

Predictive models of the effects of global warming on the adaptability of native common bean in México

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ABSTRACT

Objective: This study aimed to develop predictive models to estimate the impacts of global warming on the adaptability of native common bean populations in México.

Design/Methodology/Approach: Presence records for *Phaseolus vulgaris* var. *aborigineus* (Pva) and *Phaseolus vulgaris* var. *mexicanus* (Pvm) were compiled across México. Global warming scenarios were established using Shared Socioeconomic Pathways (SSPs) across four temporal projections. A Principal Component Analysis (PCA) was performed based on 19 bioclimatic variables and 12 monthly temperature and precipitation averages. Ecological niche suitability was assessed using the Maximum Entropy model (MaxEnt, Ver. 4.3.1k).

Results: Principal Component 1 (PC1) accounted for 68% of the variance in Pva and 86% in Pvm, while PC2 explained 30% in Pva and 12% in Pvm. Adaptability was primarily influenced by temperature fluctuations and cumulative rainfall during March and September. An overall increase in ecological niche suitability was projected for both species, attributed to global warming and the resulting decline in interspecific competition from other tree and shrub species adversely affected by climatic changes.

Limitations/Implications: The study focused exclusively on two plant species. Broader assessments incorporating additional species are necessary to fully understand the ecological interactions within chaparral, forest, and grassland ecosystems.

Findings/Conclusions: The models generated demonstrated high predictive accuracy, indicating an expansion in the potential adaptability range of the two native common bean species in response to global warming.

Keywords: *Phaseolus*, diversity, environment, conservation, sustainability.

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INTRODUCTION

In México, several centers of genetic diversity and domestication of native populations of common bean (*Phaseolus vulgaris*) have been identified (Matsuoka *et al.*, 2002; Kwak *et al.*, 2009; Mamidi *et al.*, 2011; Hernández *et al.*, 2013; Bellucci *et al.*, 2014). In the state of Durango, multiple presence records have been documented for various *Phaseolus* species,



including *P. vulgaris* var. *aborigineus* and *P. vulgaris* var. *mexicanus* (Debouck, 1979; Cárdenas *et al.*, 1996; Punzo & Ramírez, 2008; Wallander *et al.*, 2022; CIAT, 2023; GBIF, 2023a, b), and certain domestication sites have been proposed (Punzo & Ramírez, 2008; Zavala, 2010; INAH, 2024). However, it is believed that domestication in this region occurred more recently than in western and southwestern México. It is essential to analyze the available data in light of human migration patterns across the Americas and interregional interactions among population groups (Zavala, 2010), as well as the documented presence of several *Phaseolus* species from the southwestern United States to South America (Bellucci *et al.*, 2014). Global warming, land-use change, ecosystem fragmentation, and overexploitation of grasslands have significantly reduced native populations of common bean. It is believed that certain individuals from the Durango Race Population Complex were instrumental in deriving the landraces and improved common bean varieties currently cultivated in northern and central México. This germplasm is now widely used in breeding programs for drought-tolerant common bean across the globe. Climate variability, driven by global warming, has led to substantial agricultural losses. Experts in agrometeorology have highlighted the imminent risks posed by climate change to native crop populations (Lippmann *et al.*, 2019), traditional landraces, and improved germplasm currently used for human consumption worldwide. Production risks have been exacerbated by meteorological instability, contrasting agricultural practices (subsistence *vs.* intensive farming), and the physicochemical degradation of soils. In México, there is a recognized need for precise methodologies to predict the effects of global warming on the geographic distribution and genetic diversity patterns of native common bean populations, as well as on agricultural productivity levels. In north-central México, the magnitude of climate change impacts remains largely unknown, particularly concerning native populations, intermediate forms, and cultivated varieties of common bean, which currently underpin breeding programs, food security, nutrition, and public health. Common bean populations exhibit dynamic intra- and inter-population genetic diversity, influenced by gene flow, environmental factors, population heterogeneity, germplasm introduction, and agronomic management of cultivated common beans. Native populations, intermediate forms, and landraces constitute the genetic foundation of improved varieties and, collectively, form the Durango Race Population Complex (Singh *et al.*, 1991). This complex is recognized as a reservoir of genes conferring moisture stress tolerance (drought), expressed through phenological escape, post-stress recovery, and other mechanisms enabling growth under water-limited conditions. These traits are actively used in global breeding programs, enhancing the adaptability of common bean across diverse environments and production systems. Expanding knowledge and conservation efforts targeting the genetic diversity of native common bean populations is imperative. Efficient characterization of this diversity is crucial to optimize its use in developing modern varieties, mitigating adverse effects, and improving resilience to global warming. Assessing the magnitude of global warming's impact requires the analysis of historical climate records (1950-2020) and projections for 2021-2100. Consequently, global warming has been categorized into several climate change scenarios based on Shared Socioeconomic Pathways (SSPs), which allow for the evaluation of its effects on native common bean populations under different time frames

(2021-2040, 2041-2060, 2061-2080, and 2081-2100) and greenhouse gas emission levels (2.5, 4.5, 6.0, and 8.5) as adopted by the Intergovernmental Panel on Climate Change (IPCC). The available data can be analyzed using modern computational technologies to optimize the development of predictive models on the adaptability of both native and cultivated common bean in México. Global databases (Fick & Hijmans, 2017) and MaxEnt software enable highly accurate ecological niche suitability modeling for a wide range of organisms. MaxEnt's integration with the R programming environment has enhanced its versatility and expanded its applications (Fan *et al.*, 2022). The implementation of Artificial Intelligence and Machine Learning has further improved analysis capabilities and the generation of predictive models, allowing for precise estimation of current and future adaptability in numerous plant and animal species. These technologies continue to offer extensive opportunities for agricultural and forestry research currently being conducted in México.

