



DOI: [10.29298/rmcf.v16i91.1572](https://doi.org/10.29298/rmcf.v16i91.1572)

Research Article

Agroecological characterization of *Agave rhodacantha* Trel. and potential areas for its cultivation in the state of Guerrero

Caracterización agroecológica de *Agave rhodacantha* Trel. y áreas potenciales para su cultivo en Guerrero

Jorge Huerta-Zavala¹, Alicia Sarmiento-Villagrana¹, Héctor Ramón Segura-Pacheco², Elías Hernández-Castro¹, Flaviano Godínez-Jaimes³, Paulino Sánchez-Santillán^{4*}

Fecha de recepción/Reception date: 8 de mayo de 2025.

Fecha de aceptación/Acceptance date: 4 de agosto de 2025.

¹Universidad Autónoma de Guerrero, Doctorado en Sostenibilidad de los Recursos Agropecuarios, Campus Tuxpan. México.

²Universidad Autónoma de Guerrero, Maestría en Ciencias Agropecuarias y Gestión Local, Campus Tuxpan. México.

³Universidad Autónoma de Guerrero, Maestría en Matemáticas Aplicadas. México.

⁴Universidad Autónoma de Guerrero, Maestría en Producción de Bovinos en el Trópico. México.

*Autor para correspondencia; correo-e: ssantillan@uagro.mx

*Corresponding author; e-mail: ssantillan@uagro.mx

Abstract

Agave rhodacantha is a little-known species due to the small size and scattered distribution of its populations. It has recently been identified in the *Norte* Region of the state of *Guerrero*, where it is appreciated for its organoleptic properties and high yields in *mezcal* production. However, its current spread does not adequately consider edaphoclimatic requirements or the impacts associated with the loss of natural vegetation. The objective of this study was to determine the distribution areas and agroecological requirements of *A. rhodacantha* as a first step toward optimizing its cultivation in *Guerrero*, improving production yields, and preventing damage to native vegetation. Thirty-two specimens were analyzed in the field, recording phenotypic, agroclimatic, and agroecological data, supplemented with information from 76 herbarium specimens (MEXU), 63 validated observations from iNaturalist, and semi-structured interviews with local producers. The information was integrated using Geographic Information Systems (GIS), which made it possible to define optimal, suboptimal, and marginal agroecological areas in the state. 397 518.35 ha were defined as optimal, 1 218 307.30 ha as suboptimal, and 66 079.97 ha as marginal. The *Norte*, *La Montaña* and *Centro* regions have the largest optimal areas, where warm subhumid or semi-dry semi-warm climates prevail, with altitudes of 800 to 1 400 m and annual rainfall of 600 to 1 200 mm. The scarcity of cultivated areas and the high organoleptic quality of *mezcal* obtained from *A. rhodacantha* represent an opportunity for its commercialization in differentiated markets with better prices.

Key words: Crimson Spire agave, edaphoclimatic, georeferencing, *mezcal*, productive potential, GIS.

Resumen

Agave rhodacantha es una especie poco conocida debido al tamaño reducido y disperso de sus poblaciones. Recientemente se ha identificado en la Región Norte de Guerrero, donde es valorada por sus propiedades organolépticas y altos rendimientos en la producción de mezcal. Sin embargo, su propagación actual no considera adecuadamente los requerimientos edafoclimáticos ni los impactos asociados a la pérdida de la vegetación natural. El objetivo de este estudio fue determinar las áreas de distribución y los requerimientos agroecológicos de *A. rhodacantha* como primer paso para optimizar su cultivo en Guerrero, mejorar los rendimientos productivos y evitar daños a la vegetación nativa. Se analizaron 32 ejemplares en campo, registrando datos fenotípicos, agroclimáticos y agroecológicos, complementados con información de 76 especímenes del herbario (MEXU), 63 observaciones validadas de iNaturalist y entrevistas semiestructuradas a productores locales. La información fue integrada mediante Sistemas de Información Geográfica (SIG), lo que permitió definir áreas agroecológicas óptimas, subóptimas y marginales en el estado. Se delimitaron 397 518.35 ha como óptimas, 1 218 307.30 ha subóptimas y 66 079.97 ha marginales. Las regiones Norte, Montaña y Centro muestran mayores superficies óptimas, donde prevalecen los climas cálido subhúmedo o semiseco semicálido, altitudes de 800 a 1 400 m y precipitaciones anuales de 600 a 1 200 mm. La escasez de áreas cultivadas y la alta calidad organoléptica del mezcal obtenido de *A. rhodacantha* representan una oportunidad para su comercialización en mercados diferenciados con mejores precios.

Palabras clave: Cien hojas, edafoclimático, georreferenciación, mezcal, potencial productivo, SIG.

Introduction

Agroecological characterization and the identification of potential areas for species of interest or commercial value are essential for optimizing forest resources, protecting species, boosting local economies and adapting to climate change (Espinosa-Álzate & Ríos-Osorio, 2016; Rivas-Meza et al., 2024). These actions not only promote sustainable production but also contribute to the well-being of rural communities and the advancement of scientific knowledge on efficient agricultural practices in the cultivation of agave and other plants (Huerta-Zavala et al., 2019; Rivas-Meza et al., 2024).

In the state of *Guerrero*, agave has significant economic, cultural, and religious importance. It is estimated that there are approximately 16 species of agave, both wild and cultivated, including *Agave rhodacantha* Trel. (Villaseñor, 2016). This species was first collected in 1909, in *Mocorito, Sinaloa*, and was formally described

in 1920 (Standley, 1926). In the 1940s and 1950s, prisoners on *María Madre* Island exploited its long fibers to manufacture rope (Gentry, 1982). In *Guerrero*, it is known locally as Mexican *maguey*, rocky soil *maguey* or Crimson Spire agave. Studies on its geographical distribution are limited due to the small size and scattered nature of its populations. According to the IUCN Red List of Threatened Species (García-Mendoza *et al.*, 2019), these populations are declining.

To date, *A. rhodacantha* has been recorded in the states of *Colima*, *Chihuahua*, *Durango*, *Jalisco*, *Nayarit*, *Oaxaca*, *Puebla*, *Sinaloa*, *Sonora* and *Zacatecas* (Gentry, 1982; González-Elizondo *et al.*, 2009; Rivera-Lugo *et al.*, 2018; Vargas-Ponce *et al.*, 2009; Villaseñor, 2016). According to iNaturalist (2024), its introduction has also been reported in Morocco and India; however, upon validation of the specimens, its presence was only confirmed in one location in Morocco.

