic factors and to delineate suitable growing areas for *K. coccinea*. The results show that the Maxent model predicts well (AUC > 0.9). This indicates that the study has very high accuracy and reliability. The most suitable habitat parameters for *K. coccinea* are the precipitation of the wettest quarter (723.2~968.4 mm), annual precipitation (1512.7~1991.4 mm; 3035.4~4680.4 mm), temperature annual range (8.3~23.2 ℃; 24.8~27.3 ℃), precipitation of the driest quarter (94.5~633.6 mm), precipitation of the warmest quarter (567.3~977.9 mm), mean diurnal range (3.5~7.7 ℃), precipitation of the driest month (38.2~199.1 mm), precipitation of the coldest quarter (182.9~633.6 mm). The most suitable distribution areas for *K. coccinea* are concentrated in tropical and subtropical regions, which are Guangxi, Hunan, Yunnan, Jiangxi, Guangdong, Hainan, southeastern Chongqing, southwestern Hubei, southern and southwestern Anhui, Guizhou, Zhejiang, Taiwan, Fujian, and Hong Kong. The results of the study can provide a theoretical basis for the exploitation, cultivation, and quality of wild *K. coccinea* resources.
Keywords: *traditional Chinese medicine, Maxent, ArcGIS, climate variable, jackknife test*

Introduction

Kadsura coccinea is a plant, that belongs to the genus *Kadsura* in the family Magnoliaceae, mainly distributed in southern China, Thailand, and Korea (Zhang et al., 2022). *K. coccinea* is also known as lengfantuan in China, distributed in Hunan, Hubei, Sichuan, Shanxi, Fujian, Jiangxi, Guangdong, Guangxi, Hainan, Guizhou, Yunnan, Hongkong, Taiwan (Li et al., 2021). *K. coccinea* grows in environments with altitudes of 1500-2000 m, suitable temperatures, abundant rainfall, and cool and humid conditions. It is mostly distributed under forests, along mountain streams, and in moist valleys. *K. coccinea* is an important medicinal plant, which is mainly used by Chinese folk to treat stomach problems, rheumatoid arthritis, bruises, swelling and pain, and irregular menstruation (Yan et al., 2022). Modern pharmacological studies have also confirmed that *K. coccinea* has anti-tumor, anti-inflammatory, anti-oxidation, liver protection, anti-HIV virus, and inhibitory effects on acetylcholinesterase (Sritalahareuthai et al., 2020; Yang et al., 2019; Jia et al., 2021; Yang et al., 2021; Huang et al., 2019). As market demand continues to increase, the wild resources of *K. coccinea* have been decreasing year by year, and it is now difficult to meet the needs of humans. This has resulted in artificial cultivation becoming its main source. In recent years, due to the unreasonable selection of planting areas and large-scale blind introduction of species, the yield and

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quality of *K. coccinea* have declined to varying degrees. As a result, many farmers have suffered significant economic losses due to blind planting. This impact has gradually spread to the stability of the entire Chinese herbal medicine market economy. Before the research, we searched a large amount of literature and found that the research of *K. coccinea* mainly focused on chemical composition, pharmacological effects, and synthetic biology (Zhao et al., 2021; Long et al., 2022; Huang et al., 2022). However, few studies have reported on the effects of ecological factors such as climate and environment on the quality and yield of *K. coccinea*. Therefore, understanding the overall situation of *K. coccinea* resources, accurately grasping the ecological factors and suitable distribution areas for *K. coccinea* growth, can to some extent reduce the economic losses caused by blind planting by farmers, and is also of great significance for promoting the artificial cultivation of *K. coccinea*.

With the development of ecological statistical models and geographic information system (GIS) technology, GIS combined with environmental variables to predict the potential distribution of species has been widely used (Xie et al., 2020; Zhou and Li, 2021; Chakraborty et al., 2022). At present, the niche models commonly used to predict the potential distribution of species mainly include bioclimate analysis and prediction system (BIOCLIM) (Busby, 1991), ecological niche factor analysis (ENFA) (Hirzel et al., 2002), genetic algorithm for rule-set production (GARP) (Stockwell, 1999), maximum entropy model (MaxEnt) (Phillips et al., 2006). Among them, MaxEnt model has been widely used in the potential habitat distribution of medicinal plants and has achieved relatively accurate conclusions (Zhang et al., 2023; Xu et al., 2022; Zhan et al., 2022).

In this study, the climate suitability of *K. coccinea* under climate variables was evaluated by combining MaxEnt model and GIS technology. The purpose of this study mainly includes two aspects: (1) to find out the dominant climatic factors affecting the distribution of *K. coccinea* and their suitable range; (2) to predict the potentially suitable distribution area of *K. coccinea* in China. The results of this study can provide a theoretical basis for practical activities such as geographical selection and rational use of resources for the artificial cultivation of *K. coccinea*.