MATERIALS AND METHODS

Data used. In 2023, the Global Biodiversity Information Facility (GBIF, 2023a, b) database was consulted to obtain occurrence records for *Phaseolus vulgaris* var. *aborigineus* and *Phaseolus vulgaris* var. *mexicanus* in México. Some occurrence records were excluded by filtering out those with missing passport data and those located within 30 arc-seconds of other occurrences to avoid overrepresentation and redundancy of the studied common bean populations.

Global warming scenarios. Global warming scenarios were established using the EC-Earth3-Veg model (<https://ec-earth.org/ec-earth/ec-earth3/>), which provides detailed estimates of vegetation dynamics, water bodies, and land use, as well as atmospheric variable changes. The Shared Socioeconomic Pathways (SSPs) scenarios 2.5, 4.5, 6.0, and 8.5 were considered across four evaluation periods: 2021-2040 (current), 2041-2060, 2061-2080, and 2081-2100.

Environmental variables. Data for 19 standardized bioclimatic variables (1950-2000), available as climate raster layers in .tiff format (Table 1), were used, along with 12 layers for average monthly maximum temperature (TMAXi), 12 for average monthly minimum temperature (TMINi), and 12 for monthly accumulated precipitation (PRCi). These datasets were sourced from WorldClim version 2.1 (Fick & Hijmans, 2017). In total, 55 bioclimatic variables were used for each study period, with a spatial resolution of 30 arc-seconds (~1 km). A correlation analysis was conducted to reduce multicollinearity, excluding variables with a high correlation coefficient ($|r| \geq 0.7$).

Niche modeling. The Maximum Entropy model (MaxEnt, version 4.3.1k) was employed to estimate the potential habitat suitability of *P. vulgaris* var. *aborigineus* and *P. vulgaris* var. *mexicanus*. Habitat suitability was expressed on a scale from 0 (low suitability) to 1 (maximum suitability). The model underwent a calibration and evaluation process to minimize complexity. Calibration and evaluation were performed using the “ENMeval” package within the R statistical software (version 4.3.1; R-Core-Team, 2015). The relative quality of each calibrated model was assessed using the corrected Akaike Information Criterion (AICc).

Table 1. Bioclimatic variables used in the study of the effects of global warming on the adaptability of two common bean species.

Variable	Description	Variable	Description
BIO1	Annual Mean Temperature	BIO11	Mean Temperature of Coldest Quarter
BIO2	Mean Diurnal Temperature Range	BIO12	Annual Precipitation
BIO3	Isothermality	BIO13	Precipitation of Wettest Month
BIO4	Temperature Seasonality	BIO14	Precipitation of Driest Month
BIO5	Max Temperature of Warmest Month	BIO15	Precipitation Seasonality
BIO6	Min Temperature of Coldest Month	BIO16	Precipitation of Wettest Quarter
BIO7	Annual Temperature Range	BIO17	Precipitation of Driest Quarter
BIO8	Mean Temperature of Wettest Quarter	BIO18	Precipitation of Warmest Quarter
BIO9	Mean Temperature of Driest Quarter	BIO19	Precipitation of Coldest Quarter
BIO10	Mean Temperature of Warmest Quarter		

T°=Temperature; PP=Precipitation.

Outputs from the calibrated models were projected across the entire Mexican territory using MaxEnt, incorporating all previously described environmental variables. One hundred replicates were conducted to generate an ecological niche model, spatially represented as habitat suitability maps under current climate conditions for both *P. vulgaris* varieties. These projections were extended across México using climate scenario layers corresponding to increasing greenhouse gas concentrations (SSPs 2.5, 4.5, 6.0, and 8.5; https://www.worldclim.org/data/cmip6/cmip6_clim30s.html) for the four evaluation periods: 1) 2021-2040 (current), 2) 2041-2060, 3) 2061-2080, and 4) 2081-2100. The analysis was specifically focused on the state of Durango, where endemism has been reported for both *P. vulgaris* var. *aborigineus* and *P. vulgaris* var. *mexicanus*.

The relative importance of each bioclimatic variable influencing the species distribution under study was determined based on its contribution value and the specific effect of permutation. The overall importance of each variable was then calculated by summing its percentage contribution (PC) and permutation importance (PI), and dividing the result by two to obtain the average contribution: $(PC + PI) / 2$ (Anadón *et al.*, 2015).

RESULTS AND DISCUSSION

Principal Component Analysis (PCA). For *P. vulgaris* var. *aborigineus*, Principal Component 1 (PC1) explained 68% of the observed variance, while Principal Component 2 (PC2) accounted for 30% (Table 2). Variables BIO4 (Temperature Seasonality) and rainfall frequency in April (PRC4) showed high importance in PC1 (Figure 1). Other relevant variables included accumulated precipitation in March (PRC3) and September (PRC9). These variables remained significant across the study periods; however, a negative

Table 2. Importance of two Principal Components in explaining the variance derived from the effects of various global warming scenarios on the occurrence points of native common bean populations.