Agave rhodacantha has recently been recorded in the *Región Norte* of *Guerrero*, both in the wild and in small plantations (Huerta-Zavala *et al.*, 2025). This species is highly valued for its *mezcal* production due to its organoleptic properties, which include a sweet and smooth profile, balanced alcohol content, and subtle smoky notes. In addition, it stands out for the weight of its stems (*piñas*), which can reach up to 120 kg (Arroyo-Antúnez, 2024).

Due to its productive value, it is mainly propagated by shoots, both in disturbed agricultural areas and in areas of natural vegetation —such as lowland deciduous forests and cedar forests— without considering its specific soil, climate, and agroecological requirements, or the environmental impacts resulting from the loss of vegetation cover (Arroyo-Antúnez, 2024). Given this situation, the objective of the study was to delimit the potential distribution areas of the species in *Guerrero* and evaluate its agroecological needs in order to promote optimal growth, maximize yields, and encourage sustainable practices that contribute to mitigating ecosystem degradation.

Materials and Methods

Study area, fieldwork and herbaria

This research was conducted in the state of *Guerrero*, in Southern Mexico, between the extreme coordinates 16°18' and 18°48' N, and 98°3' and 102°12' W. *Guerrero* has a surface area of 63 564.87 km² (Instituto Nacional de Estadística y Geografía [Inegi], 2022).

For the morphometric and agroecological characterization of *A. rhodacantha*, 13 surveys were conducted in the *Región Norte* of the state between November 2016 and April 2024. Adult specimens were selected from different locations and climatic conditions where this species could be found, with the aim of adequately representing the variability of its natural and cultivated populations. Information on agronomic, edaphoclimatic and agroecological factors was obtained from each specimen and each sampling site (Huerta-Zavala et al., 2019).

In total, 32 specimens were identified, characterized, and georeferenced; of these, 26 were herbarium specimens, which were deposited in the UAGC (*Universidad Autónoma de Guerrero*), MEXU (*Universidad Nacional Autónoma de México*), and ENCB (Instituto Politécnico Nacional) herbaria. Given the scarcity of records of *A. rhodacantha*, information contained in 76 specimens deposited in the MEXU herbarium (Rivera-Lugo et al., 2018) was included, and so were 63 validated observations from the iNaturalist (2024) website for other states of the Mexican Republic. The information was supplemented by seven semi-structured interviews conducted with members of the *Mezcalli del Sur* organization and producers of this species in the state of *Guerrero*.

Distribution and potential areas

The georeferenced information for each specimen (including agronomic, edaphoclimatic, and agroecological factors) was integrated using ArcGIS 10.3.1 Copyright© 1999-2015 (Environmental Systems Research Institute [ESRI], 2015), following the methodology proposed by Huerta-Zavala et al. (2019) and Reynoso-Santos et al. (2016) for determining nighttime temperature. Cartographic data from the *Instituto Nacional de Estadística y Geografía* (National Institute for Statistics and Geography) (Instituto Nacional de Estadística, Geografía e Informática [INEGI], 2001, 2010; Inegi, 2020, 2021a, 2021b, 2022, 2023, 2024), the *Comisión Nacional Forestal* (National Forest Commission) (Conafor, 2013), and the *Comisión Nacional para el Conocimiento y Uso de la Biodiversidad* (National Commission for the Knowledge and Use of Biodiversity) (Conabio, 2016, 2020).

The requirements of *A. rhodacantha* (Table 1) were established through GIS integration of georeferenced data and specialized literature, as proposed by Muñoz-Flores et al. (2018) and Reynoso-Santos et al. (2016). Map algebra in ArcGIS© 10.3.1 (ESRI, 2015) was utilized for the delimitation of the area, reclassifying each variable into optimal, suboptimal, and marginal ranges. Marginal areas were defined using the OR operator (≥ 1 marginal variable); optimal areas, using the AND operator (all variables optimal), and suboptimal areas, as non-marginal areas with ≥ 1 suboptimal variable.

Table 1. Edaphoclimatic and agroecological requirements of *Agave rhodacantha* Trel. in Guerrero.

Variable	Optimal	Suboptimal	Marginal	Source
Altitude (m)	[800, 1 400]	[300, 800) and (1 400, 1 800]	[100, 300) and (1 800, 2 400]	Ige; García-Mendoza et al. (2019); Gentry (1982)
Climate code	Aw ₀ , Aw ₀ (w), Aw ₁ , Aw ₁ (w), Aw ₂ (w), BS ₁ hw(w) and	A(C)w ₀ (w), A(C)w ₁ (w), A(C)w ₂ (w), BS ₁ (h')w and BS ₁ (h')w(w)	(A)C(w ₀), (A)C(w ₀)(w), C(w ₁)(w), C(w ₂)(w)	Ige; Gentry (1982); Vázquez-García et al. (2007)

	BS ₁ hw(x')		and BS ₀ (h')w(w)	
Climate type	Warm subhumid and Semi-dry semi-warm	Semi-warm subhumid and Semi-dry very warm	Very warm dry, and Temperate subhumid	Ige; Gentry (1982); Vázquez-García et al. (2007)
Average temperature (°C)	[20, 26]	[18, 20) and (26, 28]	[16, 18) and (28, 30]	Ige; Gentry (1982); Ruiz-Corral et al. (2002)
Minimal temperature (°C)	[5, 10]	[2, 5)	[-2, 2)	Ige; Gentry (1982); Ruiz-Corral et al. (2002)
Maximal temperature (°C)	[32, 38]	(38, 42]	(42, 44]	Ige; Gentry (1982); Ruiz-Corral et al. (2002)
Nighttime temperature (°C)	[10, 18]	[5, 10) and (18, 28]	[-1, 5) and (28, 34]	Reynoso-Santos et al. (2016); Ruiz-Corral et al. (2002); Tena-Meza et al. (2023)
Evapotranspiration (mm)	[700, 900]	[600, 700) and (900, 1 000]	[400, 600) and (1 000, 1 100]	Ige
Annual rainfall (mm)	[600, 1 200]	[400, 600) and (1 200, 1 500]	[200, 400) and (1 500, 2 000]	Ige; Gentry (1982); Reynoso-Santos et al. (2016)
Days with hail	Without hail	[1, 3]	(3, 5]	Huerta-Zavala et al. (2019, 2024)
Slope of the terrain (%)	[25, 35]	[15, 25) and (35, 40]	[5, 15) and (40, 45]	Huerta-Zavala et al. (2019)
Geological class	Sedimentary and Extrusive igneous	Metamorphic	Intrusive igneous	Huerta-Zavala et al. (2019, 2024)
Geology type	Conglomerate, Sandstone-conglomerate, Limestone, Shale-sandstone, Limestone-shale, Shale, Basic extrusive igneous rock, Acidic extrusive igneous rock and Intermediate extrusive igneous rock	Metasedimentary, Metavolcanic, Cataclasite, Schist and Gneiss	Acidic intrusive igneous rock	Ige; García-Mendoza et al. (2022), Huerta-Zavala et al. (2024)
Soil groups and texture	Regosol (coarse and medium-textured) and Leptosol (fine, coarse and medium-textured)	Phaeozem (fine, coarse, and medium-textured), Luvisol (fine and coarse) and Cambisol (coarse and medium-textured)	Kastanozem (medium-textured), Vertisol (fine) and Andosol (medium-textured)	Ige; Gentry (1982); García-Mendoza et al. (2022); Huerta-Zavala et al. (2024)
Land use and vegetation	Annual rain-fed agriculture, Sv low deciduous forest shrubland and induced grassland	Sv subtropical shrubland	Annual irrigation agriculture, Sv oak forest shrubland, xerophytic mesquite forest, Sv xerophytic mesquite shrubland	Ige; Olvera-Vargas et al. (2022); Huerta-Zavala et al. (2024)

