Article

Not peer-reviewed version

Eco-Geography of *Dioscorea Composita* (Hemsl.) and Prediction of Climate Change Effects on Its Current and Future Distribution in México-Central America

Jocelyn Maira Velázquez-Hernández , José Ariel Ruíz-Corral * , Noé Durán-Puga , Diego González-Eguiarte , Fernando Santacruz-Ruvalcaba , Giovanni Emmanuel García-Romero , Jesús Germán De La Mora-Castañeda , Carlos Félix Barrera-Sánchez , Agustín Gallegos-Rodríguez

Posted Date: 4 July 2023

doi: 10.20944/preprints202306.2217.v1

Keywords: Climate change effects; nutraceutical species; distribution; Ecological niche model; Mesoamerica

Article

Eco-Geography of *Dioscorea Composita* (Hemsl.) and Prediction of Climate Change Effects on Its Current and Future Distribution in México-Central America

Jocelyn M. Velázquez-Hernández [1], José Ariel Ruíz-Corral [2,*], Noé Durán-Puga [1], Diego R. González-Eguiarte [1], Fernando Santacruz-Ruvalcaba [3], Agustín Gallegos-Rodríguez [4], Jesús Germán de la Mora-Castañeda [5], Carlos Félix Barrera-Sánchez [2] and Giovanni Emmanuel García Romero [6]

[1] Departamento de Producción Sustentable, Universidad de Guadalajara, Zapopan, Jalisco, México.
[2] Departamento de Ciencias Ambientales, Universidad de Guadalajara, Zapopan, Jalisco, México.
[3] Departamento de Producción Agrícola, Universidad de Guadalajara, Zapopan, Jalisco, México.
[4] Departamento de Producción Forestal, Universidad de Guadalajara, Zapopan, Jalisco, México.
[5] Facultad de Ciencias Biológicas y Agropecuarias, Universidad de Colima, Tecomán, Colima, México.
[6] Dirección del Medio Ambiente del Municipio de Guadalajara, Jalisco, México.
* Correspondence: author: ariel.ruiz@academicos.udg.mx

Abstract. *Dioscorea composita* is a plant native to México and Central America with a high concentration of diosgenin precursors. Currently, México is one of the two most important countries producers of this yam; however, climate change is altering the environmental conditions of its natural habits, threatening its preservation and productivity. This is why this research was focused to characterize the eco-geography of *D. composita* and predict its potential geographic distribution under climate change scenarios in México-Central America. A collection of 408 geo-referenced accessions was used to determine its climatic adaptation, ecological descriptors, and the current and future potential geographic distribution, which was modeled with MaxEnt model through the Kuenm R-package. For future climate scenarios, an ensemble of the GCMs HadGEM-ES and CCSM4 was used. Results showed that *D. composita* adapts to warm humid and very humid agro-climates and that the most contributing variables for its presence are annual and seasonal moisture availability indices, seasonal photoperiod, annual thermal range, Bio14 and Bio11. The year 2050 RCP 4.5 climate scenario would contract the potential distribution of *D. composita*, whilst the 2050 RCP 8.5 scenario would expand it, indicating that this species could be a good crop option under this scenario of emissions.

Keywords: ecological niche model; *Dioscorea composita;* MaxEnt; Change Climate

1. Introduction

Dioscorea composita Hemsl is a wild species that has its origin in México and Central America [1], although some authors consider Mexico as the most probable center of origin [2,3]. *Dioscorea composita* has been historically recognized for the production of secondary metabolites of pharmaceutical importance, including diosgenin. However, due to advances in the chemical synthesis of these compounds, the relevance of natural diosgenin in medicine has diminished over time [3]; consequently, the industry's interest in this plant decreased, which caused that diverse aspects of this plant to remain understudied until now. Nevertheless, recently, the interest in this species has resurfaced, since it has been discovered that it may constitute a promising therapeutic agent against cancer [4,5]. In addition, *D. composita* is a plant with socioeconomic importance that has great nutritional and ethnobotanical value [3]. Currently, it can be considered a nutraceutical plant with use in states of southeastern México [6]. All this situation motivated the present investigation, whose objectives were to characterize the eco-geography and environmental adaptation of *D. composita*, as

 doi:10.20944/preprints202306.2217.v1

well as to predict its current and future potential distribution under climate change scenarios in its original region of occurrence (México-Central America). Climate change is causing variations in temperature and precipitation patterns, as well as in the frequency of extreme weather events [7] causing alterations in the range of species distribution, and modifying the composition and characteristics of ecosystems. México and Central America are some of the most impacted regions by climate change, due to their geographic and orographic characteristics, together with the unequal territorial distribution of natural resources [8]. Climate scenarios modeled for the middle of this century, predict increases in temperature from 1 to 3°C and a decrease in precipitation of around 10%, causing diverse environmental combinations that provoke particular climatic conditions, which alter adversely the agroclimatic conditions of these regions [9], which include the central and northern part of México [10,11]; as well as the tropical and subtropical zones [12]. Central America has experienced the ravages of this phenomenon, causing drought mainly in El Salvador, Guatemala, and Honduras in 2014 and 2015, endangering temperate and cloudy forests [8]. These changes in weather patterns impact the current distribution areas of numerous wild species in México and Central America. In the Mexican occurrence sites of *D. composita*, it is estimated that by the year 2050, the annual mean temperature will increase 2-3 °C and annual precipitation will decrease 10-50 mm, in relation to the average climatology 1961-2010 [13]; while, for the Central American occurrence sites, an increase of 2.5-3°C, and a decrease of 25-70 mm of precipitation are expected by the year 2050 [14]. However, the possible effects of these climatic changes on the presence and potential distribution of *D. composita* have not yet been assessed.

2. Materials and Methods

2.1. Occurrence data

After data curation to mainly discard duplicate and erroneous information [15] a database of *D. composita* occurrence sites in México-Central America was conformed considering a final list of 408 geo-referenced accessions (Table 1). University herbaria, digital herbariums, floristic inventories, and scientific articles were considered as data sources. We only considered the species occurrence sites in México-Central America because they are considered the natural populations of *D. composita* (this region is its center of origin), therefore, they are adequate to characterize the eco-geography of this species and the final purposes of this research [16].

Table 1. Sources of occurrence data for *D. composita* in México-Central America.

Institution	Accessions
Universidad Nacional Autónoma de México (Instituto de Biología)	179
Instituto Nacional de Ecología y Cambio Climático	131
Instituto Nacional de Estadística, Geografía e Informática (Dep. Botánica)	3
Universidad Autónoma de Veracruz (Centro de Investigaciones Tropicales)	1
Universidad Autónoma de Veracruz (Instituto de Investigaciones Biológicas)	10
Colegio de la Frontera Sur (Unidad Tapachula)	5
Universidad Autónoma de Chiapas	5
Universidad Autónoma de Puebla	4
Universidad Juárez Autónoma de Tabasco	5
Universidad Autónoma Benito Juárez de Oaxaca	4
Universidad Autónoma de Guerrero	8
JSTOR Plant Science and the Global Plants Initiative	3
Trópicos.org	1
Red de Herbarios del Noroeste de México.	16
Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Herbario Digital)	7
Global Biodiversity Information Facility (GBIF)	26
Total	**408**

2.2. Climatic data

Raster images of temperature, precipitation, evapotranspiration (ETP), and photoperiod were used, from the Agroclimatic Information System for México-Central America (SIAMEXCA) [13], which has a resolution of 30'' arc and correspond to climatic normals for the period 1961-2010. Additional parameters were derived from these images using the IDRISI Selva software [17], adding a total of 31 variables (Table 2). For climate change scenarios, we used raster images year 2050 RCPs 4.5 and 8.5 derived from an ensemble of two GCMs corresponding to the Coupled Model Inter-comparison Project Phase 5 (CMIP5): HadGEM-ES (European Network for Earth System-Met Office Hadley Center) and CCSM4 (Community Climate System Model), since they have been shown to adequately address and describe continental vegetation, including various types of vegetation [18], in addition to showing good adjustment to the climatic conditions of México and Central America [14,19,20]. Those models have been used successfully formerly to predict suitability of crops under climate change scenarios [21].