Principal Component	2021-40	2041-60	2061-80	2081-2100	Eigen value	Explained Variance	Cumulative Variance
<i>Phaseolus vulgaris</i> var. <i>aborigineus</i>							
CP 1	0.47	0.54	0.51	0.48	282.4	0.68	0.68
CP 2	0.44	-0.58	0.35	0.59	125.3	0.30	0.98
<i>Phaseolus vulgaris</i> var. <i>mexicanus</i>							
CP 1	0.70	0.54	0.34	0.34	128.7	0.86	0.86
CP 2	0.43	0.21	0.62	0.62	18.3	0.12	0.98

PC=Principal Components 1 and 2.

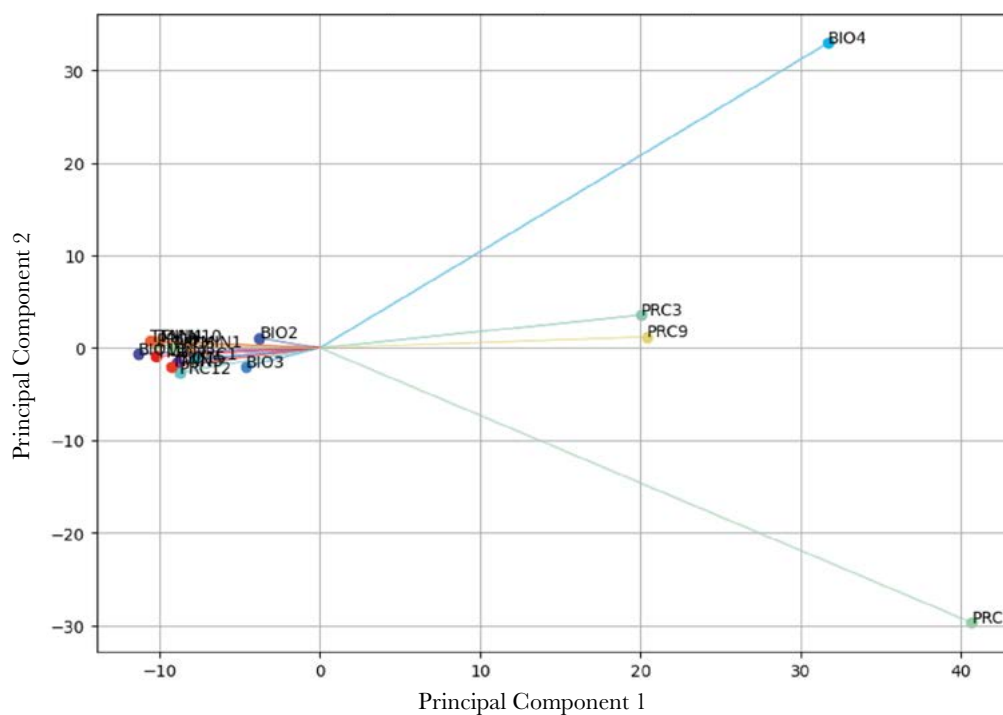


Figure 1. Two-dimensional graph of Principal Components 1 and 2 for bioclimatic variables related to the adaptation of *P. vulgaris* var. *aborigineus* in different global warming scenarios.

effect was observed during the 2041-2060 period for variables grouped within PC2. These results suggest an adaptive response in native populations of *P. vulgaris* var. *aborigineus*, likely triggered by changes in meteorological variables and ecosystem reorganization driven by global warming.

In the case of *P. vulgaris* var. *mexicanus*, PC1 explained 86% of the variance, while PC2 accounted for only 12%. PC1 included BIO3 (Isothermality) and accumulated precipitation in April (PRC3) and September (PRC9). Meanwhile, maximum temperature in April (TMAX4), mean diurnal temperature range (BIO2), and April precipitation (PRC4) were highly influential in PC2 (Figure 2). A similar environmental response pattern was