Ige = Georeferenced information on specimens; Sv = Secondary vegetation.

According to Hijmans et al. (2005) and Santillán-Fernández et al. (2025), it is essential to consider as many variables as possible, since minimal variations in the

gradients of one variable can cause significant changes in the gradients of other associated variables. For this reason, no correlation test was performed between the 15 variables in the present study.

As a result, national and state (*Guerrero*) distribution maps were generated, together with maps of the soil, climatic, and agroecological potential classified as optimal, suboptimal, and marginal (Reynoso-Santos *et al.*, 2016), all georeferenced under the GCS WGS 1984 coordinate system (Datum: WGS 1984; units: degrees).

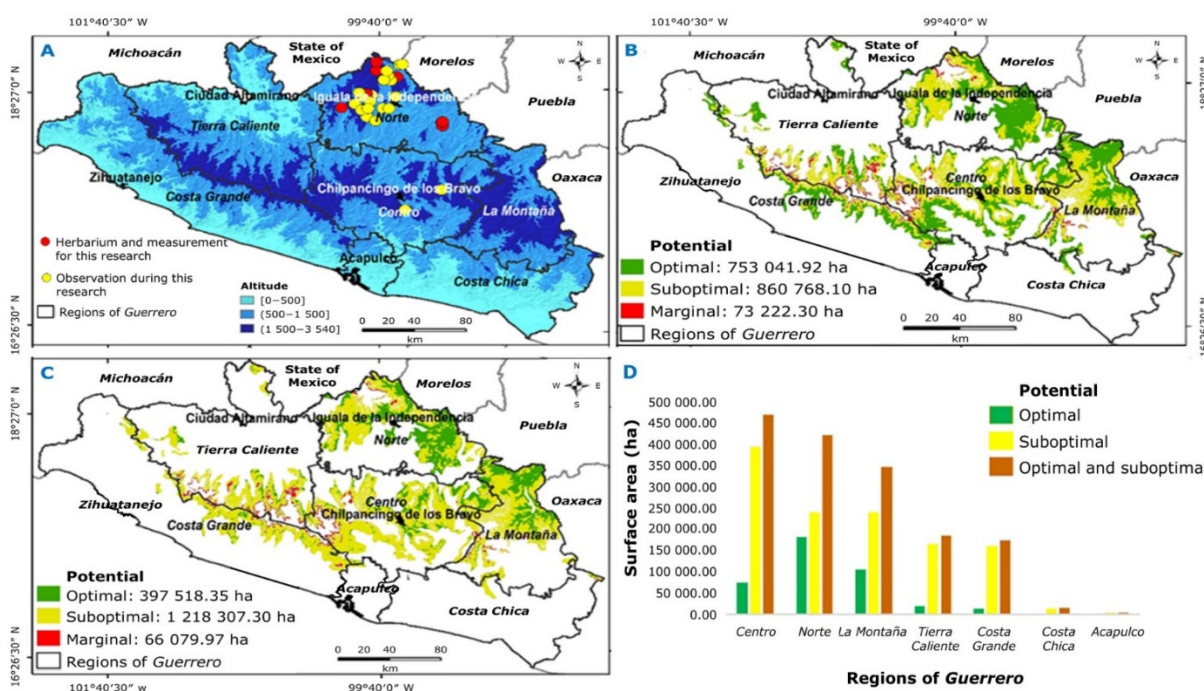
Areas with agroecological potential were determined by excluding areas of native vegetation (low deciduous forest, oak, pine, and cedar forests, and combinations thereof), human settlements, infrastructure, and bodies of water from areas with edaphoclimatic potential. Priority was given to areas already impacted by human activities, such as agricultural, grazing, and eroded areas (Huerta-Zavala *et al.*, 2024).

The model was evaluated through field visits to 18 sites with *A. rhodacantha* plantations located in areas predicted to be optimal and suboptimal. The category assigned by the GIS was compared with the *in situ* assessment based on edaphoclimatic requirements. Accuracy was quantified by: (A) Overall accuracy: proportion of correctly classified site, (B) Sensitivity: proportion of optimal sites in the field correctly identified, (C) Omission error (false negatives): optimal sites in the field classified as suboptimal, and (D) Commission error (false positives): suboptimal sites in the field classified as optimal. The statistical significance was determined using a binomial test ($p < 0.05$) (Fielding & Bell, 1997).

Results

A. rhodacantha is found naturally in the state of *Guerrero* (Figure 1A), with records of both cultivated and wild populations. In the *Atenango del Río* municipality, four

locations were identified with crops and one with a wild population; in *Ixcateopan de Cuauhtémoc*, four locations with crops and one with a wild population; in *Taxco de Alarcón*, six locations with crops; in *Cuetzala del Progreso*, three locations with crops; in *Pilcaya*, two locations with crops and one with a wild population; in *Teloloapan*, three locations with crops; in *Iguala de la Independencia*, two cultivated areas; in *Tetipac*, one wild population and one cultivated area; in *Cocula* and *Chilpancingo de Los Bravo*, one cultivated area, and, finally, in *Chilapa de Álvarez*, one cultivated area.



A = Distribution of *Agave rhodacantha* Trel. in Guerrero; B = Edaphoclimatic potential; C = Agroecological potential; D = Optimal, suboptimal, and total agroecological potential by region in Guerrero. *Ciudad Altamirano* = *Ciudad Altamirano* locality; *Iguala de la Independencia* = *Iguala de la Independencia* municipality; *Chilpancingo de los Bravo* = *Chilpancingo de los Bravo* municipality; *Zihuatanejo* = *Zihuatanejo* locality; *Acapulco* = *Acapulco* Region; *Costa Grande* = *Costa Grande* Region; *Costa Chica* = *Costa Chica*

Region; *Centro* = *Centro* Region; *La Montaña* = *La Montaña* Region; *Tierra Caliente* = *Tierra Caliente* Region; *Norte* = *Norte* Region.