Table 2. Environmental variables considered in this research.

Variable	Description	Temporal scale
BIO01	(Annual mean temperature)	Annual
BIO05	(Maximum temperature of the warmest month)	Month
BIO06	(Minimum temperature of the coldest month)	Month
BIO07	Temperature annual range	Annual
BIO08	(Mean temperature of the wettest quarter)	Quarter
BIO09	(Mean temperature of the driest quarter)	Quarter
BIO10	(Mean temperature of the warmest quarter)	Quarter
BIO11	(Mean temperature of the coldest quarter)	Quarter
BIO12	Annual precipitation	Annual
BIO13	Precipitation of the wettest month	Month
BIO14	Precipitation of the driest month	Month
BIO16	Precipitation of the wettest quarter	Quarter
BIO17	Precipitation of the driest quarter	Quarter
BIO18	Precipitation of the warmest quarter	Quarter
BIO19	Precipitation of the coldest quarter	Quarter
N-AMT	November-April mean temperature	Seasonal
M-OMT	May-October mean temperature	Seasonal
M-OXT	May-October maximum temperature	Seasonal
N-AXT	November-April maximum temperature	Seasonal
AXT	Annual maximum temperature	Annual
M-OIT	May-October minimum temperature	Seasonal
N-AIT	November-April minimum temperature	Seasonal
AIT	Annual minimum temperature	Annual
ATO	Annual thermal oscillation	Annual
M-OP	May-October precipitation	Seasonal
N-AP	November-April Precipitation	Seasonal
M-OPH	May-October photoperiod	Seasonal
N-APH	November-April photoperiod	Seasonal
AMAI	Annual moisture availability index	Annual
M-OMI	May-October moisture availability index	Seasonal
N-AMI	November-April moisture availability index	Seasonal

2.3. Environmental characterization of the occurrence sites

Environmental conditions of the *D. composita* occurrence sites were characterized by extracting values from raster images corresponding to 31 variables. This extraction was made with the system

ArcMap 10.8 [22] and by using geographical coordinates for each site. With the extracted data, a data matrix was built in Microsoft Excel.

2.4. Selection of environmental variables

To obtain accurate biological information, species distribution models must be built with predictor variables that have a direct influence on the presence of the species [23]. Thus, it is important to make a good selection of variables, avoiding among other aspects, the multi-collinearity of variables, which can cause a misinterpretation of the model, due to the high level of correlation between variables [24]. Besides, severe multi-collinearity can increase the variance of regression coefficients, making them unstable [25]. Before any statistical analysis, we applied the Shapiro-Wilk test for data normality and found no normality for all variables ($p<0.05$). Thus, we used Spearman's r for correlation analysis. Data from the environmental data matrix were used to perform the correlation analyses; this statistical analysis was carried out with programs developed in the R software version 4.05 [26]. To determine the presence of multi-collinearity, a threshold value of correlation coefficient >0.8 [27] was established. This way, the correlated variables with a coefficient <0.8 were selected, and among the variables with collinearity, the one considered most relevant for the species presence was selected. Furthermore, with the selected variables, preliminary Maxent modeling was performed to identify the environmental variables with the greatest contribution to the distribution of *D. composita*. This produced a final list of selected variables, with which MaxEnt was run again to obtain an optimal model of *D. composita* niches distribution.

2.5. Eco-geography of D. composita: Determination of climatic adaptation and ecological descriptors

The climatic adaptation of *D. composita* was determined by identifying the occurrence of the species in different agro-climatic regions, for this, the map of agro-climatic regions for México and Central America was used [16]. In this way, a list of the agro-climatic conditions in which this species is present was derived.

For the determination of the ecological descriptors, the extracted data matrix was used, considering only information from 20 environmental variables, which were selected after the correlation analysis to discriminate variables highly correlated.

2.6. Ecological niche modeling

The MaxEnt algorithm was used for ecological niche modeling (ENM) of *D. composita* in the current climate scenarios as well as in the climate change scenarios addressed in this research. MaxEnt model was implemented with the assistance of the Kuenm R-package [26,28], which automates and optimizes the ENM process. The preliminary models were created using Kuenm's Kuenm_ceval function, which utilizes occurrence data and environmental predictors, and their efficiency was evaluated through the cal_eval function that determines their statistical significance. To ensure accuracy, ten replicates were performed via cross-validation, using logistic outputs for current and future climatic scenarios. Final model assessments included partial ROC calculations and omission rates (based on E = 5%) using an independent dataset. The functions kuenm_mod and kuenm_feval were used to finalize the models and perform evaluations, respectively [28]. The quality of the model was assessed with the AUC value from the ROC curve, and the Akaike Information Criterion (AIC), corrected for small sample sizes (AICc) [28]. To identify any potential model transfer extrapolation risks, mobility-oriented parity (MOP) analyses were conducted using the kuenm_mmop function [29].

For this research, models were tested using a sequential order of the FC (L, LQ, H, LQH, LQHP, LQHPT) and regularization multiplier (RM) values of 0.1 to 10 with 0.1 increases, a maximum omission rate of 5%, and run 25 k-fold replicates of each configuration; 500 iterations were used [30]. Two models were generated for each parameter setting, one based on the complete set of occurrences and the other based only on the training data.

3. Results

3.1. Statistical analysis and environmental variables selection

Based on Spearman's correlation analysis, 20 environmental variables were selected and used to characterize the eco-geography of *D. composita*. However, for the purpose of the species distribution modeling, the preliminary ENM with MaxEnt revealed that seven variables are the ones that contribute the most to the eco-geographical distribution of *D. composita*, which were used for the final ENM processes with Kuenm R-package [31].

3.2. Eco-geography of D. composita

Figure 1 shows the current geographical distribution of *D. composita* in the agro-climatic regions of México and Central America. The occurrence sites for this species are distributed mainly from the north of Veracruz in México to some areas of Guatemala, Belize, and El Salvador. In this area, most of the *D. composita* accessions are located in the agro-climates humid warm (209 accessions, 51.2%), and very humid warm (83, 20.3%), remarking the preference of this species for humid warm climates.

The map of Figure 1 also shows presence sites in other regions of México with different environmental conditions, proving the ability of *D. composita* to colonize new habitats and adapt to other environmental conditions. Thus, *D. composita* is currently distributed in 10 agro-climates that go from temperate to very warm and from semi-arid to very humid environments (Table 3).