Materials and methods

K. coccinea distribution information acquisition

The distribution information of *K. coccinea* was collected from the Chinese Virtual Herbarium (http://www.cvh.ac.cn), the National Specimen Information Infrastructure (http://www.nsii.org.cn/2017/home.php), the Global Biodiversity Information Facility database (https://www.gbif.org/), to remove duplicate information, and finally, we collected 132 pieces of sample distribution information, as shown in *Figure 1*. According to the requirements of the Maxent model, all distribution point data (latitude and longitude are in decimal format) are stored in .csv format.

Climate variable data acquisition

Climate variable data downloaded from the Worldclim website (https://www.worldclim.org/data/index.html), are BIO1 (Annual Mean Temperature), BIO2 (Mean Diurnal Range), BIO3 (Isothermality), BIO4 (Temperature Seasonality), BIO5 (Max Temperature of Warmest Month), BIO6 (Min Temperature of Coldest Month), BIO7 (Temperature Annual Range), BIO8 (Mean Temperature of Wettest

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Quarter), BIO9 (Mean Temperature of Driest Quarter), BIO10 (Mean Temperature of Warmest Quarter), BIO11 (Mean Temperature of Coldest Quarter), BIO12 (Annual Precipitation), BIO13 (Precipitation of Wettest Month), BIO14 (Precipitation of Driest Month), BIO15 (Precipitation Seasonality), BIO16 (Precipitation of Wettest Quarter), BIO17 (Precipitation of Driest Quarter), BIO18 (Precipitation of Warmest Quarter), BIO19 (Precipitation of Coldest Quarter) (*Table 1*). As required by the Maxent model, the above 19 climate factors are stored in .asc format.

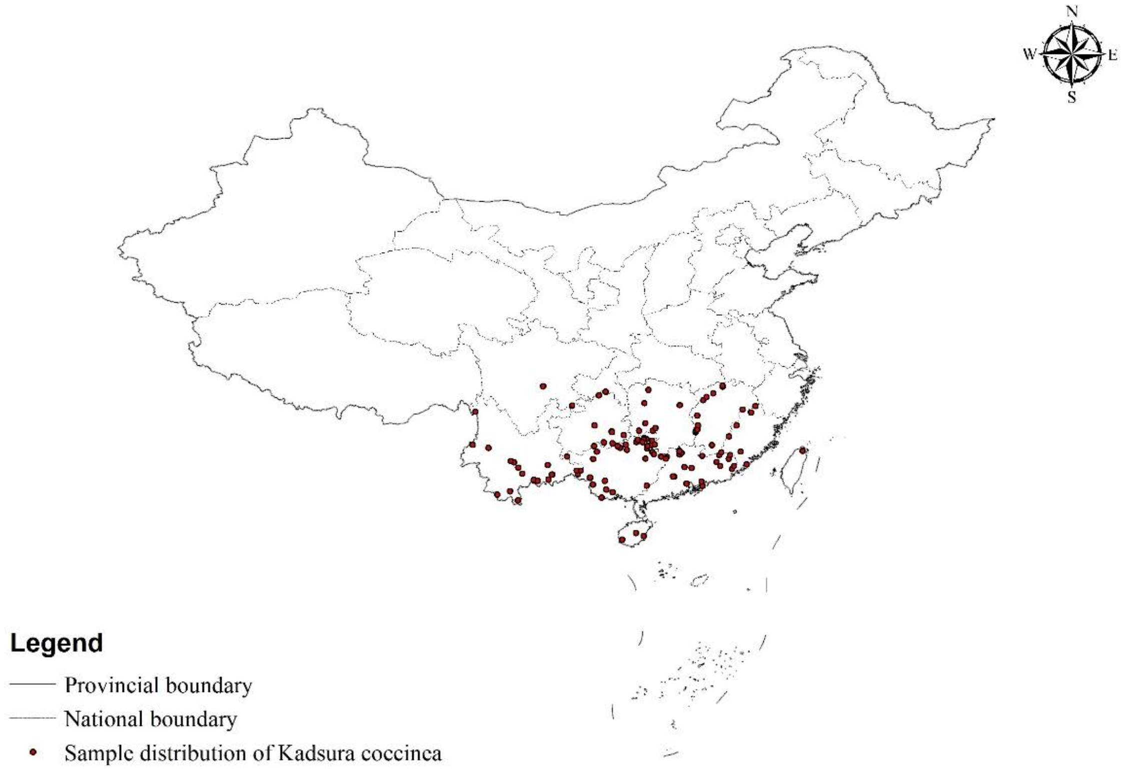

Figure 1. *Sample distribution information*

Maximum entropy model construction

The coordinate information of *K. coccinea* and the data of 19 climate factors were imported into the Maxent3.3.3, and 25% of the distribution points were randomly selected as the test date (the remaining 75% of the distribution points were the training date by default), the maximum number of iterations was 10^6, and the model operation was repeated 10 times. We also created the response curve, receiver-operating characteristic (ROC), and the Jackknife method. The Jackknife is used to test the weight of each climate variable on the suitable growth conditions for *K. coccinea*, and the others are default values.