Figure 1. Current distribution and potential areas for the cultivation of *Agave rhodacantha* Trel. in *Guerrero*.

Edaphoclimatic and agroecological areas of *Agave rhodacantha*

In *Guerrero*, 753 041.92 hectares were identified as having optimal edaphoclimatic potential (Table 2, Figure 1B), and 397 518.35 hectares were identified as having optimal agroecological potential (Table 2, Figure 1C). The *Centro*, *Norte*, and *La Montaña* regions stand out for having the largest optimal and suboptimal agroecological areas, positioning themselves as the most suitable areas for the cultivation of *A. rhodacantha* (Figure 1D).

Table 2. Potential edaphoclimatic and agroecological areas of *Agave rhodacantha* Trel. in *Guerrero*.

Region	Optimal (ha)	Suboptimal (ha)	Marginal (ha)
Edaphoclimatic potential			
<i>Norte</i>	230 851.18	197 824.46	5 827.55
<i>Centro</i>	189 098.80	278 573.53	20 585.33
<i>La Montaña</i>	145 839.51	199 228.69	7 106.89
<i>Costa Grande</i>	103 762.39	70 202.95	10 702.37
<i>Tierra Caliente</i>	71 148.10	109 094.26	28 432.28
<i>Costa Chica</i>	9 481.06	5 018.88	540.86
<i>Acapulco</i>	2 860.88	825.33	27.02
State total	753 041.92	860 768.10	73 222.30
Agroecological potential			
<i>Norte</i>	181 601.40	239 469.04	4 312.87

<i>La Montaña</i>	106 463.77	240 277.55	5 431.14
<i>Centro</i>	75 432.22	394 625.63	18 166.53
<i>Tierra Caliente</i>	20 187.70	165 331.39	27 207.78
<i>Costa Grande</i>	13 172.56	161 078.44	10 394.10
<i>Costa Chica</i>	467.57	14 032.26	540.53
<i>Acapulco</i>	193.12	3 493.00	27.02
State total	397 518.35	1 218 307.30	66 079.97

Table 3 shows the ten municipalities in *Guerrero* with the largest optimal and suboptimal agroecological areas for growing *A. rhodacantha*, five of which are located in the *Región Norte*.

Table 3. Municipalities with the largest optimal agroecological area for the cultivation of *Agave rhodacantha* Trel. in *Guerrero*.

Region	Municipality	Optimal (ha)	Suboptimal (ha)	Optimal and suboptimal (ha)
<i>Norte</i>	<i>Huitzuco de los Figueroa</i>	70 680.09	38 604.73	109 284.82
<i>La Montaña</i>	<i>Olinalá</i>	26 839.38	38 892.65	65 732.03
<i>Centro</i>	<i>Ahuacuotzingo</i>	21 841.94	35 823.49	57 665.43
<i>Norte</i>	<i>Taxco de Alarcón</i>	20 937.41	19 674.01	40 611.42
<i>La Montaña</i>	<i>Tlapa de Comonfort</i>	19 804.18	37 012.83	56 817.00
<i>Norte</i>	<i>Atenango del Río</i>	19 771.02	23 644.87	43 415.88
<i>Norte</i>	<i>Teloloapan</i>	16 766.92	52 649.89	69 416.81
<i>La Montaña</i>	<i>Huamuxtitlán</i>	15 944.90	9 055.52	25 000.42
<i>La Montaña</i>	<i>Xochihuehuetlán</i>	13 742.68	11 303.31	25 045.99
<i>Norte</i>	<i>Buнавista de Cuéllar</i>	10 355.83	15 624.94	25 980.77

Table 4 shows the results obtained from the GIS model prediction, as well as the field assessment carried out at 18 sites with *A. rhodacantha* plantations.

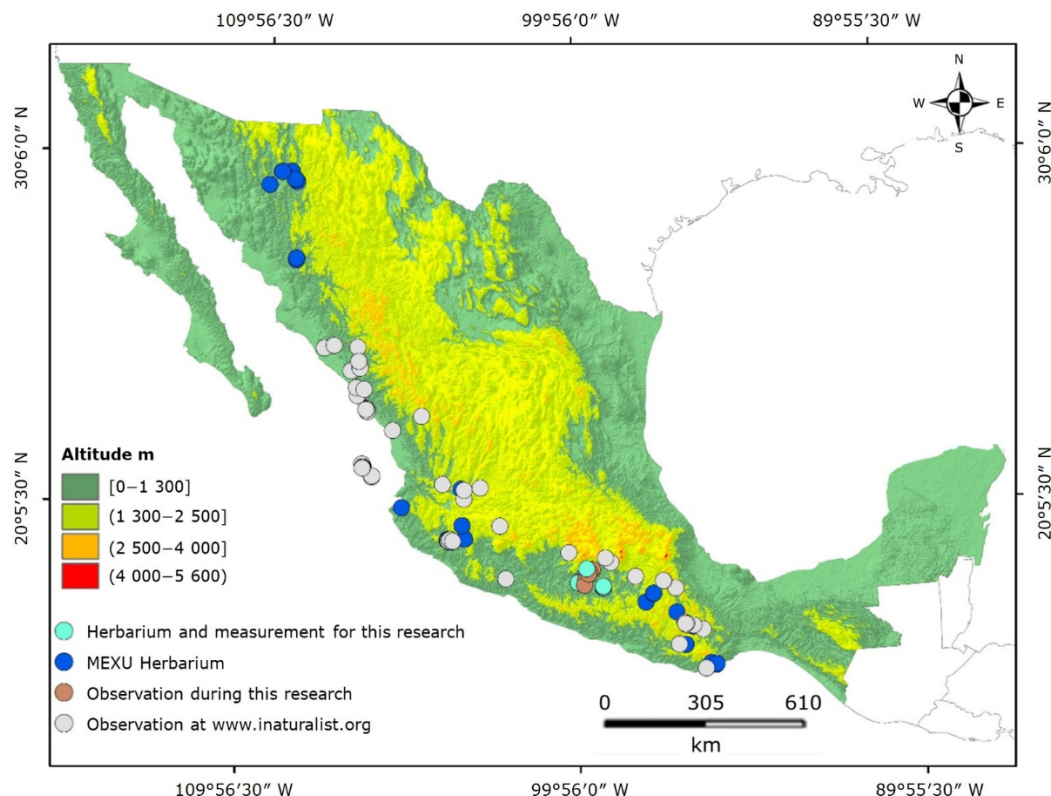
Table 4. Validation of the GIS model for the cultivation of *Agave rhodacantha* Trel. in Guerrero.