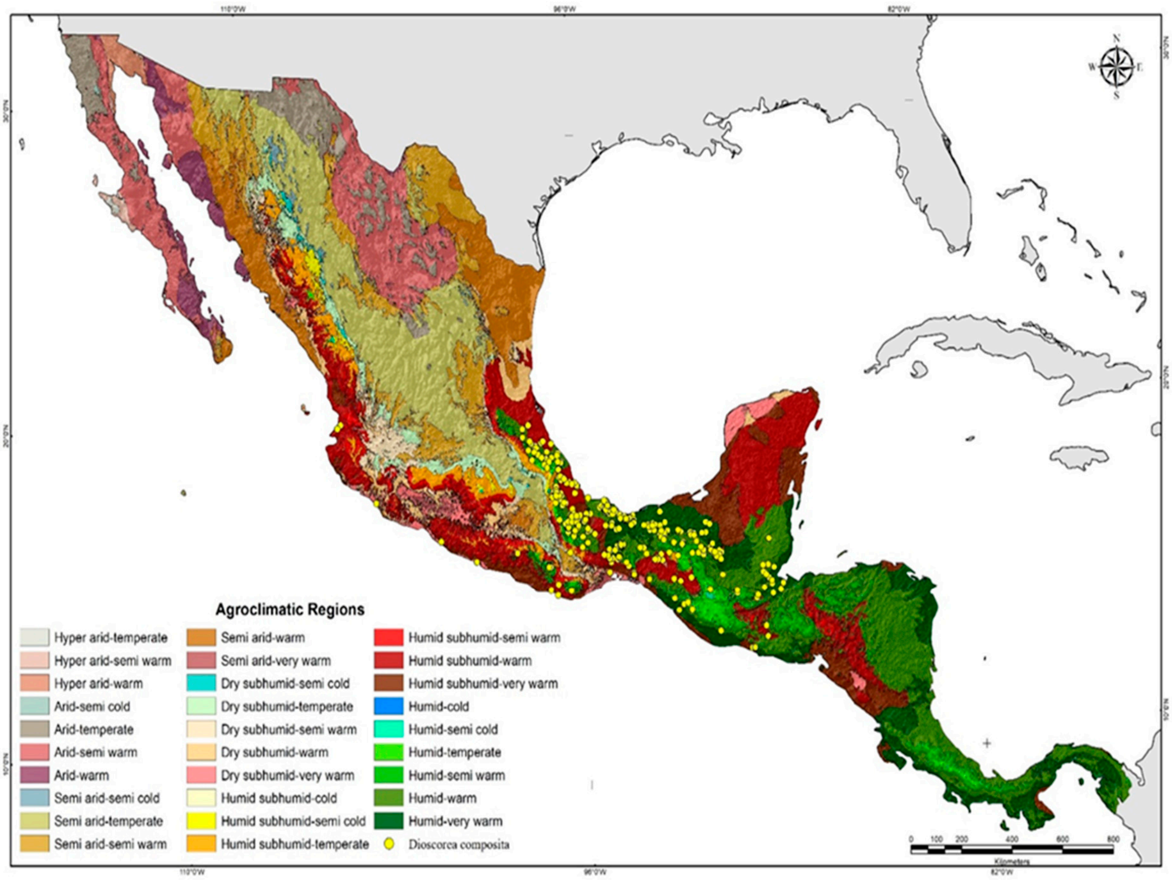

Figure 1. Current distribution of *D. composita* in agroclimatic regions of México and Central America.

Table 3. Intervals of annual moisture availability index and annual mean temperature for 10 agro-climatic regions of México-Central America where *D. composita* is currently distributed.

Agro-climatic region	Annual moisture availability index*	Annual mean temperature (°C)*
Semi-arid very warm	0.2 to 0.5	> 26
Dry sub-humid very warm	0.5 to 0.65	> 26
Dry sub-humid temperate	0.5 to 0.65	12 to 18
Humid sub-humid semi-warm	0.65 to 1.0	18 to 22
Humid sub-humid warm	0.65 to 1.0	22 to 26
Humid sub-humid very warm	0.65 to 1.0	> 26
Humid temperate	> 1.0	12 to 18
Humid semi-warm	> 1.0	18 to 22
Humid warm	> 1.0	22 to 26
Humid very warm	> 1.0	> 26

Climatic characterization of each accession site is described in the Supplemental File. Based on such data, in Table 4, the ecological descriptors of *D. composita* are shown, which include the minimum, maximum and optimal range for each parameter. We decided not to include the average value but the optimal intervals, which correspond with the highest frequency of the species occurrence sites. Since this climatic characterization derives from its center of origin, the most original habitats of *D. composita* were taken into account to do it, hence, this climatic characterization should be considered as a valid reference of its eco-geography. These results may be worthy to perform the species agro-ecological zonation and other applications, now that Latin American governments are more involved in the inventory of native plant genetic resources [32].

Four important climatic aspects for *D. composita* presence may be distinguished in Table 4 data: moisture availability, temperature conditions, thermal range, and photoperiod, most of them important as annually as well as seasonal parameters. The species is present in Mesoamerica region, from 5 to 3001 m above sea level, although its optimal elevation range is 5-1125 m.

It is interesting to notice that some of the ecological descriptors included in Table 4, are not commonly reported, such as the moisture available index (MAI), in this table expressed by the annual and seasonal moisture indices. We obtained that *D. composita* distributes in the range of 0.42 to 3.75, with an optimal interval of 1.1 to 2.9, which is in correspondence with the optimal interval of annual precipitation of 1940 to 3839 mm (Table 4). The thermal oscillation also influences the distribution and development of tubers, the optimal range determined for *D. composita* is from 10.1 to 12.9 °C, whereas photoperiod was selected as an important seasonal variable in the period spring-summer (May-October) as well as in autumn-winter (November-April), with optimal ranges of 12.9-13.15 h and 11.27-11.5 h, respectively. The optimal range for the annual mean temperature (23-28°C) proves that *D. composita* is a species whose natural habitat is the warm thermal zones (Table 4).

Table 4. Ecological descriptors of *D. composita,* based on 1961-2010 average values.

Variable	Minimum	Maximum	Optimum
Annual mean moisture index	0.49	4.95	1.128-2.932
May-October mean moisture index	0.92	10.52	2.02-4.78
November-April mean moisture index	0.026	3.82	0.62-2.62
Annual mean precipitation	737	4874	1940-3839
May-October mean precipitation (mm)	648	3658	1524-2880
November-April mean precipitation (mm)	*26*	*1657*	*416-1059*
Annual mean temperature	12.1	29	23-28
Annual mean maximum temperature	17	35	28-33.5
Annual mean minimum temperature	*7.2*	*23*	*18-22.5*
May-October mean temperature	11	31.9	24-29
May-October mean maximum temperature	15.5	39.4	29-35

 doi:10.20944/preprints202306.2217.v1

May-October mean minimum temperature	6.51	24.5	19-23
November-April mean temperature	11.6	30.3	22-26.9
November-April mean maximum temperature	17.8	35.7	26.5-32
November-April mean minimum temperature	5.5	24.9	17.5-21.8
May-October mean photoperiod	12.30	13.59	12.90-11.15
November-April mean photoperiod	10.44	11.70	11.27-11.50
Annual mean thermal oscillation	8.22	21.10	10.1-12.9
Annual range of temperature	11.73	22.4	16.87-20.15
Elevation	5	3001	5-1125

3.3. Modeling the potential distribution of Dioscorea composita

Kuenm R-package enabled to obtain 341 MaxEnt models (Figure 2), all of them significant, however, only one model positively met the Akaike criterion (AIC=0) and a maximum omission rate of 5%. The Kuenm R-package implemented with MaxEnt determined that 2.0 was the optimum regularization multiplier. The model finally selected to depict the distribution of *D. composita* was judged excellent since the AUC of the ROC curve accounted for 0.946.

