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Fire

effect on the diversity of forest species in a medium superennifolia forest of Mexico

pág. 173

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Contenido

Año 17 • Volumen 17 • Número 1 • enero, 2024

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Resumen y Abstract: Deberá integrarse un resumen en inglés y español (siguiendo ese orden), de máximo 250 palabras, donde se destaque obligatoriamente y en este orden: a) objetivo; b) diseño / metodología / aproximación; c) resultados; d) limitaciones / implicaciones; e) hallazgos/ conclusiones. El resumen no deberá incluir citas, referencias bibliográficas, gráficas ni figuras.
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Conclusiones: Son la generalización de los resultados obtenidos; deben ser puntuales, claras y concisas, y no deben llevar discusión, haciendo hincapié en los aspectos nuevos e importantes de los resultados obtenidos y que establezcan los parámetros finales de lo observado en el estudio.
Agradecimientos: Son opcionales y tendrán un máximo de tres renglones para expresar agradecimientos a personas e instituciones que hayan contribuido a la realización del trabajo.
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> Ogata N. (2003b).

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Wild Edible Mushroom Lore in a Suburban Mestizo Community

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ABSTRACT
Objective: To record the mycological lore related to wild edible mushrooms (WEM) in Santa Ana Jilotzingo, a mestizo rural community greatly influenced by the urban area of Mexico City.
Design/Methodology/Approach: Unstructured and semi-structured interviews were conducted over the course of three years.
Results: Sixty-six WEM species were recorded. Ninety-one traditional names were documented: 65 Spanish names, 3 Nahuatl names, 4 mixed names, and 19 indeterminate names. Local gatherers have a precise knowledge of the biology, ecology, and distribution of the used species; the knowledge preserved by older people is more diverse and accurate. Nowadays, gathering WEM in the rainy season has lost its relevance as an economic activity. However, WEM foraging as a livelihood food supplement remains important for the community.
Study Limitations/Implications: The 2020 pandemic hindered the field work.
Findings/Conclusions: In the study area, relevant mycological lore still survives despite complex adverse conditions, such as acculturation, migration, and deforestation.

Keywords: ethnomycology, macromycetes, nomenclature, urbanization.

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INTRODUCTION

Wild edible mushrooms (WEM) are a non-timber forest resource of great value and relevance worldwide, thanks to their ancestral use as food, medicine, and sacred elements. Mexico has the second largest mycocultural heritage in the world, and its lore and exploitation have been of paramount relevance for the survival of Mesoamerican pre-Hispanic cultures. Nowadays, WEM continue to be an important cultural element for various indigenous and mestizo communities. More than 450 species are consumed in the country, and they are known by over 5,000 traditional names (Pérez-Moreno *et al.*, 2020). The analysis of the fungal-community relation in Mexico has focused mainly on ethnic groups. In contrast, their use in Mestizo populations settled in rural areas strongly influenced by urbanization has received little attention. These conurbation areas

experience several problems, including acculturation, deforestation, changes in land use, and biodiversity loss. These situations have caused strong transformations in the natural environment cosmovision of these populations and, consequently, in the use of their natural resources, including the loss of mycological lore (Ruan-Soto, 2018). Therefore, the objective of this study was to record, describe, and analyze the WEM lore of the inhabitants of Santa Ana Jilotzingo, a Mestizo community from a rural area strongly influenced by the northwestern urban area of Mexico City.

MATERIALS AND METHODS

Study Area

Santa Ana Jilotzingo, municipality of Jilotzingo, State of Mexico (19° 25' 59" and 19° 33' 26" N and 99° 19' 56" and 99° 28' 25" W) (Figure 1) has a predominantly temperate sub-humid climate, with summer rains C(w), according to the modifications made by García (1973) to the classification developed by Köpen. The forest represents most of the territorial extension (67.56%), with an altitude of 2,400 to 3,700 m a.s.l., with 12.48%, 5.53% and 4.41% of the areas dedicated to agriculture, pasture, and urban use, respectively. The municipality has a population of 19,877 inhabitants. The community of Santa Ana Jilotzingo has 998 inhabitants, 509 of which are women and 489 are men (INEGI, 2020).

Ethnomycological Method

The field study was conducted from June to December 2012 and 2014 to 2020. The municipal authorities were contacted to inform them of the purpose of the research and obtain their authorization. Subsequently, local collaborators were selected for the research using the snowball sampling technique (Sandoval, 2002). During the participant observation and ethnomycological surveys, unstructured and semi-structured interviews were conducted. Nine key collaborators and 45 randomly selected persons were interviewed (n=54). The semi-structured interviews were based on a guide of questions that sought to obtain information related to the traditional names, phenology, biology, ecology, mushroom concept, culinary practices, and WEM lore transmission. The transcriptions of the interviews were the basis of the data analysis, and the comparative method was applied.

Species Collection and Identification

Sporomes were collected with preferential sampling based on the knowledge of key collaborators. Routine mycological techniques were used for the fungal taxonomic identification, based on macro- and microscopic characteristics, and using specialized keys. The specimens were taken to the IZTA herbarium of the FES Iztacala, UNAM.

RESULTS AND DISCUSSION

Sixty-six species of edible wild mushrooms were recorded, out of which 59 can be classified as terricolous, 4 as lignicolous, 1 as fungicolous, and 2 as both lignicolous and terricolous (Figure 2). Ninety-one traditional names were documented: 65 Spanish names,