Municipality	Locality	Geographic coordinate	GIS model prediction	Field assessment
<i>Teloloapan</i>	<i>Telixtac</i>	18°20'39.06" N 99°50'11.72" W	Suboptimal	Optimal
<i>Teloloapan</i>	<i>Coatepec Costales</i>	18°21'42.20" N 99°43'26.28" W	Optimal	Optimal
<i>Teloloapan</i>	<i>Metztlán</i>	18°18'17.57" N 99°37'39.82" W	Optimal	Optimal
<i>Taxco de Alarcón</i>	<i>El Cedrito</i>	18°32'56.31" N 99°34'00.69" W	Optimal	Suboptimal
<i>Taxco de Alarcón</i>	<i>El Cedrito</i>	18°32'43.22" N 99°34'09.05" W	Optimal	Suboptimal
<i>Taxco de Alarcón</i>	<i>El Sombrero</i>	18°35'11.63" N 99°35'21.37" W	Suboptimal	Suboptimal
<i>Taxco de Alarcón</i>	<i>Landa</i>	18°33'01.97" N 99°37'18.93" W	Suboptimal	Suboptimal
<i>Chilapa de Álvarez</i>	<i>El Arco</i>	17°36'04.77" N 99°11'41.67" W	Optimal	Optimal
<i>Chilpancingo de los Bravo</i>	<i>Mazatlán</i>	17°25'38.56" N 99°27'50.94" W	Optimal	Optimal
<i>Cocula</i>	<i>Atlixac</i>	18°11'46.59" N 99°41'00.14" W	Optimal	Optimal
<i>Ixcateopan de Cuauhtémoc</i>	<i>Pachivia</i>	18°24'19.36" N 99°46'52.73" W	Optimal	Optimal
<i>Ixcateopan de Cuauhtémoc</i>	<i>Tecociapa</i>	18°26'16.57" N 99°48'13.37" W	Optimal	Optimal
<i>Pilcaya</i>	<i>Santa Teresa</i>	18°41'07.32" N 99°29'01.69" W	Optimal	Optimal
<i>Tetipac</i>	<i>San Antonio</i>	18°37'36.53" N 99°35'58.86" W	Suboptimal	Suboptimal
<i>Cuetzala del Progreso</i>	<i>Zihuatel</i>	18°17'23.19" N 99°47'13.91" W	Suboptimal	Suboptimal
<i>Cuetzala del Progreso</i>	<i>El portón</i>	18°18'09.13" N 99°44'16.31" W	Suboptimal	Suboptimal
<i>Iguala de la Independencia</i>	<i>El Naranjo</i>	18°24'20.66" N	Optimal	Optimal

		99°31'53.11" W		
<i>Iguala de la Independencia</i>	<i>La Loma</i>	18°18'09.82" N	Optimal	Optimal
		99°34'59.62" W		
Overall accuracy	83.33 %	Sensitivity (Optimal)		91.67 %
Error of omission	8.33 %	Error of commission		15.38 %
Specificity (Suboptimal)	66.67 %	Accuracy (Optimal)		84.62 %

Discussion

In *Guerrero*, there are few sites where *A. rhodacantha* plantations are found, and even fewer where wild populations exist. This is similar to what has been observed in the rest of the country, as it is present only in 138 locations in Mexico (iNaturalist, 2024; Rivera-Lugo et al., 2018) (Figure 2), including the 32 locations in *Guerrero* analyzed in this study.



Source: Own data, from the MEXU herbarium and the iNaturalist (2024) website.

Figure 2. Distribution of *Agave rhodacantha* Trel. in Mexico.

In regard to the scarcity of *A. rhodacantha* populations, García-Mendoza *et al.* (2019) mentioned that it is necessary to take action to protect the genetic diversity of wild populations before environmental impacts drastically reduce their numbers. These same authors suggest that *A. rhodacantha* is very likely a species complex, which can be inferred from the phenotypic differences in flower, stem, leaf, and spine sizes found in its populations (Huerta-Zavala *et al.*, 2025) (Figure 3A-3E).



A = Flowers from an adult specimen in a plantation, *San Martín Pachivia* locality, *Ixcateopan de Cuauhtémoc*; B = Wild juvenile specimen, *San Martín Pachivia* locality; C = Detail of thorns and bracts, *San Martín Pachivia* locality; D = Adult specimen in plantation ready for harvest, *Tuzantlán* locality, *Atenango del Río*; E = Adult specimen in plantation beginning to form a *quiote*, *Tuzantlán* locality.

Figure 3. Specimens of *Agave rhodacantha* Trel.

Within this context, it is necessary to delve deeper into its taxonomy, as well as into forms of sexual propagation (by seeds), since it was observed during field trips that planting in plantations is almost exclusively by shoots, and that producers do not obtain seedlings from seeds due to their lack of experience and training in these actions (Arroyo-Antúnez, 2024; Huerta-Zavala et al., 2025).

The municipalities with the largest optimal agroecological area for establishing *A. rhodacantha* plantations are: *Huitzuco de los Figueroa*, *Olinalá*, *Ahuacuotzingo*, *Taxco de Alarcón*, *Tlapa de Comonfort*, *Atenango del Río* and *Teloloapan*, are located within the main *mezcal*-producing regions of *Guerrero*, which are the *Norte*, *Centro*, and *La Montaña* regions, as reported by other authors (Barrientos-Rivera et al., 2019; Huerta-Zavala et al., 2025), who mentioned that the *Agave angustifolia* Haw. complex (to which *A. rhodacantha* belongs) is best represented in these *mezcal*-producing regions of the state.

The optimal agroecological area for *A. rhodacantha* in *Guerrero* is determined by the warm subhumid and semi-dry semi-warm climate, as well as by the narrow altitudinal range where this species grows optimally (800-1 400 m) and by an average annual rainfall between 600 and 1 200 mm, covering a small area (397 518.35 ha) compared to that calculated for other species in *Guerrero*, such as *A. angustifolia* (1 020 998.26 ha) (Huerta-Zavala et al., 2019) or *A. cupreata* Trel. & Berger (673 084.16 ha) (Huerta-Zavala et al., 2024). This agrees with the findings of Saldaña-Vázquez et

al. (2022) for this species in the state of *Puebla*, where they reported that *A. angustifolia* and *A. americana* L. have larger potential distribution areas (without specifying surface areas) than *A. rhodacantha*, due to the specific edaphoclimatic requirements of this species.