Dominant climate factor screening

After each operation of the Maxent model, climate factors with a contribution rate of 0 are discarded until the remaining climate factors show a contribution rate. Based on the comprehensive analysis of the contribution rate and the Jackknife test results, we obtained the dominant climatic factors affecting the suitability of *K. coccinea*.

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Table 1. *A List of climate variables*

Climatic variables	Name	Unit
BIO1	Annual Mean Temperature	℃
BIO2	Mean Diurnal Range (Mean of monthly (max temp-min temp))	℃
BIO3	Isothermality (BIO2/BIO7) (×100)	1
BIO4	Temperature Seasonality (standard deviation ×100)	1
BIO5	Max Temperature of Warmest Month	℃
BIO6	Min Temperature of Coldest Month	℃
BIO7	Temperature Annual Range (BIO5-BIO6)	℃
BIO8	Mean Temperature of Wettest Quarter	℃
BIO9	Mean Temperature of Driest Quarter	℃
BIO10	Mean Temperature of Warmest Quarter	℃
BIO11	Mean Temperature of Coldest Quarter	℃
BIO12	Annual Precipitation	mm
BIO13	Precipitation of Wettest Month	mm
BIO14	Precipitation of Driest Month	mm
BIO15	Precipitation Seasonality (Coefficient of Variation)	1
BIO16	Precipitation of Wettest Quarter	mm
BIO17	Precipitation of Driest Quarter	mm
BIO18	Precipitation of Warmest Quarter	mm
BIO19	Precipitation of Coldest Quarter	mm

Maxent model accuracy

ROC analysis is a method to evaluate the pros and cons of species prediction models. It calculates a series of sensitivities and specificities by setting multiple different critical values for continuous variables. The AUC value is the area under the ROC curve, which is used to evaluate the fitting degree of the model in the prediction of species distribution. AUC ranges from 0 to 1. The larger the value, the higher the reliability of the prediction result. When the AUC is equal to 1, it means that the model prediction result is the same as the actual distribution. The evaluation standard of AUC is: 0.5 ~ 0.6 means prediction failure, 0.6 ~ 0.7 is poor, 0.7 ~ 0.8 is fair, 0.8 ~ 0.9 is good, and 0.9 ~ 1.0 is very good (Xu et al., 2020).

Suitable habitat analysis

MaxEnt3.3.3 draws the response curve of dominant climatic factors and analyzes the characteristics of dominant climatic factors that affect the potential distribution of *K. coccinea*. Taking the probability of presence ≥0.5 as the screening condition, the most suitable range value of the dominant climate factor was obtained. The peak value of the probability of presence is determined as the most suitable value of the dominant climate factor.

Habitat grade zoning

MaxEnt model predicted the potential distribution of *K. coccinea* in China, and the results were loaded into ArcGIS10.5 for visual analysis. The output format of the MaxEnt model is an ASCII raster layer, which is imported into ArcGIS10.5 and

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superimposed on the map of China. We manually classify it according to the concept of ecological similarity and the reclassification function of ArcMap, and finally divide four levels of areas, which are high-suitability areas (≥50%), medium-suitable areas (30% ~ 50%), low-suitable areas (10% ~ 30%) and non-suitability area (≤10%).

Results

Maxent model accuracy evaluation

The value of AUC is proportional to the strength of the judgment ability of the model. The ROC curve training data of the MaxEnt model is 0.953, greater than 0.9, and tends to 1, indicating that the MaxEnt model predicts the results accurately and has high reliability. The results are shown in *Figure 2*.