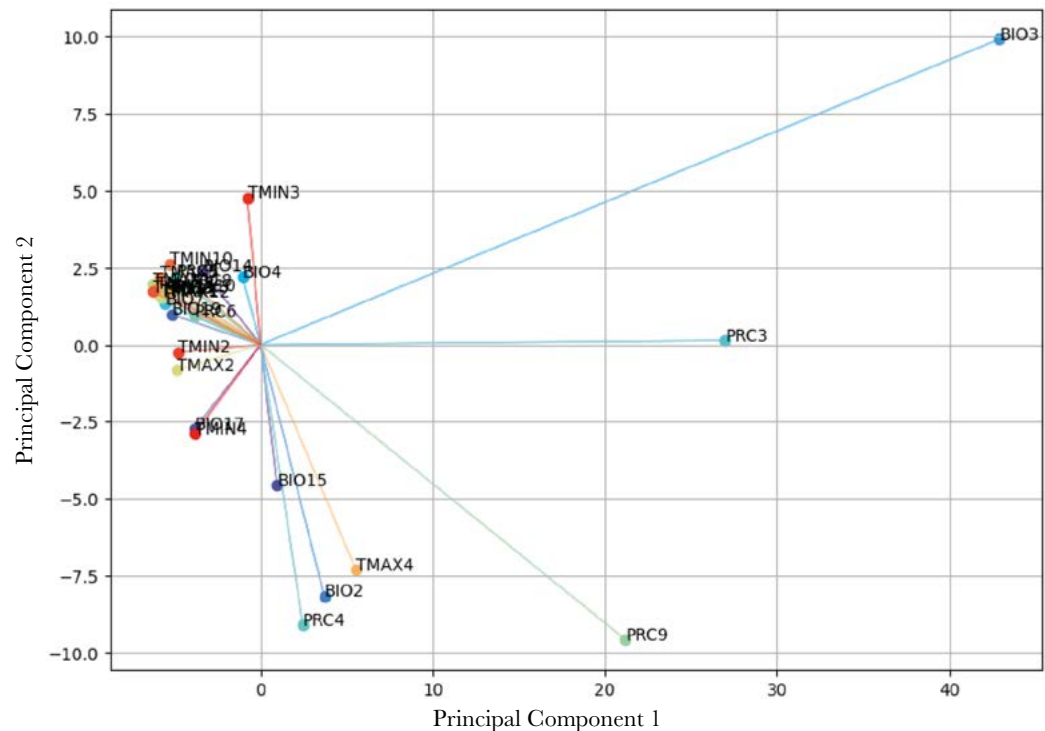


Figure 2. Two-dimensional graph of Principal Components 1 and 2 for bioclimatic variables related to the adaptation of *P. vulgaris* var. *mexicanus* in different global warming scenarios.

observed in both species, with temperature and precipitation being key drivers; however, *P. vulgaris* var. *mexicanus* demonstrated interactions with a broader range of meteorological variables, facilitating its occurrence across wider areas of western, southern, and central highland regions of México.

Model accuracy. High levels of accuracy were observed, based on the area under the curve ($AUC > 0.99$), in the final models obtained for both species across all evaluated scenarios, indicating a high and consistent predictive precision. The variables identified as important by the models differed between plant species and showed variation in their impact across the study periods (Table 3; Table 4). In the current period (2021-2040), *P. vulgaris* var. *aborigineus* was significantly influenced by annual temperature variation (BIO4; Seasonality) and accumulated precipitation in March (PRC3), April (PRC4), and September (PRC9). These variables were particularly relevant, as the onset of rainfall defines the beginning of the growing season, while September precipitation supports pod formation and grain filling. Temperature variation throughout the year determines the frost-free period, and since common bean exhibits thermophilic behavior, its growth depends on rising base temperatures ($>8-10$ °C; Barrios & López, 2009). Favorable temperatures typically begin in April and gradually decline starting in October (Medina *et al.*, 2011), accelerating the maturation process in common bean plants due to the combined effects of photoperiod reduction and water stress, which commonly occur toward the end of the common bean growth cycle.

Table 3. Relative importance of bioclimatic variables affecting the adaptability of two common bean species across different periods and global warming scenarios.

Species	Estimation Period			
	2021-2040	2041-2060	2061-2080	2081-2100
<i>P. vulgaris</i> var. <i>aborigineus</i>	BIO4	PRC4	PRC4	BIO4
	PRC3	PRC3	PRC9	PRC9
	PRC9	PRC9	PRC3	PRC3
	PRC4	BIO3	BIO4	PRC4
<i>P. vulgaris</i> var. <i>mexicanus</i>	BIO3	BIO3	PRC9	PRC9
	PRC3	PRC3	BIO2	PRC3
	PRC9	PRC9	PRC3	BIO3
	TMAX4	BIO4	BIO3	TMAX4

BIO4=Temperature Seasonality, PRC3=Accumulated Rainfall in March, PRC9=Accumulated Rainfall in September, PRC4=Accumulated Rainfall in April, BIO3=Isothermality, TMAX4=Average Maximum Temperature in April, BIO2=Mean Diurnal Temperature Range.

Table 4. Relative importance of bioclimatic variables affecting the adaptability of two common bean species across different periods and global warming scenarios.

Species	Variable	Time Period			
		2021-40	2041-60	2061-80	2081-2100
<i>P. vulgaris</i> var. <i>aborigineus</i>	BIO4	35.2	4.7	9.4	40.8
	PRC3	19.4	15.0	14.0	15.5
	PRC9	13.9	13.6	19.4	17.4
	PRC4	11.8	45.7	36.1	8.1
	BIO3	6.3	7.3	0.1	0.1
	BIO2	0.0	0.0	8.3	7.6
<i>P. vulgaris</i> var. <i>mexicanus</i>	BIO3	19.4	13.5	2.8	5.9
	PRC3	10.8	9.5	5.1	6.2
	PRC9	6.6	7.1	22.0	8.2
	TMAX4	2.6	1.6	0.8	5.0
	TMAX3	2.1	2.5	0.1	0.1
	BIO2	1.0	2.1	7.6	4.8

BIO4=Temperature Seasonality, PRC3=Accumulated Rainfall in March, PRC9=Accumulated Rainfall in September, PRC4=Accumulated Rainfall in April, BIO3=Isothermality, TMAX3=Average Maximum Temperature in March, TMAX4=Average Maximum Temperature in April, BIO2=Mean Diurnal Temperature Range.

Phaseolus vulgaris var. *mexicanus*. A high relative importance of isothermality (BIO3) was observed (Table 3; Table 4), primarily due to this species' tolerance to daily temperature fluctuations and the contrast between these variations and annual average. This trait favored the colonization of extensive areas across México, particularly in the state of Durango. It also increased the species' ability to expand its presence across prediction periods initially colonizing areas with temperature profiles similar to those of its current adaptive ecosystem, and subsequently exploring the potential to extend its presence area

(adaptability) under diverse environmental conditions. In addition, the average maximum temperature recorded in April (TMAX4) and the minimum temperature in March (TMIN3) were significant, as these variables define the onset of spring a critical period for the germination, growth, and development of native common bean plants. These variables also influence the soil drying rate after rainfall in March (PRC3), along with strong diurnal temperature fluctuations (BIO2).