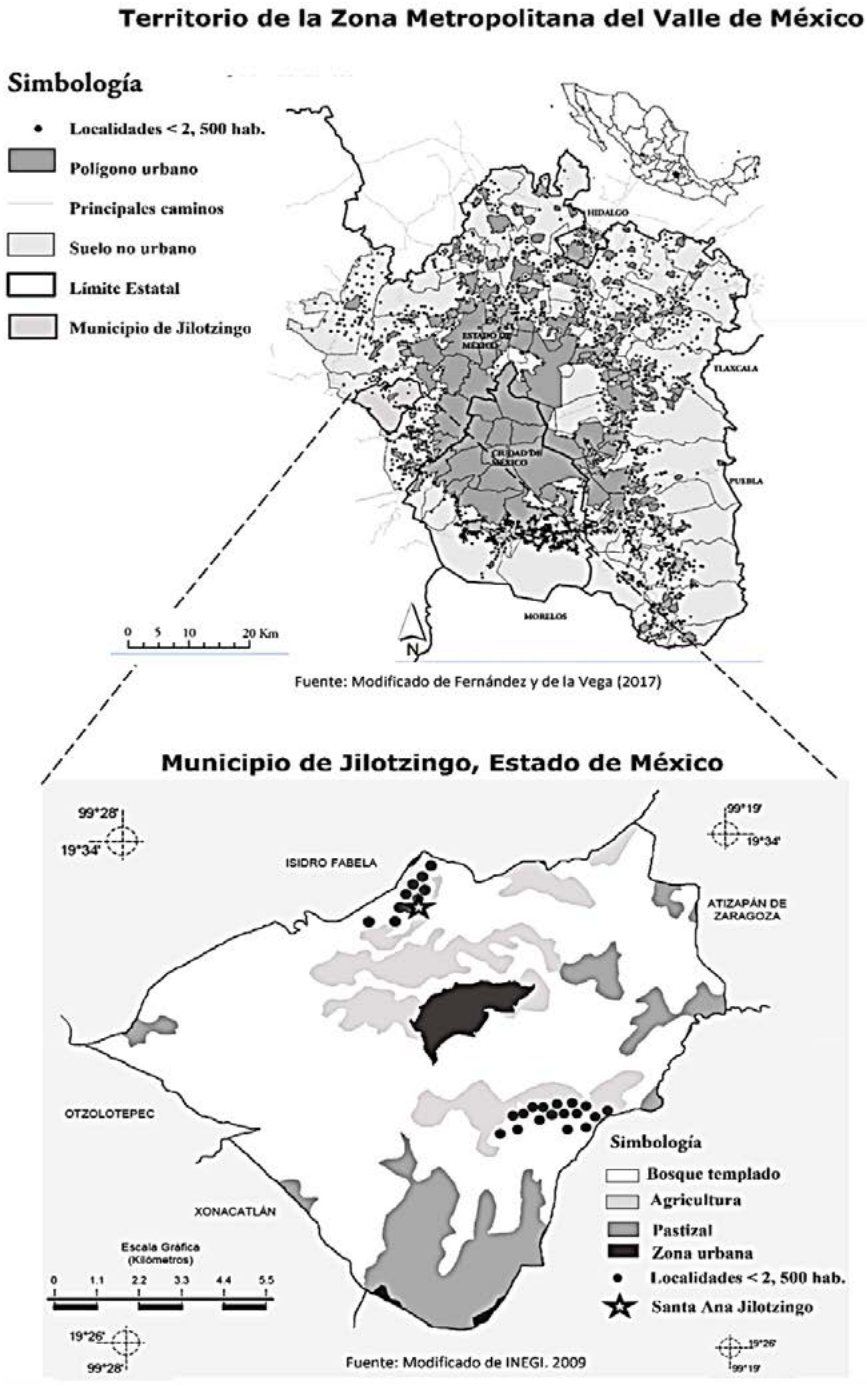

Figure 1. Location of Santa Ana Jilotzingo, Jilotzingo, State of Mexico, modified from the original figure developed by INEGI (2009).

3 Nahuatl names, 4 mixed names (a combination of Nahuatl and Spanish names), and 19 indeterminate names, with unspecified origin (*e.g.*, *chamacuero* or *solis*).

WEM belonged to three trophic groups: 53 ectomycorrhizal, 12 saprophytic, and 1 parasitic (Table 1). The number of species and traditional names reported in this study

Figure 2. Wild edible mushrooms consumed in Santa Ana Jilotzingo: a) *Lactarius deliciosus* (enchilado=seasoned with chili); b) *Ramaria* sp. (patita de pájaro=bird's little leg); c) *Phaeoclavulina* sp. ("ixlitos"); d) *Clavulina cinerea* ("ixlitos"); e) *Amanita vaginata* ("comal"); f) *Hypomyces lactifluorum* (trompa de cochino=pig's trunk); g) *Clavariadelphus truncatus* (chichi de vaca=cow udder); h) *Gyromitra infula* ("chamacuero"); and i) *Amanita* aff. *novinupta* ("solis").

represent a greater biocultural abundance than other areas of central Mexico (Domínguez-Romero *et al.*, 2015; Montoya *et al.*, 2019). Forty-nine percent of the 99 traditional names documented in Santa Ana Jilotzingo belong to simple primary names given by the shape of some object, such as *comales* (griddle), *panalito* (honeycomb), *mazorca* (corncob), or

Table 1. Species of wild edible mushrooms known to the community of Santa Ana Jilotzingo.