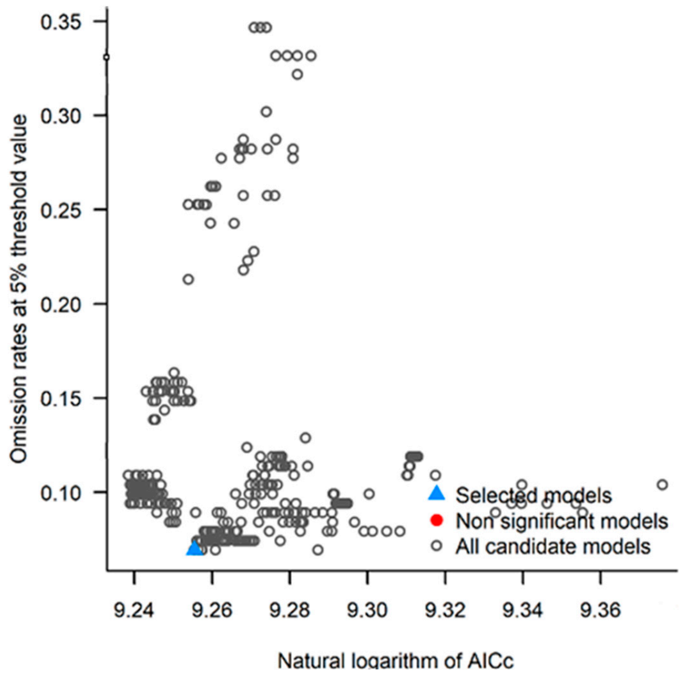

Figure 2. Models obtained and evaluated by Kuenm R-Package for *D. composita.*

The Jackknife test revealed that the variables with the greatest contribution to the distribution niche model of *D. composita* are AMAI (38.4%), NAPH (20.7%), and ATO (17.1%) (Table 5).

Table 5. Contribution of seven environmental variables to depict the presence and distribution of *D. composita*.

Environmental variables	Contribution (%)	Permutation importance (%)
Annual moisture availability index	38.4	3.5
November-April photoperiod	20.7	26.8
Annual thermal oscillation	17.1	9.5
May-October moisture index	9.1	42.7
November-April moisture availability index	8.4	6.2
Precipitation of the driest month	3.7	2.9
Mean temperature of the coldest quarter	2.5	8.3

Furthermore, results from the Jackknife analysis also indicated that when testing the three cases "with only variable", "without variable", and "with all variables", the variable with the highest gain was ATO (annual mean thermal oscillation), with a regularized training gain > 1.1 (Figure 3). Other important environmental variables were NAPH (November-April mean photoperiod), AMAI (annual mean moisture availability index), MOMAI (May-October mean moisture availability index), NAMAI (November-April mean moisture availability index), BIO07 (Temperature Annual Range) BIO14 (precipitation of the driest month), and BIO11 (mean temperature of the coldest quarter), all of them with regularized training gains > 1.0 (Figure 3).

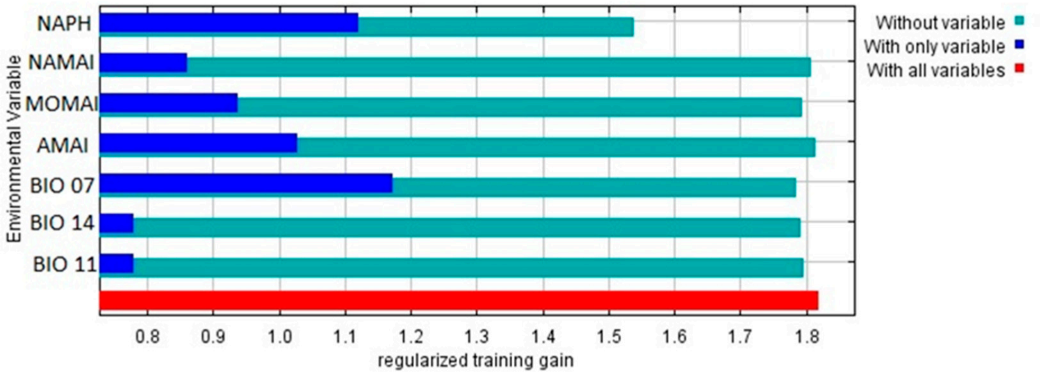

Figure 3. Results of Jackknife test of the relative importance of predictor environmental variables in MaxEnt model for *D. composita* in México and Central America.

Areas with current environmental aptitude for *D. composita* were generated as a binomial map (Figure 4). We used the method of Balance training omission, predicted area, and threshold value (BTOPATV) to delimit suitable areas for *D. composita*. Thus, Figure 3 shows the current and potential distribution of *D. composita*. The total potential distribution area for *D. composita* accounted 692,123 km2, and is located in Durango, Nayarit, Jalisco, Colima, Michoacán, Guanajuato, San Luis Potosí, Tamaulipas, Quintana Roo, Yucatán, Campeche, Tabasco, Veracruz, Guerrero, Oaxaca, and Chiapas, in México, and in some areas of Guatemala, Belize, El Salvador, Honduras, and Nicaragua.

Figure 4. Areas with environmental suitability for *D. composta* in México and Central America.

3.4. Impact of climate change on the potential distribution of D. composita

To generate potential distribution maps under climate change scenarios (2050 RCP 4.5 and RCP 8.5), we also generated binary maps by using the Balance Training Omission, Predicted Area, and Threshold Value (BTOPATV) method. Since an appropriate selection of a thresholding method enables to avoid an important bias in the final distribution map [33], several aspects must be taken into account, such as minimizing the omission rate of the map as possible but without neglecting to seek a realistic map [16], this is why we decided to use BTOPATV.

Figure 5 shows the environmental suitability areas for *D. composita* in the year 2050 under two different climate paths (RCP 4.5 and RCP 8.5). Both contraction and expansion areas were produced for the distribution of *D. composita.*