Accumulated rainfall in September (PRC9) also showed a significant influence on the ecosystem's suitability for the adaptation of native common bean populations, especially as temperatures increased between 2061 and 2100 due to global warming. This global phenomenon will increase environmental demands and water requirements in plants, particularly during flowering and grain filling periods, which occur in August and September. The results indicated that global warming will influence the expansion of the ecological niche suitability area in México for the two *P. vulgaris* species studied. However, the impact of this expansion on other plant species must be considered, especially in ecosystems such as pine-oak forests, desert shrublands, grasslands, and other Mexican biomes. The predictive results revealed that the most critical ecological factors were primarily related to water availability at the beginning of the frost-free period, when temperatures become favorable for the growth and development of native common bean populations. Water availability and favorable temperature ranges (13 to 28 °C) determine the timing of germination and seedling emergence, as well as the duration of the reproductive phase, during which common bean is particularly sensitive to water stress in flowering, pod formation, and grain filling stages (Reyes *et al.*, 2014). Additionally, temperature patterns throughout the year, variations among occurrence sites, and diurnal thermal fluctuations significantly influenced the adaptability of native common bean populations in Mexico. The most important variables in the models differed between the plant species. In *P. vulgaris* var. *aborigineus*, annual temperature variation (BIO4; Seasonality) and rainfall frequency in April (PRC4) were the most relevant. These bioclimatic variables were critical in the adaptability models for this species. Other important variables, based on permutation importance, included TMIN1 (Mean Minimum Temperature in January), and rainfall frequency in August (PRC8) and December (PRC12). Minimum temperatures were significant due to the severe effects of frost on common bean seeds and seedlings when temperatures fall below 0 °C in January and early February. Rainfall accumulation in August was linked to the beginning of the reproductive period (flowering phase), affecting pod development and seed production. Rainfall in December can lead to premature germination or seed damage, especially during mild winters with high temperature variability, followed by frost damage in January and February due to low temperatures. Physical dormancy, provided by seed coat thickness, is a key mechanism observed in native common bean populations to prevent off-season germination and protect the embryo from frost damage during winter (Soltani *et al.*, 2021). In *P. vulgaris* var. *mexicanus*, adaptability was associated with multiple bioclimatic variables, most of which had low permutation importance. BIO3 (Isothermality) was highly significant in defining occurrence points, as this species requires favorable and stable temperatures across sites and months of the year. However, values decreased across the study periods. Depending on the prediction period, other important variables included rainfall frequency

in September (PRC9), March (PRC3), and April (PRC4), as well as the average maximum temperature in April (TMAX4). *P. vulgaris* var. *mexicanus* showed broad adaptability potential in México and specifically in the state of Durango, due to its strong interaction with various meteorological variables. Long-term global warming effects favored the expansion of the ecological niche for native common bean populations in México and in Durango, particularly for *P. vulgaris* var. *mexicanus*. Temperature and rainfall records prior to seedling emergence, during the vegetative and reproductive phases, were associated with prolonged periods of biomass accumulation and seed production in native common bean populations belonging to the Durango Race Population Complex. *P. vulgaris* var. *mexicanus* exhibited a strong interaction with temperature and rainfall patterns recorded during the early vegetative months (March-April) and during pod development (September). Therefore, it is expected that its adaptive range will expand in the coming years. The expansion of the ecological niche occupied by native common bean populations especially *P. vulgaris* var. *mexicanus* was associated with a release from interspecific competition, particularly from tree species negatively affected by global warming. Based on the results, it is possible that certain *Phaseolus* species and landraces from northern and western México (Zavala, 2010) were introduced into Durango as part of human migration into areas surrounding the La Ferrería archaeological site. This hypothesis is supported by the reduction in collection sites, most of which are located in the Guadiana Valley region, where historical human migration from Zacatecas and possibly other areas of Jalisco has been documented. Studying the origin of native common bean populations is essential to understand the evolutionary process that led this species to become a widely cultivated crop at local, national, and global levels. Genetic recombination, combined with natural and human-directed selection, along with agricultural practices implemented by local farmers, led to significant morphological changes in plants and seeds of native common bean populations. Temperature patterns during the first quarter of the year define when common bean seeds initiate physiological processes of germination and seedling emergence, also influencing the duration of vegetative and reproductive phases, which typically conclude by the end of September or mid-October. Rainwater availability during March and April also influences the start of the plant growth period, which in turn defines the length of the growing season. Longer growing seasons in native common bean populations increase the likelihood of successfully completing the biological cycle, producing abundant seeds that enhance species survival in subsequent cycles. Conversely, shortened growing seasons reduce the potential to produce sufficient biomass and photoassimilates to support the grain-filling period. Rainfall in September was associated with high seed yield and physiological efficiency, as water availability during pod formation determines the duration of the filling period and the degree of photoassimilate translocation to developing seeds. Between 2041 and 2060, Isothermality (BIO3) gained importance due to rising temperatures, with uniform daily and annual values for this environmental variable across suitable sites. This will favor the multiple presence of native common bean populations (*P. vulgaris* var. *aborigineus*). As an endemic species adapted to restricted areas of the Guadiana Valley in Durango, the uniformity of temperature (daily, annual, and across occurrence points) will enhance its adaptability range during the 2041-2060 period. Relative importance varied across time

periods for temperature records throughout the year (BIO4) and accumulated rainfall in March (PRC3), April (PRC4), and September (PRC9), which remained stable during the 2061-2100 period.