Species name	Trophic group	Habitat	Phenology	Associated vegetation	Traditional name	
Agaricus campestris (L.) Fr.	SA	TE	Jun-Jul	Grassland	Hongo de San Juan (ES) Sanjuanero (ES) Sanjuanes (ES)	
Albatrellus ellisii (Berk.) Pouzar	EC	TE	Sep-Oct	BQ	Carda (ES)	
Amanita aff. *novinupta*	EC	TE	Aug-Sep	BA	Mantecoso (ES) Tuetanillo (ES)	
Amanita rubescens Pers.	EC	TE	Aug-Oct	BP-A/BQ	Solis (IN)	
Amanita basii Guzmán & Ram-Guill.	EC	TE	Jul-Sep	BA	Amarillo (ES) Yema – Yemita (ES) Tecomate (NA) Quishimon-Quishimones (IN)	
Boletus smithii Thiers	EC	TE	Aug-Oct	BA	Bonsha (IN) Bonshon (IN) Cema de madroño (ES) Queta de madroño (IN)	Semas o Quetas
Boletus aestivalis Peck.	EC	TE	Aug-Oct	BA-P/BP	Cema blanca (ES) Queta blanca (IN) Cema de oyamel (ES) Queta de oyamel (IN) Cema de ocote (IN) Queta de ocote (IN)	
Retiboletus griseus (Frost) Manfr.	EC	TE	Aug-Nov	BQ	Cema de encino (ES) Queta de encino (IN)	
Leccinellum rugosiceps (Peck)	EC	TE	Sep-Nov	BQ/BQ-P	Cema de escoba (ES) Queta de escoba (IN)	
C. aff. *tabernensis* *Cantharellus* sp.	EC EC	TE TE	Aug-Oct Aug-Oct	BQ BA	Duraznillo (ES) Pericón (ES)	
Clavariadelphus pistillaris L. ex Fr *Clavariadelphus truncatus* Donk	EC EC	TE TE	Aug-Sep Aug-sep	BQ BQ	Chichi de vaca (MI) Lágrimas (ES)	
Clavulina cinerea (Bull.) J. Schröt. *Clavulina cristata* (Holmsk.) J. Schröt. *Phaeoclavulina* sp.	SA SA EC	TE TE/LI TE	Aug-Sep	BA-P BA-P BP	Isles-Islitos (IN) Ixlitos (NA)	
Collybia dryophila (Bull.) P. Kumm.	SA	TE	Jul-Sep	BP	Shorita o Chorita (IN)	
Gyromitra infula (Schaeff.) Quél.	SA	TE/LI	Jul-Sep	BA-P	Chamacuero (IN)	
Helvella crispa (Scop.) Fr.	EC	TE	Jul-Sep	BA	Gachupín (ES)	
Helvella elastica Bull.	EC	TE	Jul-Sep	BA	Comedia (ES)	
Helvella lacunosa Afzel	EC	TE	Aug-Oct	BP/BA	Cabeza negra (ES) Negritos (ES) Señoritas (ES)	
Hygrophoropsis aurantiaca (Wulfen) Maire	SA	LI	Jul-Sep	BA	Falso duraznillo (ES)	
Hygrophorus chrysodon (Batsch)	EC	TE	Jul-Sep	BQ-P	Patriota (ES)	
Hypomyces lactifluorum (Schwein.) Tul. & C. Tul.	PA	FU	Aug-Sep	BA	Orejas rojas (ES) Trompa de cochino (MI)	Orejas
Lactarius aff. *indigo*	EC	TE	Aug-Sep	BQ	Orejas azules (ES) Añil (ES) Azul (ES)	
Russula brevipes Peck	EC	TE	Jul-Sep	BA-P	Orejas blancas (ES) Motico (IN)	

Table 1. Continues...

Species name	Trophic group	Habitat	Phenology	Associated vegetation	Traditional name	
Infundibulicybe gibba (Pers.)	EC	TE	Aug-Oct	BP	Tejamanil de ocote (MI) Tablita de ocote (ES)	Tejamanil o Tablitas
Infundibulicybe squamulose (Pers.)	EC	TE	Aug-Oct	BA-P	Tablita de oyamel (ES) Tejamanil de oyamel (MI)	
Lactarius deliciosus (L.: Fr.) Gray	EC	TE	Jul-Sep	BA-P	Enchilados (ES)	
Bovista fusca Lév. *Lycoperdon perlatum* Pers. *Lycoperdon* sp. 1 *Lycoperdon* sp. 2	SA SA SA SA	TE TE TE TE	Sep-Nov Aug-Sep Aug-Sep Aug-Sep	BA BA/BP BA BA	Pedos de burro (ES) Burundanga (ES)	
Lyophyllum decastes (Fr.) Singer *Lyophyllum* sp.	EC EC	TE TE	Jul-Sep Jul-Sep	BQ BQ/BQ-P	Hongo de Lobo (ES) Clavito (ES) Quinguimu (IN) Quishimones (IN) Amontonado (ES)	
Amanita vaginata (Bull.: Fr.) Vitt. *Melanoleuca grammopodia* (Bull.) Murrill *Melanoleuca* sp.	EC EC EC	TE TE TE	Aug-Sep Sep-Oct Ago-Sep	BA BP/BA-P BQ-P	Comal-Comalito (NA)	Comales
Morchella angusticeps Peck *Morchella esculenta* (L.) Per	EC EC	TE TE	Oct-Dec Oct-Dec	BA BA	Panalito (ES) Mazorca (ES) Pancita (ES)	
Neoboletus sp.	EC	TE	Sep-Oct	BA-P	Galambo (IN)	
Pleurotus sp.	EC	LI	Sep	BQ-P	Seta de madera (ES) Hongo de maguey (ES)	Patitas o pies de pájaro
Ramaria araiospora var. *araiospora* Marr & D.E. Stuntz	EC	TE	Sep	BQ/BQ-P	Pata-Patita de pájaro (ES) Pie de pájaro roja (ES)	
Ramaria cystidiophora Marr & D.E. Stuntz	EC	TE	Aug-Oct	BQ	Pata-Patita de pájaro de anís (ES) Pie de pájaro de anís (ES)	
Ramaria fennica (P. Karst.) Ricken	EC	TE	Aug-Sep	BQ-P	Pata de pájaro morada (ES) Pie de pájaro morada (ES)	
Ramaria flava (Schaeff.) Quél.	EC	TE	Aug-Oct	BQ	Pata-Patita de pájaro amarilla (ES) Pie de pájaro amarilla (ES)	
Ramaria rubiginosa Marr & D.E. Stuntz	EC	TE	Aug-Sep	BA-P		
Ramaria sp. 1	EC	TE	Aug-Sep	BA-P		
Ramaria sp. 2	EC	TE	Aug-Sep	BQ		
Ramaria flavigelatinosa Marr & D.E. Stuntz	EC	TE	Aug-Sep	BQ	Tembloroso (ES)	
Ramaria rasilispora var. *rasilispora* Marr & D.E. Stuntz *Ramaria* sp. 3	EC EC	TE TE	Aug-Oct Aug-Oct	BQ BQ-P	Pata-Patita de pájaro blanca (ES) Pie de pájaro blanca (ES)	
Ramaria rubricarnata var. *rubricarnata* R. *Ramaria* sp. 4 *Ramaria* sp.5	EC EC SA	TE TE LI	Aug-Sep Aug-Sep Aug-Oct	BA BQ BA-P	Pata-Patita de pájaro naranjada (ES) Pie de pájaro naranja (ES)	
Russula violacea *Russula* coff. *fragantissima* *Russula* sp. 1	EC EC EC	TE TE TE	Aug-Oct Aug-Oct Aug-Oct	BA-P BQ-P/BA-P BA	Hongo de madroño (ES)	
Strobilomyces sp.	EC	TE	Aug-Oct	BQ	Carbonera (ES)	

Table 1. Continues...