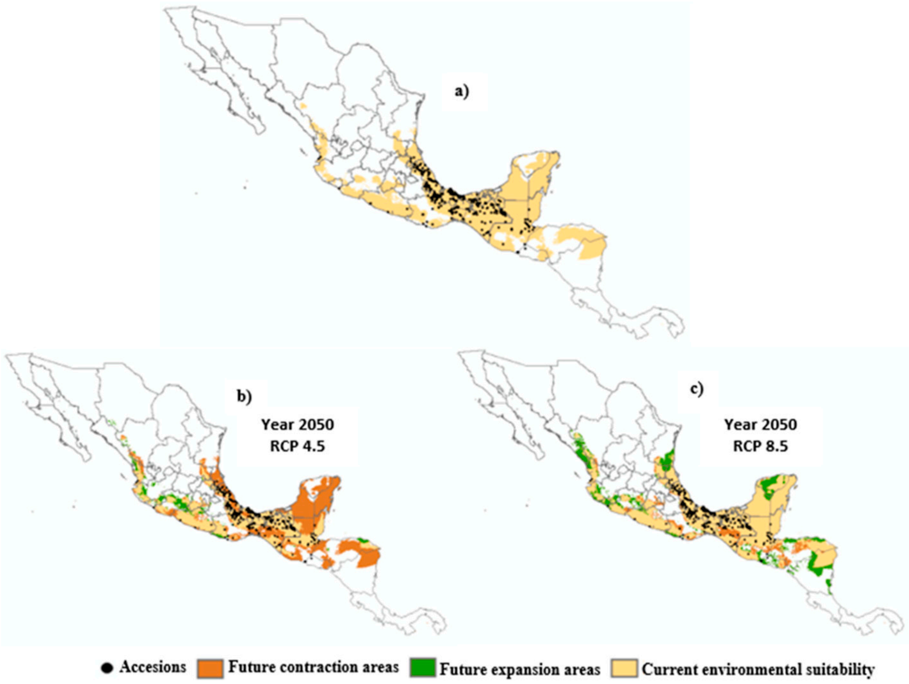

Figure 5. Current and potential distribution of *D. composita* under three climatic scenarios: a) 1961-2010; b) year 2050 rcp 4.5; c) year 2050 rcp 8.5. Areas of contraction and expansion of environmental suitability are shown in orange and green colors, respectively.

Table 6 indicates that when considering both contraction and expansion areas, a negative balance is predicted under RCP 4.5, suggesting that climate change would have an adverse impact on the environmental suitability for *D. composita*. The contraction in the environmental suitability area in México would affect the states of Durango, Michoacán, San Luis Potosí, Tamaulipas, Oaxaca, Quintana Roo, Yucatán, Campeche, Veracruz, and Chiapas, whilst other affected areas would be located in Guatemala, Belize, El Salvador, and Honduras. Opposite, with RCP 8.5, a positive balance is predicted, which includes an increase in the environmental suitability area for *D. composita*. The expansion of the environmental suitability would imply territory of México in the states of Durango, Jalisco, Michoacán, Tamaulipas, Yucatán, and Campeche, as well as territory of Guatemala, El Salvador, Honduras, and Nicaragua.

Table 6. Current and predicted environmental suitability by the year 2050 for *Dioscorea composita* in México-Central America.

	Area (km^2)		
	1961-2010	**2050 RCP4.5**	**2050 RCP8.5**
Environmental suitability	692,123	365,680	763,589
Suitability expansion		46,826	154,530
Suitability contraction		373,269	83,064
Suitability without change		318,854	609,059

 doi:10.20944/preprints202306.2217.v1

4. Discussion

D. composita occurrence sites are concentrated in a region of humid warm climates that goes from the north of Veracruz, México, to the north of Guatemala. Since México-Central America is the most likely center of origin for *D. composita* [1], this geographic area could be suggested as a possible center of origin of this species, although, this hypothetical assertion must be proven with phylogenetically targeted genomic, morphological, and Earth system data [34]. In addition, as expected, niche modeling with MaxEnt showed this region with the highest environmental suitability for *D. composita*, which appends another argument to support such a hypothetical suggestion, since it is known that the centers of origin of the species meet the best environmental conditions for their growth [35].

Even when *D. composita* mostly distributes in humid warm climates, the presence of occurrence sites in other environmental conditions evidences the species' capabilities to adapt to an ampler climatic scope. This provides *D. composita* the possibility of better adaptation to novel climates that global warming is bringing on [36–38].

The former results match with previous reports that state that the species of the genus *Dioscorea* are distributed in warm climates as well as in temperate zones [39], even at elevations above 2,200 m [40]. Likewise, our results agree with previous findings that *Dioscorea* species also are adapted to both tropical and subtropical zones [41,42].

According to annual mean precipitation range characterization for 18 species of *Dioscorea* genus with a presence in India [40], they distribute in environments with annual precipitation ranging from 2165 to 3778 mm, reinforcing the wetland plants' character. In our research, we obtained a range of 737 to 4,874 annual millimeters; the value 737 mm corresponds with an accession located on the borderline of Mexican states Guerrero and Oaxaca, near the Pacific coast. In fact, 12 of 27 occurrence sites located near the Pacific coastline, register annual precipitation lower than 1,500 mm, indicating that *D. composita* has strived to adapt to novel drier environments. These accessions could be of interest for a possible breeding program focused on giving rise to varieties better capable to cope with climate change drought episodes.

Photoperiod also was determined to be an important variable for *D. composita* distribution. Short days have been reported to favor *Dioscorea* species tubers, whereas a photoperiod of more than 12 hours has been shown to promote the growth of leaf area, long stems, and vigorous vines [43,44].

Results evidenced that annual thermal oscillation (ATO) and annual thermal range (ATR) contributed to explaining *D. composita* presence and distribution; the optimal intervals determined for *D. composita* are 10.1-12.9 °C and 16.9-20.2 °C, respectively (Table 4). These values are indicative of a species not typically from thermo-regulated climates, as might be expected due to its presence in mostly humid and warm climates, but rather of a species that tolerate the occurrence of extreme temperatures. According to the Köppen-García Climate Classification System [45], these environments correspond to extreme thermal climates (ATO = 7 – 14 °C).

Growth of the *Dioscorea* species requires temperatures in the range of 25 to 30 °C to exhibit normal development; we obtained a very similar range (23-28 °C, Table 4) as an optimal interval in this parameter [41]. This author also reports that the growth of *Dioscorea* species is restricted by temperatures below 20 °C; such conditions are present in the occurrence sites located in the original region of distribution of *D. composita* (yellow color area in map of Figure 3). However, for the rest of the distribution sites, temperatures keep below 20 °C many days during the year (Supplemental File), denoting *D. composita* is being subjected to adaptation in other environments.

Warm temperatures favor foliage growth, but they also favor high respiration rates, which retard tuber growth and alter the production of diosgenin [46]. However, the optimal range determined in this research for the mean maximum temperature in the hot season (May-October) was 29-35 °C, which supposes certain comfort status of *D. composita* even under temperatures considered extreme (>32 °C) for many plant species [47,48].

Niche model with an AUC value greater than 0.7 can make good estimations [49]. Classify the accuracy of the models according to their AUC value in five categories: 0.50-0.60 insufficient model; 0.60-0.70 poor model; 0.70-0.80 average acceptable model; 0.80-0.90 good model, and 0.90-1.00

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 4 July 2023 doi:10.20944/preprints202306.2217.v1

excellent model [50,51]. According to this classification, the obtained models for all climatic scenarios studied are excellent to describe the potential distribution of *D. composita* and constitute an adequate tool to derive the eco-geographic characterization of the territories where this species is distributed [15].

The results of the Jackknife test revealed that the environmental variables that most determine the presence and distribution of *D. composita* are AMAI, NAPH, ATO, MOMAI, NAMAI, Bio14, and Bio11 (Table 5). These results partially match with previous reports y [37] which mention that the most important variables in the growth and development of the species, especially in the production of diosgenin, are precipitation and solar radiation. For *Solanum tuberosum* with which the species of the genus *Dioscorea* are compared for the production of tubers, the most important environmental variables are annual precipitation and average soil temperature, in such a way that at higher soil temperature and lower soil moisture, the distribution of the species that produce tubers is limited [52].