The prioritization of already impacted areas (agricultural/livestock/degraded) for the cultivation of *A. rhodacantha* (Conafor, 2013; Inegi, 2021b) minimizes deforestation of forests and jungles. Furthermore, the implementation of diversified agroforestry systems, such as those implemented in *Puebla* and *Oaxaca* (Barrera-Cobos et al., 2023; Simonit et al., 2020), improves ecosystem services and producers' income.

Validation of the GIS model at 18 independent sites showed high reliability (overall accuracy: 83.33 %; sensitivity in optimal areas: 91.67 %), with acceptable omission (8.33 %) and commission (15.38 %) errors for ecological models (Fielding & Bell, 1997). Discrepancies (16.7 %) occurred in ecotones with slopes >35 % and geological substrates not mapped in detail, confirming their usefulness for identifying productive areas at the regional scale. Although formal spatial cross-validation was not applied due to the limited sample size, the observed robustness suggests that the model is reliable. However, the following is recommended: (1) On-site verification at distribution edges and suboptimal areas, (2) Increased observations in these areas to improve robustness (Muñoz-Flores et al., 2018), and (3) Implementation, in future studies, of such techniques as spatial k-fold cross-validation to assess spatial autocorrelation (Roberts et al., 2017).

Far from being perceived as a weakness, the limited areas available for the establishment of *A. rhodacantha* should be explored in the search for differentiated markets for this species' *mezcal*, which *mezcal* lovers value highly due to its organoleptic properties. In this regard, Camacho-Vera et al. (2021) mentioned the growing demand by domestic and foreign buyers who are interested in identifying genuine, traditional *mezcal* and who focus their attention on their organoleptic quality, which may prove a profitable commercial strategy for local producers of this species.

Conclusions

The study identified 397 518.35 ha (6.25 % of *Guerrero*) with optimal agroecological potential for *A. rhodacantha*, concentrated in the *Norte*, *La Montaña*, and *Centro* regions of the state under specific conditions: a warm subhumid climate; an altitude of 800-1 400 masl, and 600-1 200 mm rainfall. The evaluation of the GIS model predictions showed high reliability (83.33 % overall accuracy; 91.67 % sensitivity), supporting its use for planning sustainable crops in already degraded areas. The scarcity of existing plantations represents a strategic opportunity for differentiated markets, given the unique organoleptic quality of *mezcal* from the Crimson Spire agave. However, the declining trend in their wild populations requires immediate genetic conservation measures and taxonomic studies to ensure their preservation.

Acknowledgments

The authors are grateful to Rafael Ochoa Miranda, Eng. for his support in designing and validating the GIS, to the producers of *A. rhodacantha* for facilitating the sampling of specimens and plots, and to the management of *Casa León Rojo* for providing the organoleptic description of the *mezcal* from the Crimson Spire agave. The first author acknowledges the scholarship awarded by the *Secretaría de Ciencia, Humanidades, Tecnología e Innovación* (Secretariat of Science, Humanities, Technology and Innovation) for his doctoral studies.

Conflict of interest

The authors declare that they have no conflict of interest in the preparation of this paper.

Contribution by author

Jorge Huerta-Zavala: methodological design, fieldwork, GIS analysis and main authorship; Alicia Sarmiento-Villagrana: methodological validation and co-authorship; Héctor Ramón Segura-Pacheco: writing summaries (abstracts/summaries) and critical reviews; Elías Hernández-Castro: data quality control and editing of the manuscript; Flaviano Godínez-Jaimes: data verification and scientific revision; Paulino Sánchez-Santillán: scientific supervision, initial design and final revision.

References

- Arroyo-Antúnez, V. Y. (2024). *Caracterización de sistemas agroproductivos de agaves mezcaleros en cuatro localidades de la Región Norte de Guerrero* [Tesis de Maestría, Universidad Autónoma de Guerrero]. ResearchGate. https://www.researchgate.net/publication/394576835_CHARACTERIZACION_DE_SISTEMAS_AGROPRODUCTIVOS_DE_AGAVES_MEZCALEROS_EN_CUATRO_LOCALIDADES_DE_LA_REGION_NORTE_DE_GUERRERO
- Barrera-Cobos, S., Maimone-Celorio, M. R., Salomé-Castañeda, E., González-Canchola, A., y Herrera-Pérez, L. (2023). Análisis de la producción de mezcal en San Diego la Mesa Tochimiltzingo, Puebla (reserva Sierra del Tentzo), México. *Agricultura, Sociedad y Desarrollo*, 20(1), 66-91. <https://doi.org/10.22231/asyd.v20i1.1525>
- Barrientos-Rivera, G., Esparza-Ibarra, E. L., Segura-Pacheco, H. R., Talavera-Mendoza, Ó., Sampedro-Rosas, M. L., y Hernández-Castro, E. (2019).

- Caracterización morfológica de *Agave angustifolia* y su conservación en Guerrero, México. *Revista Mexicana de Ciencias Agrícolas*, 10(3), 655-668. <https://doi.org/10.29312/remexca.v10i3.1554>
- Camacho-Vera, J. H., Durán-Ferman, P., y Vargas-Canales, J. M. (2021). Complejidad y trayectoria del sistema productivo mezcal en la sierra sur de Oaxaca, México. *Revista de Ciencias Sociales*, 27(4), 76-92. <https://dialnet.unirioja.es/servlet/articulo?codigo=8229879>
- Comisión Nacional Forestal. (2013). *Inventario Estatal Forestal y de Suelos. Guerrero*. Secretaría de Medio Ambiente y Recursos Naturales. <https://old-snigf.cnf.gob.mx/producto/resultados-del-inventario-estatal-de-guerrero/>
- Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. (2016). *Pendiente, escala 1:4000000* [Carta topográfica]. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. <http://geoportal.conabio.gob.mx/descargas/mapas/imagen/96/pendientegw>
- Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. (2020). *pH 15-30 cm (Predicción), escala 1:4000000*. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. http://geoportal.conabio.gob.mx/descargas/mapas/imagen/96/ph_30cm_pgw
- Environmental Systems Research Institute. (2015). *ArcGIS Desktop: Release 10.3.1* [ArcMap]. Environmental Systems Research Institute. <https://support.esri.com/en-us/products/arcmap>
- Espinosa-Álzate, J. A., y Ríos-Osorio, L. A. (2016). Caracterización de sistemas agroecológicos para el establecimiento de cacao (*Theobroma cacao* L.), en comunidades afrodescendientes del Pacífico Colombiano (Tumaco-Nariño, Colombia). *Acta Agronómica*, 65(3), 211-217. <https://doi.org/10.15446/acag.v65n3.50714>