Species name	Trophic group	Habitat	Phenology	Associated vegetation	Traditional name
Suillus pseudobrevipes A.H. Sm. & Thiers	EC	TE	Aug-Sep	BA-P	Babosos (ES)
Tremella mesenterica Retz.	SA	LI	Aug-Sep	BA	Shoron (IN)
Tricholoma cf. *fulvum* (DC.) Bigeard & H. Guill	EC	TE	Aug-Sep	BA	Hongo de oyamel (ES) Amargos (ES)
Tricholoma aff. *flavovirens*	EC	TE	Aug-Sep	BA	Hongo de venado (ES)
Tricholoma sp.	EC	TE	Aug	BQ-P	Hongo de venado blanco (ES)
Turbinellus floccosus (Schwein.) *Turbinellus kauffmanii* (A.H. Sm.) *Giachini*	EC EC	TE TE	Aug-Sep Sep	BA BA	Cotixe (IN) Corneta-Cornetitas(ES) Trompeta-Trompetita (ES)

Trophic groups: EC: ectomycorrhizal; PA: parasitic; SA: saprotrophic. Habitat: TE: terricolous; LI: lignicolous; and FU: fungicolous. Phenology: Jul: July; Aug: August; Sep: September; Oct: October; Nov: November. Vegetation type: BQ: *Quercus* forest; BP: *Pinus* forest; BQ-P: *Quercus-Pinus* forest; BA: *Abies* forest; and BA-P: *Abies-Pinus* forest. Traditional names: ES: Spanish; NA: Nahuatl; IN: indeterminate; and MI: mixed.

corneta (funnel). Thirty-five percent are secondary names related to various similar species, grouped in ethnotaxa; the first lexeme indicates the group to which it belongs (buns, ears, *tejamanileros*, or *tablitas*) and the second lexeme differentiates the species based on their color or their associated vegetation (white, oyamel, ocote, or oak buns).

The community's gatherers conceive mushrooms as organisms whose characteristics clearly differentiate them from plants and animals. Three main ideas were recorded regarding the origin of mushrooms: a) spontaneous generation; b) propagation from other fungal structures; and c) presence of a seed in the soil. Gatherers believe that the main environmental conditions favorable for the mushrooms' development are humidity, temperature, light, soil, organic matter (leaves, needles, or wood), and associated vegetation. Likewise, mushrooms are divided into two major groups: a) "those above" which grow at higher altitudes in the *Abies religiosa-Pinus* spp. forests; and b) "those below" which grow at lower altitudes in the pine-oak forests (*Pinus* spp. and *Quercus* spp.). Additional areas are recognized in coarse grass and pasture or the plains. Gatherers have a very accurate knowledge of the phenology of the species throughout the year.

WEM are mainly collected to supplement human diet and to generate extra income for the families. According to testimonies, the community still practices recreational, opportunistic, and intensive harvesting, although less frequently than in previous decades. Intensive harvesting is mainly focused on sales and self-consumption and is mostly in charge of *hongueras* and *hongueros* (mushroom gatherers) who, alone or with their families, travel long distances and spend several hours seeking edible mushrooms to ensure that the greatest number of species are collected. Sales in the area are limited to a small number of people, who do not consider themselves as mushroom gatherers; these sales are made on demand or by offering any available mushrooms to their acquaintances. People from Santa Ana Jilotzingo who provide tourist services on Saturdays and Sundays at the Capoxi dam also sell WEM and offer fresh and stewed mushrooms.

The following nine common ways of cooking WEM were recorded:

1. Roasted with salt on a griddle or on a grill.
2. As ingredients in broths or soups, seasoned with *epazote*.
3. Fried with *epazote*, onion, and garlic.
4. As ingredients in *quesadillas*.
5. Served with *mole*.
6. Cooked with eggs.
7. Battered and fried.
8. In pies.
9. Cooked in green sauce (with or without meat).

The lore transmission in the community under study occurs in several directions: vertically (from parents to children), horizontally (between individuals of the same generation, such as siblings, cousins or couples), and obliquely (from one generation to another, without the need for a consanguineous relationship, *e.g.*, from parents-in-law, neighbors, friends or acquaintances). Lore is exchanged in the field, during the commercialization process, and in food preparation. In general, elders can identify a greater number of WEM, know their traditional names, and have more accurate information than younger people. This phenomenon has been documented in Santa Ana Jilotzingo as well as in other areas of the State of Mexico, where a decline in mycological lore has been recorded among the new generations, as a consequence of urbanization (Lara-Vázquez *et al.*, 2013).

CONCLUSIONS

Ethnomycological lore survives in the suburban mestizo community, mostly concentrated among the elders, despite the deep environmental and sociocultural changes that have taken place, including acculturation, deforestation, and changes in land use.

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Analysis of backyard agriculture and livestock production activities in the South Huasteca Region in San Luis Potosí, Mexico

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ABSTRACT

Objective: To carry out a diagnosis and assess the importance of backyard agriculture and livestock production in rural communities of the XV District in the South Huasteca Region of the State of San Luis Potosí, Mexico, on the social, economic and nutritional context of the population.

Design/Methodology/Approach: The study was carried out with two blocks of surveys, the first with the local government and the second with peasants, evaluating the socioeconomic status, importance of livestock and agriculture, nutritional status and culture. The method was deductive and descriptive; the information was with multivariate analysis of principal components.

Results: Government support does not reduce poverty. Families feel secure with their material goods. The nutritional status of the population is lacking. Raising chickens, turkeys and Creole pigs prioritizes livestock activity. Self-consumption and the commercialization of plant species is a traditional activity. There is a culinary culture.

Limitations on study/Implications: The restriction of information by the municipal government; the pandemic problems to generate more information from the surveys.

Conclusions: It is necessary to create efficient programs that improve agricultural and livestock production in the region, with the purpose of improving the nutritional status of the population and generating economic resources to reduce poverty.

Keywords: Agricultural, livestock and backyard farming.