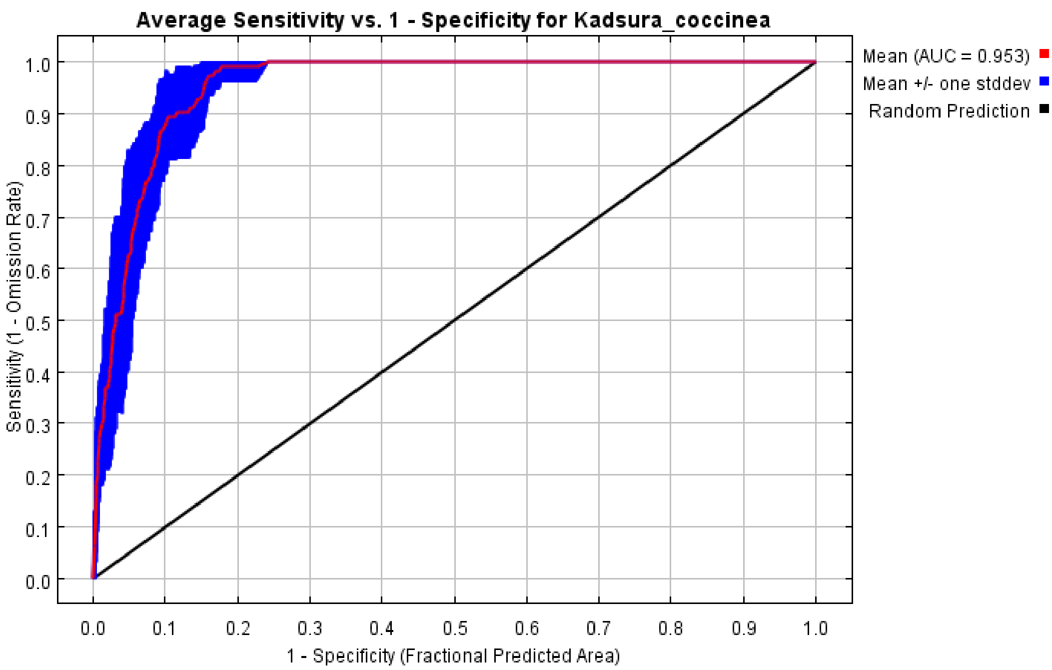

Figure 2. *ROC curve of Maxent model for Kadsura coccinea*

Dominant climate factor screening

After three calculations, the MaxEnt model retained 15 climate variables with a contribution rate greater than 0. The MaxEnt model then uses 15 climate variables for 10 iterations and takes the average as the final result. From the results, we selected 9 climate variables with a contribution rate > 1.5% for further analysis. The total contribution rate of the nine climate factors bio12, bio16, bio7, bio17, bio5, bio18, bio2, bio14, and bio19 was 93.5% (*Table 2*). Based on the Jackknife analysis (*Fig. 3*), the variables satisfying higher gains are sorted as follows: bio16, bio12, bio13, bio18, bio14, bio17, bio19, bio7, bio6, bio2, bio4. We intersect the climatic factors with high contribution rates and with higher gain in the Jackknife experiment (*Fig. 4*), and finally screen the dominant climatic factors, which are the precipitation of wettest quarter (bio16), annual precipitation (bio12), temperature annual range (bio7), precipitation of driest quarter (bio17), precipitation of warmest quarter (bio18), mean

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diurnal range (bio2), precipitation of driest month (bio14), precipitation of coldest quarter (bio19). the total contribution rate of the above eight climatic factors reached 87.1%, suggesting that they are the most important climatic variables affecting the distribution of *K. coccinea*.