Most studies about the effects of climate change on the environmental suitability for species, report more contraction than expansion areas for their potential distribution [53]. However, this type of climate change effects should not be considered a generalization, since the new environmental conditions brought about by climate change can represent comparative advantages for diverse species, mostly causing the expansion of their potential distribution areas [54]; also, some species could remain in their current distribution areas without being significantly affected by climate change. In this way, species of origin and adaptation to temperate environments would see their potential distribution reduced by the year 2050, as it is the case of *Solanum tuberosum* [52]; while species of tropical origin and adaptation to warm environments would benefit from the expansion of their potential distribution areas; an example of this statement is *Dioscorea alata*, which is predicted to have a significant increase in production and potential distribution area by 2040s decade [55].

Environmental factors are the main drivers of changes in the distribution of *Dioscorea* species [56]. Based on the values in Table 6, which describe the dynamics of environmental suitability for *D. composita* under different climate change scenarios, it is concluded that scenario RCP 4.5 would have a negative impact on the species, with a decrease in its potential distribution area. Loss of biodiversity, as a consequence of climate change, has been observed in similar environments in other species such as passion fruit, which, being a climbing species, will also be affected in scenario RCP 4.5, decreasing its potential area due to increased temperature and decreased precipitation (and hence, reduced water availability), and new physico-chemical soil characteristics [57].

Based on the results, the year 2050 RCP 8.5 climatology would have a positive effect on the environmental suitability of *D. composita*. However, studies on the effects of climate change indicate mainly impacts on areas of environmental suitability, resulting in contraction areas being greater than expansion areas [53]. Notwithstanding the foregoing, the response of each plant species may differ, with some decreasing their distribution, others changing or expanding it, and perhaps some not being affected at all [54]. While climate change has the potential to negatively affect the distribution and biodiversity of plant species, specific effects may vary depending on the species and the scenario considered. In the case of *D. composita*, the RCP 8.5 scenario suggests a positive effect on its potential distribution area. Furthermore, the variation in the impacts of climate change on population growth rates is mainly due to differences in the climatic response of the species populations [58].

5. Conclusions

Since results of this research showed that *D. composita* is mainly distributed in a compact zone of southern México-Central America with warm and humid climates. However, some *D. composita* populations were found to adapt to sub-humid and semi-arid conditions, and to semi-warm and temperate environments, which could contribute to this plant better cope with environmental stress that climate change is imposing through drought and heat episodes.

Modeling of environmental suitability for current conditions allowed for the identification of a region that stretches from northern Veracruz, México, to northern Guatemala in Central America, which could be the center of origin of *D. composita*. The parameters that most influence its distribution are the annual and seasonal moisture availability indices, the November-April mean photoperiod, the annual mean thermal oscillation, the precipitation of the driest month, and the mean temperature of the coldest quarter.

According to climate change scenarios for the year 2050, the research indicates a decrease in environmental suitability for *D. composita* under the RCP 4.5 scenario and an increase under the RCP 8.5 scenario, thus, this species could be a good crop option under this scenario of emissions.

The data generated in this research can contribute to a better understanding of the plant-environment interactions for *D. composita,* thus, easing the determination of its potentiality as a crop under the current and future climatologies, as well as design strategies for its natural populations in México and Central America. Such possible actions will undoubtedly be very useful now that *D. composita* is back in the public interest for its nutraceutical properties.

References

1. Couto, R.S.; Martins, A.C.; Bolson, M.; Lopez, R.C.; Smidt, E.C.; and Braga, J.M.A. Time calibrated tree of *Dioscorea* (*Dioscoreaceae*) indicates four origins of yams in the Neotropics since the Eocene. *Botanical Journal of the Linnean Society*, **2018**, *188*, 144-160. hps://doi.org/10.1093/botlinnean/boy052.
2. Martin, F.W.; Ortiz, S. New chromosome numbers in some *Dioscorea* species. *Cytologia* **1966**, *31*, 105-107. hps://doi 10.1508/cytologia.31.105.
3. Álvarez, Q.V., Caso, B.L., Aliphat, F.M. Galmiche TÁ. Plantas medicinales con propiedades frías y calientes en la cultura Zoque de Ayapa. Tabasco, México. *Boletín Latinoamericano y del Caribe de plantas medicinales y aromáticas*. **2017**, *16*, 428-454. Available at. https://www.redalyc.org/pdf/856/85651256007.pdf.
4. Zhang, S.; Fan, M.; Ye, G.; Zhang, H.; Xie, J. Biorefinery of *Dioscorea composita* Hemsl with ferric chloride for saponins conversion to diosgenin and recycling the waste to biomethane. *Industrial Crops and Products.* **2019**, *135*, 122-129. https://doi 10.1016/j.indcrop.2019.04.040.
5. Wei, M.; Bai, Y.; Ao, M.; Jin, W.; Yu, P.; Zhu, M.; Yu, L. Novel method utilizing microbial treatment for cleaner production of diosgenin from *Dioscorea zingiberensis* CH Wright (DZW). *Bioresource technology*. **2013**, *146*, 549-555. https://doi 10.1016/j.biortech.2013.07.090.
6. Román-Cortés, N. R., García-Mateos, M. D. R., Castillo-González, A. M., Sahagún-Castellanos, J., & Jiménez-Arellanes, M. A. Características nutricionales y nutracéuticas de hortalizas de uso ancestral en México. *Revista fitotecnia mexicana.* **2018**, *41*, *245-253.* https://doi.org/10.35196/rfm.2018.3.245-253.
7. García, E. Modificaciones al Sistema de Clasificación Climática de Köppen (Para adaptarlo a las condiciones de la República Mexicana). 5ª. Edición Instituto de Geografía UNAM-Enriqueta García. Ciudad de México. **2004**, pp.90. http://www.publicaciones.igg.unam.mx/index.php/ig/catalog/view/83/82/251-1.
8. Bolaños, G.B. Biopolíticas del cambio climático para Centroamérica. *Trace* (México, DF). **2018**, *74*, 135-158. https://doi 10.22134/trace.74.2018.111.
9. Ruiz-Corral, J.A.; Medina-García, G.; Flores-López, H.E., Ramírez-Díaz, J.L., De la Cruz-Larios, L.; Villalpando-Ibarra, J.F.; Ruiz-Álvarez, O. Impacto del cambio climático sobre la estación de crecimiento en el estado de Jalisco, México. *Revista Mexicana Ciencias Agrícolas*. **2016ª**, *13*, 2627-2638. Available at. http://www.scielo.org.mx/scielo.php?pid=S200709342016000902627& script=sci_arttext.
10. Lobato, S.R.; Altamirano, C.M.A. Detección de la tendencia local del cambio de la temperatura en México. *Tecnología y Ciencias del Agua.* **2017**, *8*, 101-116. https://doi 10.24850/j-tyca-2017-06-07.
11. Rodríguez, M.V.M; Medina, G.G.; Díaz, P.G.; Ruiz, C.J.A.; Estrada, A.J.E.; Mauricio, R.J.E. ¿Por qué México es un país altamente vulnerable al cambio climático? *Revista Mexicana Ciencias Agrícolas*. **2021**, *25*, 45-57. https://doi 10.29312/remexca.v12i25.2819.
12. Mora, C.; Caldwell, I.R.; Caldwell, J.M.; Fisher, M.R.; Brandon, M.G.; Running, S.W. Suitable days for plant growth disappear under projected climate change: potential human and biotic vulnerability. *PloS one Biology.* **2015**, *587*. https://doi 10.1371/journal.pbio.1002167.
13. Ruiz-Corral, J.A.; Medina-García, G.; García-Romero, G. Sistema de información agroclimática para México-Centroamérica. *Revista Mexicana Cienciencas. Agrícolas.* **2018**,*9*, 1-10. https://doi 10.29312/remexca.v9i1.843.
14. Barrera-Sánchez, C.F.; Ruiz-Corral, J.A.; Zarazúa, V.P.; Lépiz, I.R.; González, E.D.R. Cambio climático y distribución potencial de frijol lima en Mesoamérica y Aridoamérica. *Revista Mexicana de Ciencias Agrícolas.* **2020**, *11*, 1361-1375. https://doi10.29312/remexca.v11i6.2412.
15. Kong, F.; Tang, L.; He, H.; Yang, F.; Tao, J.; Wang, W. Assessing the impact of climate change on the distribution of *Osmanthus fragrans* using Maxent. *Environmental Science and Pollution Research.* **2021**, *28*, 34655-34663. https://doi 10.1111/2041-210X.12168.
16. Sánchez-González, J.D.J.; Ruiz, C.J.A.; García, G.M.; Ojeda, G.R.; Larios, L.D.L.C.; Holland, J.B.; García, R.G.E. *Ecogeography of teosinte. PLoS One.* **2018**, *13*, e0192676. https://doi 10.1371/journal.pone.0192676.