Adaptability and global warming

P. vulgaris var. *aborigineus*. The results indicated that the long-term effects of global warming will favor the expansion of the optimal ecological niche for native common bean populations, with a core distribution in several states within the western region (Bajío) (Jalisco and Michoacán) and central México (State of México and Morelos). The state of Durango appears to represent the northern limit of this cluster, and Oaxaca the southern limit. However, the adaptability of *P. vulgaris* var. *aborigineus* (Figure 3) was lower in comparison to *P. vulgaris* var. *mexicanus* (Figure 4). A lower population level and initial adaptability were observed for *P. vulgaris* var. *aborigineus*, which appears to be restricted to specific areas in Jalisco, Morelos, and the Guadiana Valley in Durango. The reduced number of individuals of *P. vulgaris* var. *aborigineus* was associated with lower genetic diversity and limited capacity to colonize areas with temperature and precipitation patterns different from those in its current adaptation zone.

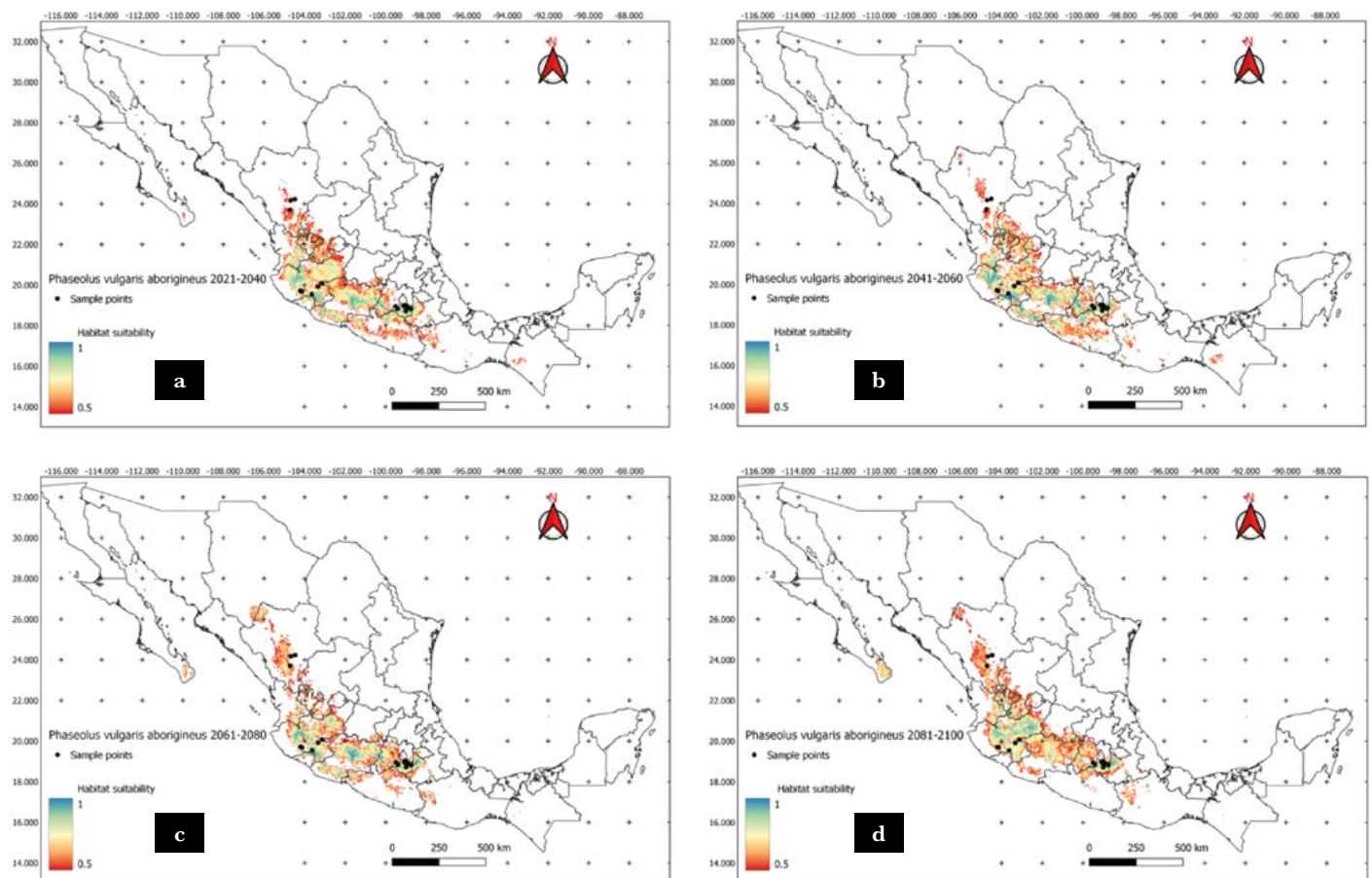


Figure 3. Current and potential distribution of native populations of *P. vulgaris* var. *aborigineus* in México, under different global warming scenarios and time periods. a) 2021-2040, b) 2041-2060, c) 2061-2080 and d) 2081-2100.