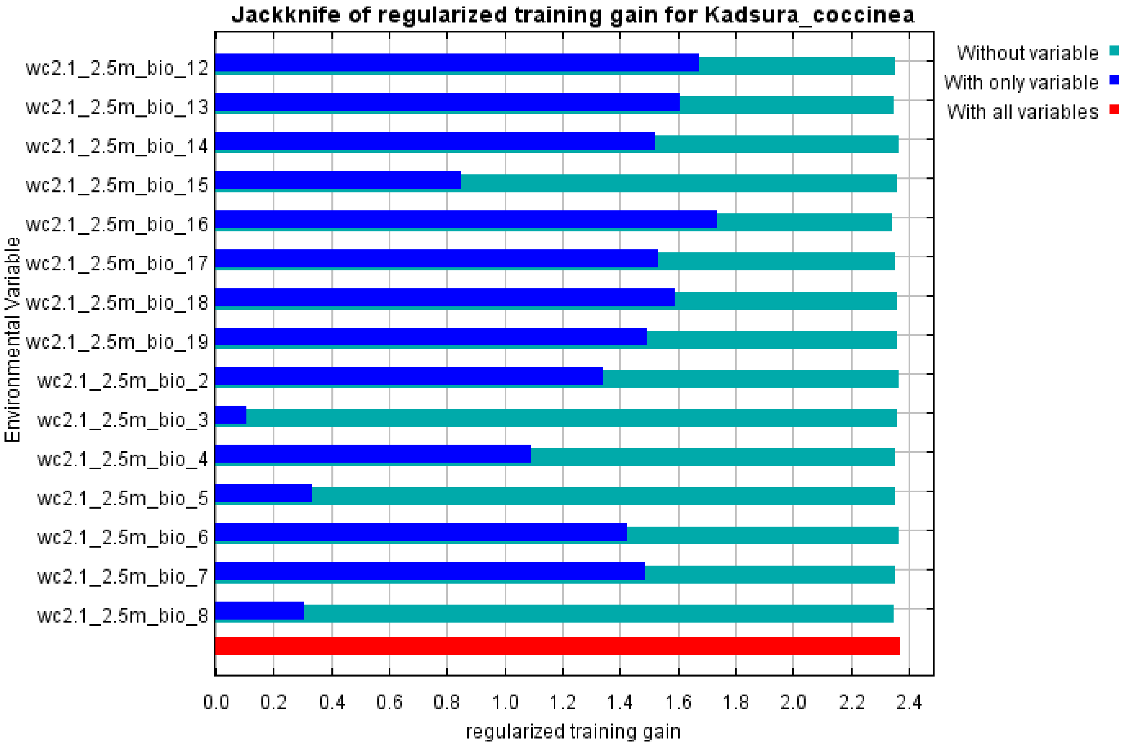

Figure 3. *The jackknife test of variable contribution in modelling*

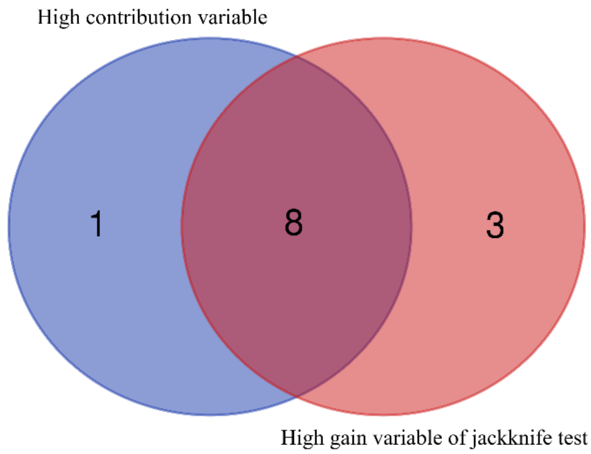

Figure 4. *The Venn diagram of the high contribution variable and high gain variable of the jackknife test*

Suitable habitat range

The climate variable response curve can judge the relationship between the probability of presence and climate factors. We use the MaxEnt model to analyze the

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range of climate factors suitable for *K. coccinea* distribution and its adaptive threshold. The results are detailed in *Figure 5* and *Table 3*.