17. Eastman, J.R. Idrisi Selva Manual. Clark Labs, Clark University. Worcester, MA, USA. **2012**, 322 p.
18. Bellouin, N.; Boucher, O.; Haywood, J.; Johnson, C.; Jones, A.; Rae, J.; Woodward, S. Improved representation of aerosols for HadGEM2. *Hadley Centre Technical Note 73, Met Office Hadley Centre*. Exeter, EXI 3PB. United Kigdom, **2007**, 42 p. https://www.google.com/search?q=Improved+representation+of+aerosols+for+HadGEM2.+Hadley+Centre+Technical+Note+73%2C+Met+Office+Hadley+Centre.+Exeter&rlz=1C1ALOY_esMX969MX973&oq=Improved+representation+of+aerosols+for+HadGEM2.+Hadley+Centre+Technical+Note+73%2C+Met++Office+Hadley+Centre.+Exeter&aqs=chrome..69i57.1981j0j15&sourceid=chrome&ie=UTF-8.
19. Instituto de Ecología (INE). México cuarta comunicación nacional ante la convención marco de las Naciones Unidas sobre cambio climático. *Secretaría de Medio Ambiente y Recursos Naturales* (SEMARNAT). D. F México. **2009**, 274 p. Available at. https://www.gob.mx/cms/uploads/attachment/file/666958/cuarta_Comunicacion.pdf.
20. Conde, C.; Estrada, F.; Martinez, B.; Sánchez, O.; Gay C. Regional climate change scenarios for México. *Atmósfera*. **2011**, *24*,125-140. Available at. http://www.scielo.org.mx/pdf/atm/v24n1/v24n1a9.pdf.
21. Zuza, E.J.; Maseyk, K.; Bhagwat, S.A.; De Sousa, K.; Emmott, A.; Rawes, W.; Araya, Y.N.. Climate suitability predictions for the cultivation of macadamia (Macadamia integrifolia) in Malawi using climate change scenarios. *PloS one*. **2021**,*16*, e0257007. https://doi.org/10.1371/journal.pone.0257007.
22. Environmental Systems Research Institute (ESRI). ArcGIS Desktop: Release 10. Environmental Systems Research Institute. Redlands, CA, USA. **2010**, 15 p. Available at. http://earthobservations.org/about_geo.shtml.
23. Newbold, T. Applications and limitations of museum data for conservation and ecology, with particular attention to species distribution models. *Progress in Physical Geography*. **2010**, *34*, 3–22. https://doi: 10.1177/0309133309355630.
24. Boria, R.A.; Olson, L., Goodman, S.M.; Anderson, R.P. Spatial filtering to reduce sampling bias can improve the performance of ecological niche models. *Ecological Modelling*. **2014**, *275*, 73–77. https://doi 10.1016/j.ecolmodel.2013.12.012.
25. del Valle, M.J.; Guerra, B.W. La multicolinealidad en modelos de regresión lineal múltiple. *Revista Ciencias Técnicas Agropecuarias*. **2012**, *21*, 4, 80-83. Available at. http://scielo.sld.cu/pdf/rcta/v21n4/rcta13412.pdf.
26. Core, T.R. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. Austria. **2021**. Available at. https://www.R-project.org/.
27. Jayasinghe, S.L.; Kumar, L. Modeling the climate suitability of tea [*Camellia sinensis (L.) O. Kuntze*] in Sri Lanka in response to current and future climate change scenarios. *Agricultural and Forest Meteorology*. **2019**, *272*, 102-117. https://doi 10.1016/j.agrformet.2019.03.025.
28. Cobos, M.E.; Peterson, A.T.; Osorio, O.L.; Jiménez, G.D. An exhaustive analysis of heuristic methods for variable selection in ecological niche modeling and species distribution modeling. *Ecological Informatics.* **2019**, *53*, 100983. https://doi.org/10.1016/ j.ecoinf.2019.100983.
29. Peterson, A.T., Cobos, M.E., Jiménez, G.D. Major challenges for correlational ecological niche model projections to future climate conditions. *Annals of the New York Academy of Sciences*. **2018**, *1429*, 66-77. https://doi.org/10.1111/nyas.13873.
30. Cao, Y.; DeWalt, R.E.; Robinson, J.L.; Tweddale, T.; Hinz, L.; Pessino, M. Using Maxent to model the historic distributions of stonefly species in Illinois streams: The effects of regularization and threshold selections. *Ecological Modelling*. **2013**, *259*, 30-39. https://doi.org/10.1016/j.ecolmodel.2013.03.012.
31. Flores, T.M.; Ortiz, E.; Villaseñor. J.L. Modelos de nicho ecológico como herramienta para estimar la distribución de comunidades vegetales. *Revista Mexicana de Biodiversidad 90*.**2019**. https://doi 10.22201/ib.20078706e.2019.90.2829.
32. Goettsch, B.; Urquiza, H.T.; Koleff, P. Acevedo, G.F. Extinction risk of Mesoamerican crop wild relatives. *Plants, People, Planet*. **2021**, *3*, 775-795. https://doi 10.1002/ppp3.10225.
33. Syfert, M.M.; Smith, M.J.; Coomes, D.A.The Effects of Sampling Bias and Model Complexity on the Predictive Performance of MaxEnt Species Distribution Models. *PLoS one*. **2013**, *8*, e55158. https://doi 10.1371/journal.pone.0055158.
34. Bowles, A. M., Williamson, C. J., Williams, T. A., Lenton, T. M., & Donoghue, P. C. The origin and early evolution of plants. *Trends in Plant Science*. **2022**, *28*,312-329. https://doi.org/10.1016/j.tplants.2022.09.009
35. Purseglove, J.W. Tropical crops: Monocotyledons. Longman Scientific and Technical. New York, NY, USA; **1985**.
36. Villers, R.L.; Trejo, V.I. El cambio climático y la vegetación en México. México: Una Visión Hacia El Siglo XXI El Cambio Climático En México, Universidad Nacional Autónoma de México, México. D.F. **2000**, 57-66. Available at. https://www.uv.mx/personal/tcarmona/files/2010/08/Villers-y-Trejo-.pdf.