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INTRODUCTION

Globally, livestock production and agriculture are part of the first link of the productive chain, and throughout history these two sectors have subsisted and contributed foods to the population. Recently, 170 countries which belong to the United Nations have become committed with the Agenda 2030 to promote sustainable development, establishing the priority of ending poverty and fulfilling the objectives of zero hunger, as well as strengthening the subject of food security. The different goals have given rise to organizations that are interested in humanity's nourishment, generating the opportunity for the demand of foods of animal origin (SIAP, 2020).

In Mexico, the situation of poverty in the country ranges from 43.9% of the population to 8.5% in extreme poverty, 23.7% vulnerable to social deprivation, 8.9% vulnerable from income, and only 23.5% of the population are not poor and vulnerable (CONEVAL, 2021b).

In particular, agriculture and livestock production known as small-scale, backyard or social predominates in the rural sector, and they are associated to the lifestyle of peasants or small-scale farmers, with a subsistence system where they continue to preserve the vicious cycle of poverty among their descendants. However, it has been shown that backyard agriculture and livestock production are associated and participate ambiguously in maintaining food security of rural families, generating some foods and a participation of 9.3% of the family economic income (Jaramillo-Villanueva *et al.*, 2017). In the agricultural sphere, the SADR (2015) has established backyard agriculture as a priority means to strengthen food security and to foster the sustainable development of rural regions.

In the livestock production scope, FAO (2012) also mentions that domestic animal breeding is part of family strategies, since it functions as a social and economic cushion that participates in the program for food security. In particular, for families on the poverty threshold, backyard livestock production is an opportunity for survival. As has already been mentioned, backyard farming generates very few resources, and its main activity is to promote auto-consumption; it uses family labor without a compensation plan, the production is low, and there are no national programs that guarantee fostering productivity. Regional and seasonal crops predominate in backyard agriculture in rural zones; corn is the predominant grass and it is associated to the dietary habits of the population. Meanwhile, backyard livestock production is characterized by having native or Creole animals of several domestic species. In both, there are no efficient production programs and they are primarily efficient sources for auto-consumption and intermittent income when there are economic needs.

The characterization of backyard systems depends on the region, and several social and cultural aspects; therefore, the objective of this study was to conduct a diagnosis of backyard agriculture and livestock production in the rural communities of the South Huasteca Region in the state of San Luis Potosí, Mexico, taking into consideration the analysis of social, economic and nutritional variables of the rural population under poverty conditions.

MATERIALS AND METHODS

The study was conducted in the ejido of Chapulhuacanito (Colonia, Limajtitla, Taxicho, Laurel, Maguey, Chichictla, Ahuehuet, Ahuimol) of the municipality of Tamazunchale, which belongs to District XV in the South Huasteca Region of the state of San Luis Potosí, Mexico (CEEPAC, 2018), located in the municipality of Tamazunchale (98° 56' 33.00" W to 98° 37' 16.32" W, Latitude 21° 09' 36.72" N to 21° 19' 37.92" N), with an altitude of 140 meters above sea level. The mean annual temperature is 25.5 °C, with an absolute maximum of 44 °C and an absolute minimum of 11 °C. The annual rainfall is 2,168.3 mm. Figure 1 (INEGI, 2020).

Figure 1. Location of the study, municipality of Tamazunchale, District XV in San Luis Potosí.
Source: Prepared by the authors with data from INE (2007).

The place has 95,037 inhabitants, 78.2% of the population is in situation of poverty, while 25.9% has deprivation from lack of access to food (CONEVAL, 2021a). Historically, the families in this municipality have been devoted to backyard animal breeding and to sowing agricultural products in a traditional way for auto-consumption; there are not enough data currently to allow characterizing the backyard productive sector of the population. Two blocks of surveys were carried out in the study: the first block of surveys was applied directly with the secretary of the municipal government and the members of the departments of Economic Development, Rural Development, and Indigenous Affairs. The questions made were focused on the backing granted at the municipal level to the population. Likewise, the directives gave a certificate of authorization for the application of the second block of surveys to the population. In the second block, 100 surveys were applied in the ejido containing a series of questions (Table 1, Q1 to Q19), whose questionnaire attempted to identify the importance of livestock production and agriculture on the following groups, classified as: A) socioeconomic status of the family; B) importance of livestock production and agriculture on the dietary and nutritional status of the family; C) cultural and traditional status of livestock production and agriculture in the family; D) importance of livestock production and agriculture on auto-consumption and the possibility for an agribusiness. All the surveys were carried out in person, visiting the authorities and each of the homes of the population to be surveyed, and these surveys were applied in a maximum time of 15 minutes. The research method was deductive and descriptive. The size of the sample complied with the reliability requirements of 95%. The people interviewed showed willingness to be part of the sample, and sampling was done with the snowball process, corroborating that the sample fulfilled similar characteristics of the backyard agriculture and livestock production sector.

Table 1. Variables (P1…P19) of the second block of surveys carried on groups of families with agricultural purposes.