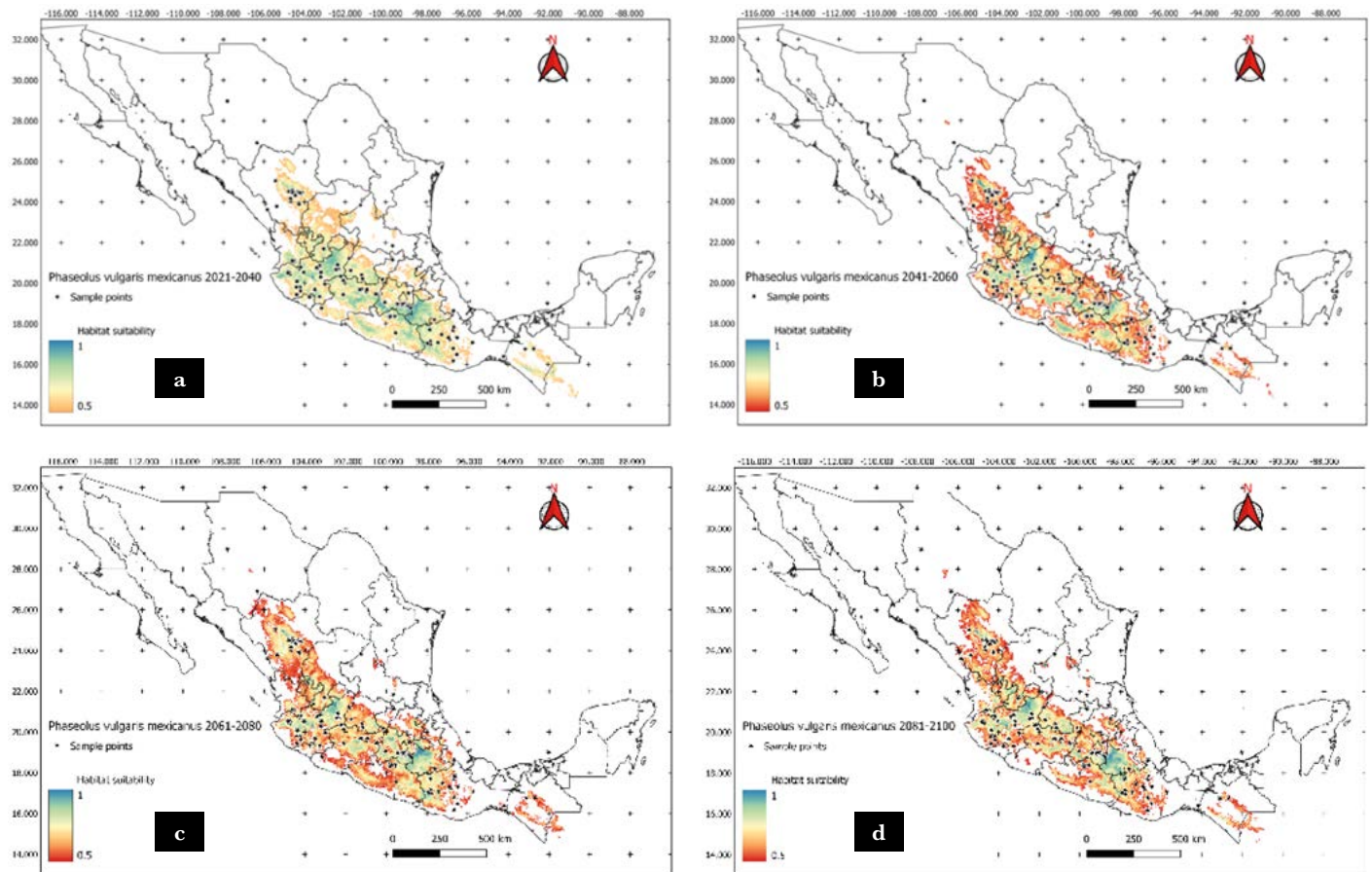


Figure 4. Current and potential distribution of native *P. vulgaris* var. *mexicanus* populations in México under different global warming scenarios and time periods: a) 2021-2040, b) 2041-2060, c) 2061-2080, and d) 2081-2100.

Considering the entire Mexican territory, *P. vulgaris* var. *aborigineus* showed potential to expand its adaptability range due to increased ecosystem suitability along the Trans-Mexican Volcanic Belt. In the state of Durango, potential expansion was observed toward the foothills of the Sierra Madre Occidental, specifically in the municipalities of Pueblo Nuevo and Mezquital to the south of current occurrence points, as well as in Canatlán, Guanaceví, and Tepehuanaes to the north of the Guadiana Valley, Durango (Figure 5).

In México, an increase in ecological niche suitability for native common bean was observed in most of the study periods, as suitability decreased in other ecosystems mainly temperate and pine-oak forests where the climate is expected to become warmer due to global warming effect. In the state of Durango, a gradual increase was observed in the area suitable for the presence of native *Phaseolus vulgaris* var. *mexicanus* populations throughout all evaluated periods. A significant expansion was recorded toward the north, in the municipalities of Canatlán, Nuevo Ideal, Pánuco de Coronado, San Juan del Río, and Indé. Additionally, habitat suitability improved in several municipalities, where certain areas became favorable for native common beans due to the projected rise in temperatures predicted by global warming models.