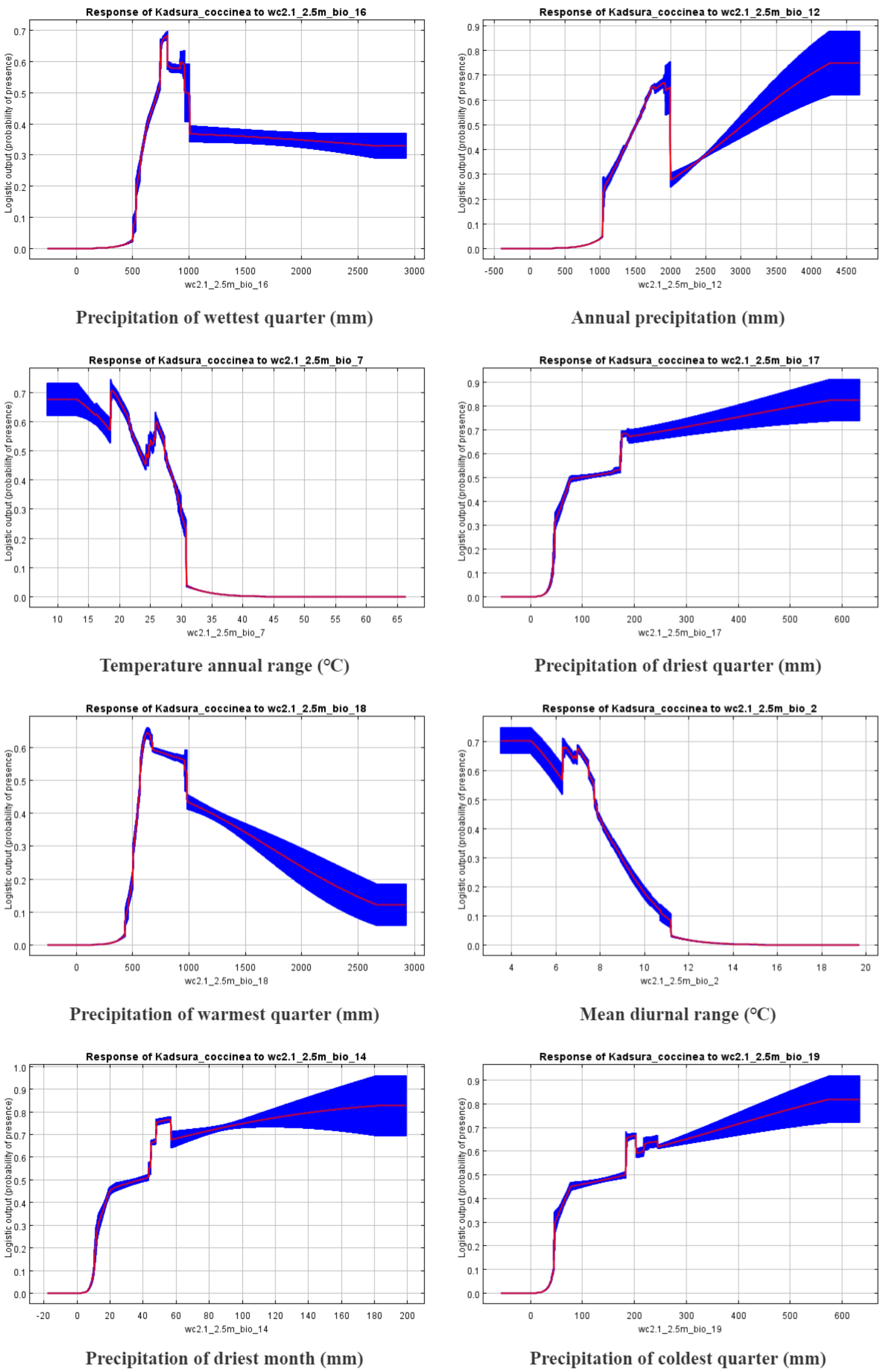

Figure 5. *The response curve of main climatic variables affecting the growth of Kadsura coccinea*

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Table 2. *High contribution rate climatic factors*

Climatic variables	Name	Percent contribution (%)
bio12	Annual precipitation	23.3
bio16	Precipitation of wettest quarter	22.5
bio7	Temperature annual range	21.2
bio17	Precipitation of driest quarter	11.9
bio5	Max temperature of warmest month	6.4
bio18	Precipitation of warmest quarter	2.4
bio2	Mean diurnal range	2.1
bio14	Precipitation of Driest Month	1.9
bio19	Precipitation of coldest quarter	1.8

Table 3. *The suitable value range for the main variables*

Climatic variables	Suitable range	Adaptive threshold
bio16	723.2~968.4 mm	806 mm
bio12	1512.7~1991.4 mm; 3035.4~4680.4 mm	4262.7 mm
bio7	8.3~23.2 ℃; 24.8~27.3 ℃	18.8 ℃
bio17	94.5~633.6 mm	576.9 mm
bio18	567.3~977.9 mm	627.7 mm
bio2	3.5~7.7 ℃	4.8 ℃
bio14	38.2~199.1 mm	181.3 mm
bio19	182.9~633.6 mm	576.9 mm

Climate suitability zoning results

The calculation results of the MaxEnt model were imported into the ArcGIS10.5, and the prediction results of the potential distribution area of *K. coccinea* in China are shown in *Figure 6*. The white area in the map represents the non-suitability area, the green area represents the low suitability area, the yellow area represents the medium suitability area, and the red area represents the high suitability area. From *Figure 5*, we can find that the areas suitable for the growth of *K. coccinea* are mainly concentrated in southern China, and the most suitable distribution areas are Guangxi, Hunan, Yunnan, Jiangxi, Guangdong, Hainan, southeastern Chongqing, southwestern Hubei, southern Anhui and Southwest, Guizhou, Zhejiang, Taiwan, Fujian, Hong Kong (*Table 4*).

Discussion

China is a vast country with a wide variety of geographical, especially in the south where the landscape is complex, with plateaus and basins, mountains and hills, as well as lakes and rivers (Wang et al., 2020). The traditional method of surveying the distribution of the *K. coccinea* resource would have yielded accurate and reliable results, but would have been too costly in terms of human, material, financial, and time resources, and would have been extremely difficult to implement. In this paper, we used GIS technology and the MaxEnt model to analyze the climate suitable zonation of *K. coccinea*, and obtained suitable growth distribution areas and suitable habitats. The zonation results were evaluated using ROC curves, and AUC values were greater than

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0.9, indicating that our model results were very good. The method of this study maximizes the cost of efficiency while improving the accuracy of prediction results.