SOCIAL MEDIA	Nutritional status of the population	Agricultural and livestock sector	LIVESTOCK: Species, management, consumption			AGRICULTURAL: Species, management, consumption			
			Birds		Pig	Citrus	Corn	Beans and lentils	Pumpkin
			Management	Consumption	Management and consumption				
What is your gender?	How many people live in your home?	What is your agricultural and livestock activity?	What type of animal species do you have?	Do you market or consume your product?	What purpose does animal husbandry have?	What citrus species do you have?	What system do you use for your corn cultivation?	What kind of bean do you have?	What is the purpose of growing pumpkin?
What is your age range?	Is the water you consume drinkable or from a well?	How many animal species does it have?	What is its zootechnical purpose?	Do you sell chicken meat and eggs?	Do you have specialized breeds, Creole or both?	What system do you use for your crops?	What is the area used for growing corn?	What system do you use for growing beans?	What system do you use when growing pumpkin?
What is your educational level?	What type of meat do you consume most in your family?	Do you receive advice for your livestock?	What production system do you use?	How do you consume chicken meat?	How do you raise animals?	What is the area for your type of crop?	What is the situation of the land for growing corn, own, borrowed or rented?	What is the area for growing beans?	What is the area for pumpkin cultivation?
The source of economic income	How often do you eat that type of meat?	Do you receive government support?	What is the condition of the animals like?	What percentage of meat and eggs do you consume?	How much space does the corral have?	Do you use fertilizer for your crop?	Do you use herbicides for corn cultivation?	Do you use herbicides for your crop?	Do you use herbicide for your pumpkin crop?
Relatives who migrated abroad and send support	How many kilos of meat does the family consume per week?	What type of support do you receive?	How much space do you have for your pen?	Do you sell the turkeys or consume them?	How is the floor?	Do you use organic fertilizer for your crops?	Do you use organic fertilizer for growing corn?	Do you use organic fertilizer for growing beans?	Do you use organic fertilizer on pumpkin?
Whose house is inhabited?	What food does the family consume the most?	Is the material received for corrals?	What type of material does the floor have?	Where do you sell turkey meat and eggs?	Do you have feeders?	Do you produce or buy organic fertilizer?	Do you produce or buy organic fertilizer?	Does bean production sell or consume it?	Do you sell pumpkin production or do you consume it yourself?
Identify if the inhabitants have electricity service.	How often do you consume that species?	What animal species have you received?	Do you have feeders?	How do you consume turkey meat or eggs?	How do you feed your animals?	Do you sell citrus production or is it for self-consumption?	Is the production for sale or self-consumption?	Where do you market the beans?	Where do you market pumpkin?
How many lights are there in the house?	Has the Health Center detected any adult with malnutrition?	How many crops do you have?	What food do you give your animals?	What percentage does turkey meat occupy in your diet?	How many times a day do you give them corn?	Where do you sell your citrus?	Where do you market your corn?	How do you consume the Castelan bean?	How do you consume pumpkin?
Does it have a drainage service?	Are there children in the family?	Do you receive advice for your cultivation?	How many times a day do you give them corn?		How many times a day do you feed commercial food?	What is the commercial presentation of the orange?	In what presentations do you consume corn?	How do you consume lentils?	What percentage of pumpkin is for self-consumption?
Do you have contracted internet service?	If the answer is A. How many children are there in the family?	Have you received fertilizer support?	How many times a day do you feed commercial food?		How many times a day do you take them to eat in the mountains?	What is the commercial presentation of the mandarin?	What percentage of corn is for self-consumption?	What percentage of beans and lentils is for self-consumption?	

Table 1. Continues...

SOCIAL MEDIA	Nutritional status of the population	Agricultural and livestock sector	LIVESTOCK: Species, management, consumption			AGRICULTURAL: Species, management, consumption			
			Birds		Pig	Citrus	Corn	Beans and lentils	Pumpkin
			Management	Consumption	Management and consumption				
	How often do children consume milk?		How many times a day do you graze them?		What type of water do you give your animals?	What is the commercial presentation of lemon?			
	How often do children consume Creole eggs?		What type of water do you give your animals?		Who cares for animal diseases?	What percentage of citrus fruits is for self-consumption?			
	How often do children eat vegetables?		Who or how cares for animal diseases?		Do you sell or consume the animals?				
	How often do children eat junk food?				Where do you sell your animal products?				
	Has the Health Center detected any children with anemia?				How do you consume animals?				
	Has the Health Center detected any children with obesity?								
	Has the Health Center detected any children with malnutrition?								
	Does the Health Center give nutritional nutrition talks?								
	What diseases do children currently have?								
What is your gender?	How many people live in your home?	What is your agricultural and livestock activity?	What type of animal species do you have?	Do you market or consume your product?	What purpose does animal husbandry have?	What citrus species do you have?	What system do you use for your corn cultivation?	What kind of bean do you have?	What is the purpose of growing pumpkin?
What is your age range?	Is the water you consume drinkable or from a well?	How many animal species does it have?	What is its zootechnical purpose?	Do you sell chicken meat and eggs?	Do you have specialized breeds, Creole or both?	What system do you use for your crops?	What is the area used for growing corn?	What system do you use for growing beans?	What system do you use when growing pumpkin?

Table 1. Continues...

SOCIAL MEDIA	Nutritional status of the population	Agricultural and livestock sector	LIVESTOCK: Species, management, consumption			AGRICULTURAL: Species, management, consumption			
			Birds		Pig	Citrus	Corn	Beans and lentils	Pumpkin
			Management	Consumption	Management and consumption				
What is your educational level?	What type of meat do you consume most in your family?	Do you receive advice for your livestock?	What production system do you use?	How do you consume chicken meat?	How do you raise animals?	What is the area for your type of crop?	What is the situation of the land for growing corn, own, borrowed or rented?	What is the area for growing beans?	What is the area for pumpkin cultivation?
The source of economic income	How often do you eat that type of meat?	Do you receive government support?	What is the condition of the animals like?	What percentage of meat and eggs do you consume?	How much space does the corral have?	Do you use fertilizer for your crop?	Do you use herbicides for corn cultivation?	Do you use herbicides for your crop?	Do you use herbicide for your pumpkin crop?
Relatives who migrated abroad and send support	How many kilos of meat does the family consume per week?	What type of support do you receive?	How much space do you have for your pen?	Do you sell the turkeys or consume them?	How is the floor?	Do you use organic fertilizer for your crops?	Do you use organic fertilizer for growing corn?	Do you use organic fertilizer for growing beans?	Do you use organic fertilizer on pumpkin?
Whose house is inhabited?	What food does the family consume the most?	Is the material received for corrals?	What type of material does the floor have?	Where do you sell turkey meat and eggs?	Do you have feeders?	Do you produce or buy organic fertilizer?	Do you produce or buy organic fertilizer?	Does bean production sell or consume it?	Do you sell pumpkin production or do you consume it yourself?
Identify if the inhabitants have electricity service.	How often do you consume that species?	What animal species have you received?	Do you have feeders?	How do you consume turkey meat or eggs?	How do you feed your animals?	Do you sell citrus production or is it for self-consumption?	Is the production for sale or self-consumption?	Where do you market the beans?	Where do you market pumpkin?
How many lights are there in the house?	Has the Health Center detected any adult with malnutrition?	How many crops do you have?	What food do you give your animals?	What percentage does turkey meat occupy in your diet?	How many times a day do you give them corn?	Where do you sell your citrus?	Where do you market your corn?	How do you consume the Castelan bean?	How do you consume pumpkin?
Does it have a drainage service?	Are there children in the family?	Do you receive advice for your cultivation?	How many times a day do you give them corn?		How many times a day do you feed commercial food?	What is the commercial presentation of the orange?	In what presentations do you consume corn?	How do you consume lentils?	What percentage of pumpkin is for self-consumption?
Do you have contracted internet service?	If the answer is A. How many children are there in the family?	Have you received fertilizer support?	How many times a day do you feed commercial food?		How many times a day do you take them to eat in the mountains?	What is the commercial presentation of the mandarin?	What percentage of corn is for self-consumption?	What percentage of beans and lentils is for self-consumption?	
	How often do children consume milk?		How many times a day do you graze them?		What type of water do you give your animals?	What is the commercial presentation of lemon?			