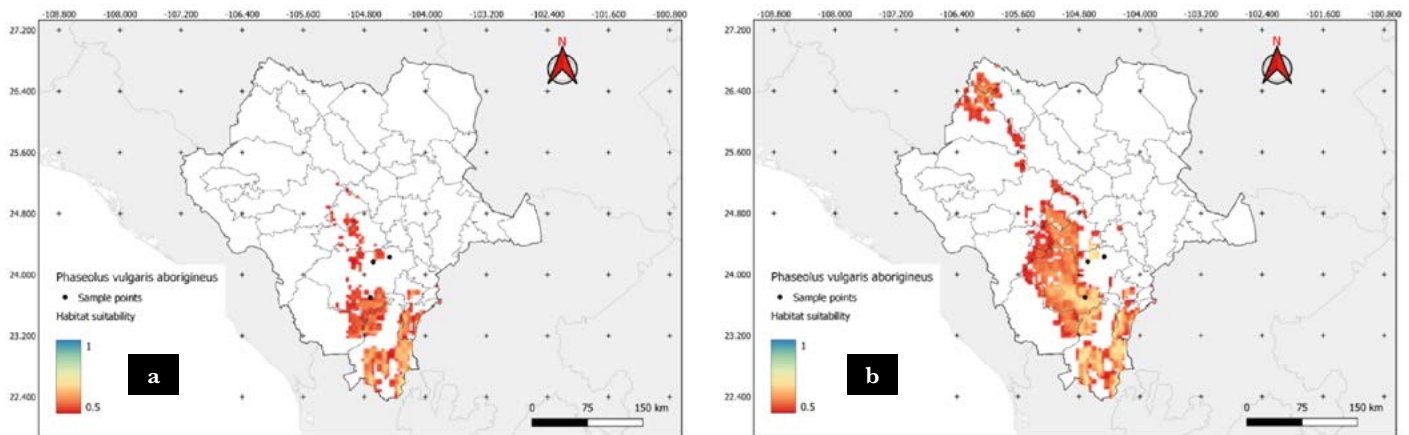


Figure 5. Current and potential distribution of native populations of *P. vulgaris* var. *aborigineus* in the state of Durango, México, under different global warming scenarios and time periods. a) 2021-2040, b) 2081-2100.

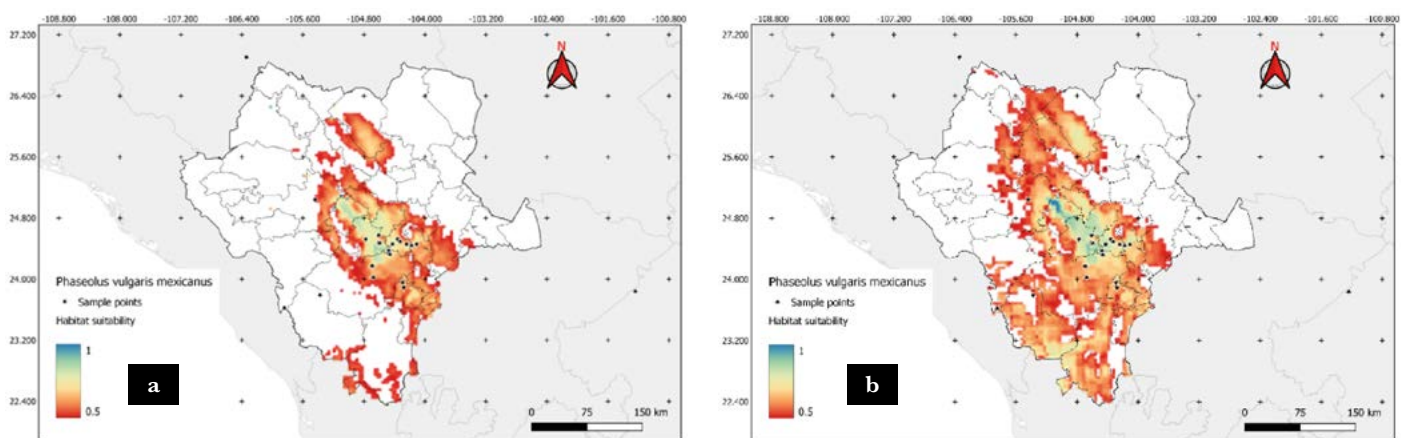


Figure 6. Current and potential distribution of native *P. vulgaris* var. *mexicanus* populations in the state of Durango, México, under different global warming scenarios and time periods: a) 2021-2040, b) 2081-2100.

CONCLUSIONS

High-accuracy models were developed to predict the effects of global warming on the potential expansion of the adaptability area for the two native *P. vulgaris* species analyzed in the study. Temperature and rainfall patterns before and at the beginning of the biological cycle (germination, emergence and vegetative phase), as well as during the reproductive phase, were associated with the persistence of native common beans populations. Under favorable conditions, extended periods for biomass accumulation and high seed production were observed in native common beans belonging to the Durango Race Population Complex.

P. vulgaris var. *mexicanus* exhibited more abundant populations and stronger interaction with environmental factors, particularly with variations in temperature and rainfall patterns during the early vegetative months and pod formation (September). As a result, ecological niche suitability is expected to expand in the coming years. In both *P. vulgaris* var. *aborigineus* and *P. vulgaris* var. *mexicanus*, the expansion of suitable areas

was related to the original population size and the release of common bean populations from interspecific competition, caused by global warming and its potential negative effects on trees, shrubs, and some herbaceous plants. Temperature patterns and rainfall occurrence during specific periods are critical climatic factors for seed viability under field conditions and for the adaptation of native common bean across different regions of México. These factors must be further studied to determine their specific influence on the effects of global warming on the distribution of native common bean populations in northern and western México.

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