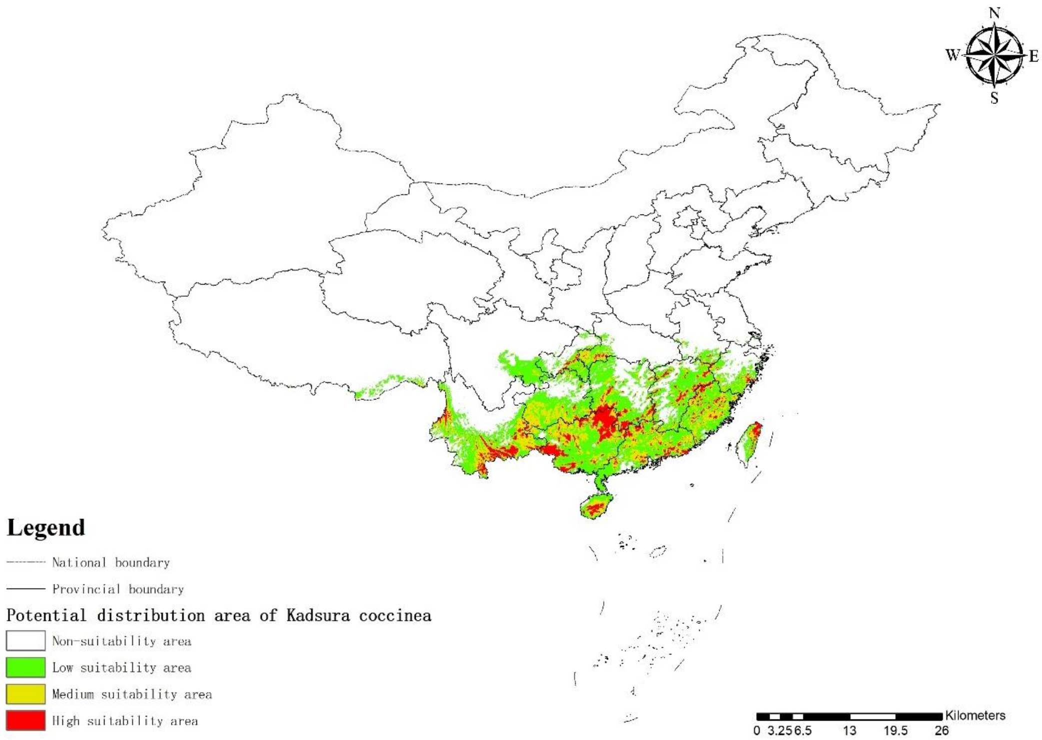

Figure 6. *Potential distribution of Kadsura coccinea in China*

Table 4. *The climatic suitability distribution area of Kadsura coccinea in China*

Name	Main suitability distribution location
Guangxi	Nanning, Fangchenggang, Qingzhou, Chongzuo, Baise, Hechi Liuzhou, Laibin, Guilin, Hezhou, Wuzhou, Yulin, Guigang
Hunan	Huaihua, Shaoyang, Yongzhou, Hengyang, Chenzhou, Zhuzhou, Loudi, Yiyang, Yueyang, Changsha
Yunnan	Nujiang, Dali, Baoshan, Dehong, Lincang, Puer, Xishuangbanna, Yuxi, Honghe, Wenshan, Qujing
Jiangxi	Nanchang, Yingtan, Fuzhou, Ganzhou, Ji'an, Pingxiang, Yichun, Jiujiang, Shangrao
Guangdong	Maoming, Zhaoqing, Qingyuan, Shaoguan, Heyuan, Meizhou, Chaozhou, Shantou, Jieyang, Shanwei, Huizhou, Guangzhou, Dongguan, Shenzhen, Foshan, Zhongshan, Zhuhai, Jiangmen, Yangjiang
Hainan	Tunchang, Ding'an, Qionghai, Wenchang, Wanning, Qiongzhong, Lingshui, Baoting, Sanya, Wuzhishan, Ledong, Dongfang, Changjiang, Baisha
Chongqing	Nanchuan, Wulong, Fengdu, Shizhu, Qianjiang, Pengshui
Hubei	Enshi, Yichang, Shennongjia
Anhui	Huangshan, Chizhou, Anqing, Liuan
Guizhou	Qianxinan, Qiannan, Qiandongnan, Tongren, Zunyi
Zhejiang	Hangzhou, Quzhou, Lishui, Wenzhou, Taizhou
Taiwan	Nantou, Taichung, Miaoli, Hsinchu, Taoyuan, Taipei, New Taipei, Keelung, Ilan, Hualien, Taitung
Fujian	Fuzhou, Ningde, Nanping, Shanming, Longyan, Zhangzhou, Xiamen, Quanzhou, Putian
Hongkong	Lidao, Tunmen