Table 1. Continues...

SOCIAL MEDIA	Nutritional status of the population	Agricultural and livestock sector	LIVESTOCK: Species, management, consumption			AGRICULTURAL: Species, management, consumption			
			Birds		Pig	Citrus	Corn	Beans and lentils	Pumpkin
			Management	Consumption	Management and consumption				
	How often do children consume Creole eggs?		What type of water do you give your animals?		Who cares for animal diseases?	What percentage of citrus fruits is for self-consumption?			
	How often do children eat vegetables?		Who or how cares for animal diseases?		Do you sell or consume the animals?				
	How often do children eat junk food?				Where do you sell your animal products?				
	Has the Health Center detected any children with anemia?				How do you consume animals?				
	Has the Health Center detected any children with obesity?								
	Has the Health Center detected any children with malnutrition?								
	Does the Health Center give nutritional nutrition talks?								
	What diseases do children currently have?								

Information analysis

The research and validation of the factors were designed in the surveys to be answered with Likert-scale responses (1-10), where one is the lowest value. Before starting the research, the survey was validated with the understanding of the questions and the time to answer them. The blocks of questions were integrated as follows:

Block One: The questions of the surveys were analyzed qualitatively and only percentages were determined.

Block Two: The information of the groups classified in the surveys were verified with an existing correlation between the different variables, the Kaiser-Meyer-Olkin (KMO) measurement was determined as the indicator of the proportion of variance, indicating that the values close to 1.0 are useful for a factorial analysis. On the other hand, Bartlett's test of sphericity indicated that the correlation level between the variables was significant and a principal components analysis was done to retain 65.5% of the information presented by the variables. The questions applied in the surveys were named original variables (v) in terms of the origin of non-observable variables (nv) and they were analyzed with the technique of factor analysis (F). The sample size n of a population, where each element of the sample was measured and the v variables of interest were quantified. Therefore, the data matrix with dimension $n \times v$ was expressed in the following way:

$$X_{v(1,2,...n)} = a_{v(11,21,...n)}F1 + ... + a_{v(1,2,...n)m}Fm + E_{v(1,2,...n)}$$

Later, the information was introduced into an Excel worksheet and transferred to a sheet on the statistical software SPSS ver. 21 to carry out their analysis.

RESULTS AND DISCUSSION

Block One

The director of the Department of Economic Development revealed that 34% of the communities that belong to the municipality are classified as highly marginalized areas; they are Tezapotla, Santiago Centro, San Francisco, Mecatlan, Chapulhuacanito, Tecomate, Cuixcuatitla, La Vega, Palitla. On the other hand, the interview with the director of Indigenous Affairs indicated that 72% of the population in the municipality is indigenous and the municipality is ruled by 33 commissaries. The interview with the director of the Department of Rural Development cited that the backing offered to peasants is the teaching of material, implements to support the farmland, and modules for livestock production. The main species that they back are poultry (chickens), double-purpose cattle, and meat-producing sheep; they also support the agricultural sector and offer training, backing species for citrus, coffee, corn, bean, nopal, sugarcane, palm and vanilla production. However, they did not provide statistical data for the backing cited.

Block Two

The results from the principal components analysis determined the main factors in each classified group, showing the percentages accumulated of variance (Table 2).

Table 2. Principal components analysis, accumulated variance.

		Questions	Variable	Accumulated (%)
BLOCK 1: Social media		P5	Are there relatives abroad who support you financially?	17.979
		P9	Do you have drainage service?	35.083
		P4	What is the main source of income?	50.712
		P8	How many light bulbs do you have?	62.692
BLOCK 2: Nutritional status of the population		P12	What is the frequency of Creole egg consumption in children?	44.611
		P18	Does the Health Sector give talks on good nutrition?	53.319
		P14	What is the frequency of junk food consumption in children?	61.173
		P19	What diseases do children currently have?	68.990
		P11	What is the frequency of children's milk consumption?	75.691
BLOCK 3: Agricultural and livestock sector		P1	What agricultural and livestock activity do you do?	30.771
		P6	Did you receive support for pens, feeders or waterers?	54.884
		P5	What type of support did you receive?	78.394
BLOCK 4: Livestock activity, species, management and self-consumption	Birds, management	P1	What type of species did you receive?	41.103
		P6	How is the floor?	54.109
		P3	Do you use specialized breeds of animals, Creoles or both?	64.593
		P9	How many times a day do you feed corn to your animals?	73.886
	Birds, consumption	P1	Is the chicken sold or for self-consumption?	34.623
		P5	Do you market the turkeys or is it for self-consumption?	59.654
		P7	How do you consume turkey meat or eggs?	75.623
	Pig	P2	Do you use pure breeds of turkey, Creoles or both?	63.601
		P12	When your animals get sick, who treats them?	73.810
		P11	What type of water do you give to animals?	81.426
BLOCK 5: Agricultural activity, species, management and self-consumption	Citrus	P3	How much is the area destined for its cultivation?	50.079
		P1	What species of crops do you have?	61.692
		P4	Do you use fertilizer for your crop?	71.138
		P8	Where do you market your crop?	80.407
	Corn	P9	How do they consume their crops?	65.190
		P2	What is the area destined for your crops?	83.134
	Bean	P3	What is the area destined for each type of crop?	71.883
		P4	Do you use herbicides for your crop?	88.269
	Pumkin	P8	How do you consume their crops?	87.323
BLOCK 6: Program or project proposal		P1	Do you belong to a government program in the agricultural sector?	51.229
		P5	How would you like government support to be given to you?	86.076

Social medium

A KMO value of 0.527 was obtained and for Bartlett's test close to 0. The covariance and anti-image correlation selected the variables in the first order: Do they have close family members working outside the state or in a foreign country who support the family economically? The second variable was: Do you have drainage service? The third variable was: What is your main source of economic income? And the fourth variable

was: How many lightbulbs are there in the household? The four variables indicated the accumulated variance of 62.692%. Based on the results reported, there is indication that in the South Huasteca Region of San Luis Potosí there are households that prioritize the activity of close family members, working outside the state or the country, and who provide financial backing to cover part of the basic expenditure on food, as has been reported by Vaquiro and Contreras (2018). The authors mention that the population of families in a situation of poverty in Mexico was 61.1% and the work of family members is important to cover part of the economic needs in the rural families. Similarly, in the communities and localities of the ejido of Chapulhuacanito, economic incomes are contributed by children, siblings, aunts and uncles who have migrated to the city of Monterrey or to the United States of America.