Fielding, A. H., & Bell, J. F. (1997). A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation*, 24(1), 38-49. <https://doi.org/10.1017/S0376892997000088>

García-Mendoza, A. J., Franco-Martínez, I. S., y Sandoval-Gutiérrez, D. (2022). El complejo taxonómico *Agave angustifolia*: restablecimiento y circunscripción del *Agave pacifica* en Sonora. En M. Esqueda, M. L. Coronado, A. Gutiérrez y M. L. Robert (Eds.), *Ecología y biotecnología aplicadas al manejo sostenible del agave en Sonora* (pp. 15–34). Centro de Investigación en Alimentación y Desarrollo, A. C., Universidad de Sonora, Centro de Investigación Científica de Yucatán, A. C. y Editorial Fontamara, S. A. de C. V. https://www.researchgate.net/publication/368359223_El_complejo_taxonomico_Agave_angustifolia_en_Sonora_2022

García-Mendoza, A. J., Sandoval-Gutiérrez, D., Casas, A., & Torres-García, I. (2019). *Agave rhodacantha* [White paper]. International Union for Conservation of Nature and Natural Resources. https://www.researchgate.net/publication/338883088_Agave_rhodacantha_View_on_wwwiucnredlistorg_THE_IUCN_RED_LIST_OF_THREATENED_SPECIES

Gentry, H. S. (1982). *Agaves of Continental North American*. University of Arizona Press. <https://doi.org/10.2307/j.ctv1t4m2h4>

González-Elizondo, M., Galván-Villanueva, R., López-Enriquez, I. L., Reséndiz-Rojas, L., y González Elizondo, M. S. (2009). *Agaves –magueyes, lechuguillas y noas– del Estado de Durango y sus alrededores*. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad e Instituto Politécnico Nacional. https://www.researchgate.net/profile/M-Socorro-Gonzalez-Elizondo/publication/322243902_Agaves_-magueyes_lechuguillas_y_noas-_del_Estado_de_Durango_y_sus_alrededores/links/5a4dc0290f7e9b8284c4e786/Agaves-magueyes-lechuguillas-y-noas-del-Estado-de-Durango-y-sus-alrededores.pdf

- Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, 25(15), 1965-1978. <https://doi.org/10.1002/joc.1276>
- Huerta-Zavala, J., Espinosa-Rodríguez, M., Sarmiento-Villagrana, A., Ochoa-Miranda, R., Segura-Pacheco, H. R., & Hernández-Castro, E. (2024). Areas with agroecological potential for *Agave cupreata* (Trel. & Berger) plantations in Guerrero, Mexico. *Agroproductividad*, 17(12), 181-187. <https://doi.org/10.32854/agrop.v17i12.2920>
- Huerta-Zavala, J., García-Mendoza, A. J., Hernández-Castro, E., Segura-Pacheco, H. R., Damián-Nava, A., y Godínez-Jaimes, F. (2025). Caracterización morfométrica de poblaciones del complejo *Agave angustifolia* (Asparagaceae: Agavoideae) en la región norte de Guerrero, México. *Polibotánica*, (59), 117-139. <https://doi.org/10.18387/polibotanica.59.7>
- Huerta-Zavala, J., Sabino-Lopez, J. E., Ochoa-Miranda, R., Damián-Nava, A., Segura-Pacheco, H. R., & Hernández Castro, E. (2019). Potential areas for plantations of *Agave angustifolia* Haw in Guerrero, Mexico. *Agroproductividad*, 12(9), 3-9. <https://doi.org/10.32854/agrop.v12i9.1420>
- iNaturalist. (2024, August 16). *Maguey Mexicano (Agave rhodacantha)* [Data set]. iNaturalist. <https://www.inaturalist.org/taxa/281059-Agave-rhodacantha>
- Instituto Nacional de Estadística y Geografía. (2020). *Climas 1902-2011* [Cartas climatológicas]. Instituto Nacional de Estadística y Geografía. <https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=889463769361>
- Instituto Nacional de Estadística y Geografía. (2021a). *Aspectos Geográficos, Guerrero*. Instituto Nacional de Estadística y Geografía. https://www.inegi.org.mx/contenidos/app/areasgeograficas/resumen/resumen_12.pdf
- Instituto Nacional de Estadística y Geografía. (2021b). *Uso del suelo y vegetación, escala 1:250000, serie VII (continuo nacional)* [Carta de uso de suelo y

vegetación]. Instituto Nacional de Estadística y Geografía. <http://geoportal.conabio.gob.mx/descargas/mapas/imagen/96/usv250s7gw>

Instituto Nacional de Estadística y Geografía. (2022). *Marco geoestadístico, diciembre 2022*. Instituto Nacional de Estadística y Geografía. <https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=889463770541>

Instituto Nacional de Estadística y Geografía. (2023). *Conjunto Nacional de Información Topográfica a Escala 1:50 000*. Instituto Nacional de Estadística y Geografía. <https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=794551091975>

Instituto Nacional de Estadística y Geografía. (2024). *Conjunto de datos vectorial edafológico. Escala 1:250 000 Serie II Continuo Nacional* [Cartas Edafológicas]. Instituto Nacional de Estadística y Geografía. <https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=794551131916>

Instituto Nacional de Estadística, Geografía e Informática. (2001). *Conjunto de datos vectoriales Fisiográficos. Continuo Nacional serie I. Provincias fisiográficas* [Conjunto de datos]. Instituto Nacional de Estadística, Geografía e Informática. <https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=702825267575>

Instituto Nacional de Estadística, Geografía e Informática. (2010). *Marco Geoestadístico 2010 versión 4.3 (Censo de Población y Vivienda 2010)* [Marco geoestadístico]. Instituto Nacional de Estadística, Geografía e Informática. <https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=702825296520>

Muñoz-Flores, H. J., Sáenz-Reyes, J. T., Rueda-Sánchez, A., Gómez-Cárdenas, M., Castillo-Quiroz, D., y Castillo-Reyes, F. (2018). Áreas potenciales para plantaciones forestales con *Brosimum alicastrum* Sw., con fines de restauración. *Revista Mexicana de Ciencias Forestales*, 9(45), 7-32. <https://doi.org/10.29298/rmcf.v9i45.133>

Olvera-Vargas, L. A., Pardo-Núñez, J., Aguilar-Rivera, N., y Contreras-Medina, D. I. (2022). Detección de *Agave angustifolia* y *Agave cupreata* con técnicas geomáticas en Guerrero, México. *Ciencia y Tecnología Agropecuaria*, 23(2), Artículo e2241. https://doi.org/10.21930/rcta.vol23_num2_art:2241