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Climate, as a major influence on plant growth and development, plant quality characteristics, and geographical distribution patterns, is an important variable in ecological niche models for assessing plant growth and distribution (Beauregard and de Blois, 2014). In this study, 19 climatic factors were selected as environmental variables and the dominant climatic factors affecting the distribution of *K. coccinea* were screened using the MaxEnt model, they were precipitation of wettest quarter (bio16), annual precipitation (bio12), temperature annual range (bio7), precipitation of driest quarter (bio17), precipitation of warmest quarter (bio18), mean diurnal range (bio2), precipitation of driest month (bio14), precipitation of coldest quarter (bio19). It can be seen from the prediction results that precipitation and temperature are the main environmental factors affecting the distribution of *K. coccinea*, especially precipitation, which is consistent with the fact that *K. coccinea* prefers a humid climate (Luo et al., 2015). We obtained the optimum habitat for *K. coccinea* by analyzing the response curves of climatic variables, including precipitation of wettest quarter (723.2~968.4 mm), annual precipitation (1512.7~1991.4 mm; 3035.4~4680.4 mm), temperature annual range (8.3~23.2 ℃; 24.8~27.3 ℃), precipitation of driest quarter (94.5~633.6 mm), precipitation of warmest quarter (567.3~977.9 mm), mean diurnal range (3.5~7.7 ℃), precipitation of driest month (38.2~199.1 mm), precipitation of coldest quarter (182.9~633.6 mm). It is suggested that these habitat conditions provide the most suitable environment for the growth and distribution of *K. coccinea*.

According to Flora of China, *K. coccinea* is found in Jiangxi, Hunan, Guangdong, Hong Kong, Hainan, Guangxi, Sichuan, Guizhou, and Yunnan (Liu, 1996). The model prediction results show that tropical and subtropical areas such as Guangxi, Hunan, Yunnan, Jiangxi, Guangdong, Hainan, southeastern Chongqing, southwestern Hubei, southern and southwestern Anhui, Guizhou, Zhejiang, Taiwan, Fujian, and Hong Kong are high suitability areas for *K. coccinea*. Through comparison, we can find that the predicted distribution area is wider than the distribution area recorded in the flora, and their differences are mainly concentrated in the distribution of the eastern coastal provinces. These areas have sufficient year-round precipitation and low average daily temperature differences, which are suitable for the growth of *K. coccinea* and can be used to plan the base for the cultivation of high-quality varieties of *K. coccinea*.

In recent years, the quality of *K. coccinea* has deteriorated to a certain extent due to the blind introduction of the species in some areas. To solve the current problems, we should be guided by science and select suitable areas to expand the planting area of *K. coccinea*, thus reducing the losses caused by blind planting. Based on the results of this study, we suggest that the ecological cultivation of *K. coccinea* can be promoted as a priority in the high-suitability area, with minimal human intervention, reducing the damage to the soil environment in the area by the introduction of the species, and ultimately achieving the best yield and quality, laying the foundation for its resource development and utilization. In addition, the results of the quality studies for *K. coccinea* in different suitable areas can be subsequently combined with quality zoning, and these research results will provide a richer reference for the expansion of *K. coccinea* cultivation areas.

Conclusions

In this paper, the distribution of *K. coccinea* was predicted by modelling the climatic suitability using MaxEnt and ArcGIS. The results of this study showed that the AUC

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values were above 0. 9, indicating that the prediction model was excellent. The results of this study are a good reference and practical guide for the selection and scientific planning of the ecological plantation of *K. coccinea*. The following conclusions were drawn:

(1) We conducted a correlation analysis of 19 climatic variables and finally identified eight dominant climatic factors, precipitation of wettest quarter (723.2~968.4 mm), annual precipitation (1512.7~1991.4 mm; 3035.4~4680.4 mm), temperature annual range (8.3~23.2 ℃; 24.8~27.3 ℃), precipitation of driest quarter (94.5~633.6 mm), precipitation of warmest quarter (567.3~977.9 mm), mean diurnal range (3.5~7.7 ℃), precipitation of driest month (38.2~199.1 mm) and precipitation of coldest quarter (182.9~633.6 mm) and their suitable ranges.

(2) The high suitability areas of *K. coccinea* in China are mainly distributed in Guangxi, Hunan, Yunnan, Jiangxi, Guangdong, Hainan, southeastern Chongqing, southwestern Hubei, southern and southwestern Anhui, Guizhou, Zhejiang, Taiwan, Fujian, and Hong Kong.

(3) Although the results of this model prediction are accurate and have a high degree of confidence, the model prediction results cannot replace the actual distribution, and there are other biological factors and human influences in the actual distribution, so the model prediction results of this study are only a reference for the actual distribution.

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