37. Shen, L.; Xu, J.; Luo, L.; Hu, H.; Meng, X.; Li, X.; Chen, S. Predicting the potential global distribution of diosgenin-contained *Dioscorea* species. *Chinese medicine.* **2018**, *13*,58. https:/ /doi.org/10.1186/s13020-018-0215-8 1-10.
38. Kipling, R.P.; Topp, C.F.; Bannink, A.; Bartley, D.J.; Blanco, P.I.; Cortignani. R.; Eory, V. To what extent is climate change adaptation a novel challenge for agricultural modellers? *Environmental Modelling & Software.* **2019**, *120*, 104492. https://doi. 10.1016/j.envsoft.2019.104492.
39. Téllez, V.O.; Ramírez, R.R.O. Las *dioscóreas* (*Dioscoreaceae)* del Estado de Morelos, México. *Anales del Instituto de Biología serie Botánica.* **1992**, 63-001. Available at. https://www.redalyc.org/pdf/400/40063104.pdf.
40. Saikia, B.; Rawat, J.S; Tag, H.; Das, A.K. An investigation on the taxonomy and ecology of *Dioscorea* in Arunachal Pradesh, India. *Journal of Frontline Research.* **2011**, *01*, 44-53. https://d1wqtxts1xzle7.cloudfront.net/31930407/Dioscorea_paper_B_saikia-with-cover-page-v2.pdf?
41. Rodríguez, W. Botánica, domesticación y fisiología del cultivo de ñame (*Dioscorea alata*). *Agronomía Mesoamericana.* **2000**, *11*, 133-152. Available at. .https://www.redalyc.org/pdf/437/ 43711221.pdf.
42. González, V.M.E. El ñame (*Dioscorea* spp.). Características, usos y valor medicinal. Aspectos de importancia en el desarrollo de su cultivo. *Cultivos Tropicales.* **2012**, *33*, 05-15. Available at. http://scielo.sld.cu/scielo.php?pid=S0258-59362012000400001&script=sci_arttext&tlng=en.
43. Coursey, D.G. Yams: *Dioscorea spp*. In: J. Smartt & N. Simmonds, *Evolution of Crop Plants*. Wiley 2nd Edition. London. **1976**, pp.70-74. Available at. https://agris.fao.org/agrissearch/search.do?recordID=US201303063121.
44. Puga, B.E. Manejo agronómico del cultivo de ñame. Guía técnica. 2 ed. MIDA. Panamá; **1995**.
45. García E. Modificaciones al Sistema de Clasificación Climática de Köppen (Para adaptarlo a las condiciones de la República Mexicana). 5ª. Edición Instituto de Geografía UNAM-Enriqueta García. Ciudad de México, México. **2004**, 90 p. http://www.publicaciones.igg.unam.mx/index.php/ig/catalog/view/83/82/251-1.
46. Onwueme IC. Sett weight effects on time of tuber formation, and on tuber yield characteristics, in water yam (*Dioscorea alata* L.). *Journal Agricultural Science*. **1978**, *91*, 317-319. https://doi 10.1017/S0021859600046402.
47. Ruiz-Corral, J.A.; Medina, G.G.; González, A.I.J.; Flores, L.H.E.; Ramírez, O.G.; Ortiz, T.C.; Byerly, M.K.F.; Martínez, P.A.R.A. Requerimientos agroecológicos de cultivos. Libro Técnico Núm. 3. 2ª Ed. INIFAP-Prometeo Editores. Guadalajara, Jalisco, México. **2013**, pp.564 Available at. https://www.researchgate.net/publication/343047223_REQUERIMIENTOS_AGROECOLOGICOS_DE_CULTIVOS_2da_Edicion.
48. FAO. ECOCROP Database. Food and Agriculture Organization of the United Nations. Rome, Italy.**2019**.
49. Phillips, S.J.; Anderson, R.P.; Schapire, R.E. Maximum entropy modeling of species geographic distributions. *Ecological Modelling*. **2006**, *190*, 231-259. https://doi 10.1016/j.ecolmodel.2005.03.026.
50. Reynoso, S.R.; Pérez, H.M.J.; López, B.W.; Hernández, R.J.; Muñoz, F.H.J.; Cob, U.J.V.; Reynoso, S.M.D. El nicho ecológico como herramienta para predecir áreas potenciales de dos especies. *Revista Mexicana de Ciencias Forestales.***2018**, *9*, 47-68. https://doi10.29298/rmcf.v8i48.114.
51. Navarro, G.M.A.; Jove, C.C.A.; Ignacio, A.J.M. Modelamiento de nichos ecológicos de flora amenazada para escenarios de cambio climático en el departamento de Tacna-Perú. *Colombia Forestal*. **2020**, *23*, 51-67. https://doi.org/10.14483/2256201x.14866.
52. Khalil. T.; Asad, S.A.; Khubaib, N.; Baig, A.; Atif, S.; Umar, M.; Baig, S. Climate change and potential distribution of potato (Solanum tuberosum) crop cultivation in Pakistan using Maxent. *AIMS Agriculture and Food.* **2021**, *6*, 663-676. https://doi 10.3934/agrfood.2021039.
53. Sork, V.; Davis, F.; Westfall.; R.; Flints, A.; Ikegami, M.; Wang, H.; Grivet, D.D. Gene movements and genetic association with regional gradients in California valley oak (*Quercus lobata Née*) in the face of climate change. *Molecular Ecology.* **2010**, *19*, 3806-3823. https://doi 10.1111/j.1365-294X.2010.04726.x.
54. Ovando, H.N.; Tun, J.; Mendoza, G.G.; Parra, T.V. Efecto del cambio climático en la distribución de especies clave en la vegetación de duna costera en la península de Yucatán. México. *Revista Mexicana de Biodiversidad.* **2020**, 91. https://doi 10.22201/ib.20078706e.2020.91.2883.
55. Srivastava, A.K.; Gaiser, T.; Paeth, H.; Ewert, F. The impact of climate change on Yam (*Dioscorea alata*) yield in the savanna zone of West Africa. *Agriculture, Ecosystems & Environment*. **2012**, *153*, 57-64. https://doi 10.1016/j.agee.2012.03.004.
56. Du, Z.X.; Wu, J. Meng, X.X.; Li, J.H.; Huang, L.F. Predicting the global potential distribution of four endangered Panax species in middle-and low-latitude regions of China by the geographic information system for global medicinal plants (GMPGIS). *Molecules.* **2017**, *22*, 10-1630. https://doi 10.3390/molecules22101630.

 doi:10.20944/preprints202306.2217.v1

57. Munar, A.M.; Carlosama, A.R.; España, J.L.M. Potenciales áreas cultivables de pasifloras en una región tropical considerando escenarios de cambio climático. *Revista de Investigación Agraria y Ambiental*. **2022**, *13*, 109-129. https://doi.org/10.22490/21456453.4637.
58. Louthan, A.M.; Morris, W. Climate change impacts on population growth across a species' range differ due to nonlinear responses of populations to climate and variation in rates of climate change. *PloS one*. **2021**,*16*, e0247290. https://doi.org/10.1371/journal.pone.0247290.