- Reynoso-Santos, R., López-Báez, W., López-Luna, A., Ruíz-Corral, J. A., Castro-Mendoza, I., Cadena-Iñiguez, P., Valenzuela-Núñez, L. M., y Camas-Gómez, R. (2016). Áreas potenciales para el cultivo del agave (*Agave americana* L.) en la Meseta Comiteca, Chiapas. *Agroproductividad*, 9(2), 56-61. <https://mail.revista-agroproductividad.org/index.php/agroproductividad/article/view/721>
- Rivas-Meza, N. W., Montalvo-Arquiñigo, N., y Vásquez-Romero, I. R. (2024). Modelación geoespacial para la caracterización agroecología-económica para el desarrollo de los cultivos de agroexportación, unidad hidrográfica Piura, Perú. *Campus*, 29(37), 113-128. <https://doi.org/10.24265/campus.2024.v29n37.06>
- Rivera-Lugo, M., García-Mendoza, A., Simpson, J., Solano, E., & Gil Vega, K. (2018). Taxonomic implications of the morphological and genetic variation of cultivated and domesticated populations of the *Agave angustifolia* complex (Agavoideae, Asparagaceae) in Oaxaca, Mexico. *Plant Systematics and Evolution*, 304, 969-979. <https://doi.org/10.1007/s00606-018-1525-0>
- Roberts, D. R., Bahn, V., Ciuti, S., Boyce, M. S., Elith, J., Guillera-Arroita, G., Hauenstein, S., Lahoz-Monfort, J. J., Schröder, B., Thuiller, W., Warton, D. I., Wintle, B. A., Hartig, F., & Dormann, C. F. (2017). Cross-validation strategies for data with temporal, spatial, hierarchical, or phylogenetic structure. *Ecography*, 40(8), 913-929. <https://doi.org/10.1111/ecog.02881>
- Ruiz-Corral, J. A., Pimienta-Barrios, E., y Zañudo-Hernández, J. (2002). Regiones térmicas óptimas y marginales para el cultivo de *Agave tequilana* en el estado de Jalisco. *Agrociencia*, 36(1), 41-53. <https://www.agrociencia-colpos.org/index.php/agrociencia/article/view/159>
- Saldaña-Vázquez, R. A., Rojas Soto, O. R., Toro Cardona, F. A., Ortega García, S., y Pérez García, T. (2022). *Bases ecológicas para la propagación de agaves mezcaleros en el Estado de Puebla* (Reporte final del proyecto Convenio CONCyTEP 400/2021). Consejo de Ciencia y Tecnología del Estado de Puebla.

https://www.researchgate.net/publication/361017963_Bases_ecologicas_para_la_propagacion_de_agaves_mezcaleros_en_el_Estado_de_Puebla

Santillán-Fernández, A., López-Frías, J. E., Tadeo-Noble, A. E., Barba-Costeño, H., Velasco-Casarez, L., y Vera-López, J. E. (2025). Zonas potenciales de *Brosimum alicastrum* Sw. y su variabilidad ante escenarios de cambio climático. *Revista Mexicana de Ciencias Forestales*, 16(87), 48-71.

<https://doi.org/10.29298/rmcf.v16i87.1507>

Simonit, S., Abardía-Martínez, A., García-Contreras, G., Ríos-Colín, A., Morales-Pacheco, R., Solano-Solano, B., González-Ortiz, M., Martínez-Rodríguez, S., Arcos-Canseco, M., Ramos-García, A., Brena-García, G., Escalona-Luttig, I., García-López, J., López-Soto, F., Beltrán-Casanova, E., Castro-Negrete, J. L., Vallejo-Molina, R., Ramos-Vásquez, M., Nello, T., y Sandi-Sagot, R. (2020). *Oportunidades de restauración funcional del paisaje en el Estado de Oaxaca, México*. Unión Internacional para la Conservación de la Naturaleza y de los Recursos Naturales.

<https://portals.iucn.org/library/efiles/documents/2020-043-Es.pdf>

Standley, P. C. (1926). *Trees and shrubs of Mexico* (Vol. 23). United States National Herbarium. <https://www.biodiversitylibrary.org/page/374942>

Tena-Meza, M. P., Navarro-Cerrillo, R. M., Villavicencio-García, R., y Contreras-Rodríguez, S. H. (2023). Caracterización agroclimática del cultivo de *Agave tequilana* Weber en la barranca del Río Santiago. *Revista Mexicana de Ciencias Agrícolas*, 14(3), 375-387. <https://doi.org/10.29312/remexca.v14i3.3085>

Vargas-Ponce, O., Zizumbo-Villarreal, D., Martínez-Castillo, J., Coello-Coello, J., & Colunga-García-Marín, P. (2009). Diversity and structure of landraces of *Agave* grown for spirits under traditional agriculture: A comparison with wild populations of *A. angustifolia* (Agavaceae) and commercial plantations of *A. tequilana*. *American Journal of Botany*, 96(2), 448-457. <https://doi.org/10.3732/ajb.0800176>

Vázquez-García, J. A., Cházaro B., M. de J., Hernández V., G., Vargas-Rodriguez, Y. L., y Zamora T., M. del P. (2007). Taxonomía del género *Agave* en el occidente de México: una panorámica preliminar. En J. A. Vázquez-García, M. de J. Cházaro B.,

G. Hernández-Vera, E. Flores-Barrios y Y. L. Vargas-Rodríguez (Eds.), *Agaves del Occidente de México* (pp. 38-82). Serie Fronteras de Biodiversidad. Universidad de Guadalajara.

https://www.researchgate.net/profile/Jose-Vazquez-Garcia/publication/256082577_Taxonomia_del_genero_Agave_en_el_occidente_de_Mexico_una_panoramica_preliminar/links/5514d3b20cf260a7cb2d98ed/Taxonomia-del-genero-Agave-en-el-occidente-de-Mexico-una-panoramica-preliminar.pdf

Villaseñor, J. L. (2016). Checklist of the native vascular plants of Mexico. *Revista Mexicana de Biodiversidad*, 87(3), 559-902.
<https://doi.org/10.1016/j.rmb.2016.06.017>



Todos los textos publicados por la **Revista Mexicana de Ciencias Forestales** –sin excepción– se distribuyen amparados bajo la licencia *Creative Commons 4.0 Atribución-No Comercial (CC BY-NC 4.0 Internacional)*, que permite a terceros utilizar lo publicado siempre que mencionen la autoría del trabajo y a la primera publicación en esta revista.