Nutritional status of the population

The KMO was 0.88 and in the total variance explained, 5 variables were selected with 75.69% from the accumulated variance. The nutritional status of the population surveyed from the South Huasteca Region is focused on the child population, and it is necessary for children to consume Creole eggs (Saldaña & Malaga Cruz, 2017) since they suffer from anemia and malnutrition; the daily consumption benefits the nutritional status providing proteins, omega 3 acids and vitamins A, D and E (Vera Rodríguez *et al.*, 2021). A field egg contributes approximately 13.5 of protein, 12.3 of fat, and 0.8 of carbohydrates (Quitral *et al.*, 2009). On the other hand, the population argues that the health centers from each community do not carry out campaigns on the healthy diet in children, and this deficiency is justified due to the problems of the COVID-19 pandemic. However, the World Health Organization recommends governments to promote a healthy diet in public facilities, schools, nursery schools, hospitals, dining rooms, prisons, and any public establishments. The practice of backyard livestock production can improve the nutrition of the population in rural zones with marginalization; the families should foster the consumption of poultry and pigs, but those species are more widely used when celebrations take place such as weddings, baptisms, birthday parties and religious celebrations (González *et al.*, 2013).

Farming sector

The KMO was 0.640. The total variance explained was with three variables: What farming activity do you perform? Is the material backing that you received for pens, feed troughs or drinking troughs? What type of support does the government give? The farming sector indicates that the families at least practice a breeding activity of some livestock species or some crop from the agricultural sector, or even better, they carry out both backyard activities. These results are similar to other reports (Aguilar *et al.*, 2019) where the relevance of backyard animal breeding is mentioned, which offers seasonal products that are used in the family's diet, for festivities, exchanges and sale. Primarily, government backing is directed to this type of backyard activities and access is given to free materials such as pens, feed troughs and drinking troughs, with the objective of improving the nutritional and economic quality of rural families.

Livestock production activity, species, management and auto-consumption

Within the livestock production activity, the following species were taken into account: a) cattle, b) poultry (chickens, turkeys), c) sheep, d) goats, e) pigs, f) rabbits, and g) bees. However, the scarce practice breeding some of the species did not result in enough information, specifically in cattle, sheep, goats, rabbits and bees; therefore, their statistical analysis was not possible. Poultry breeding predominates in all the families and a KMO of 0.076 was obtained from the information analyzed. The anti-image matrix in poultry breeding considered four main variables from the thirteen analyzed; the first variable was: What type of species do you breed? a) chickens, b) turkeys, or c) both. The second variable was: What is the floor like? The third variable was: In your system which do you use? (breed, pure breed, Creole, or crosses). And the fourth variable was: How many times per day do you feed them corn? These variables recorded 73.886% of the information. In particular, poultry breeding is relevant for auto-consumption, and three main variables were selected: The first variable was: Is what you produce in chickens to sell or for auto-consumption? The second variable was: Is what you produce in turkeys to sell or for auto-consumption? And the third variable was: If the answer is B, in what presentations do you consume the turkey meat? The responses confirmed again the importance of this species for auto-consumption.

Swine: The factorial analysis in backyard pig breeding obtained a KMO of 0.759. The anti-image matrix was with fifteen variables, analyzing breeding, management and auto-consumption. The total variance explained was 81.426% and the three main variables that the families considered were: First, in your system, do you use breeds, Creole or both? The second was: What disease is the most common in your animals and how do you recognize it? The third: What type of water do you give your animals? The results confirm that in the South Huasteca Region of *ejido* Chapulhuacanito, the activity of backyard poultry production (chickens and turkeys) and pig breeding are important, compared to the low breeding of cattle, sheep, goats, rabbits and honey production. Other studies indicate that the Maya communities perform mainly poultry and swine breeding to satisfy part of the basic needs of food, and to generate income, additional savings and their use for future emergencies (Aguilar *et al.*, 2019). In general, the households with more farming vocation have a lower income, they depend on government backing and on auto-consumption, and resort to diversification of their income as family survival strategy (Vaquiro and Contreras, 2018). In the process of this study, it was detected that the backyard pens hold Creole chickens and turkeys, and it was also seen that the spaces destined to pens and free spaces are soil floors, and the main feed is corn, once or twice per day (García *et al.*, 2015). Although the backyard poultry can pick up leaves, tender weeds, fodder, insects, fruits, tortillas and food scraps, under this type of backyard conditions there is low or null sanitary management in the pens.

For the population of this region, auto-consumption and trading poultry and byproducts is important. The traditional productive activity helps the families primarily for feed and as a source of income for emergency situations. The population also indicates that food preparation with these birds and byproducts is important (Magaña *et al.*, 2022). Therefore, the use of backyard animals is a family subsistence strategy in

the rural sphere. In the South Huasteca Region, women who are mothers agree that the most frequently cooked dishes are chicken broth with vegetables and red mole with chicken or turkey.

In the case of backyard pig breeding, there are Creole races, which are more adaptable to the climate, and they mention that when their animals get ill, they mostly treat them with home remedies based on the use of plants (Lepe *et al.*, 2023), since it is not possible for them to request a veterinarian, because of the distance and lack of economic resources for their attention. Most families do not have drinking water for these animals, and they give them water from rivers, streams, ditches and wells, and they are fed primarily with corn (García *et al.*, 2022).

Agricultural activity, species, management and auto-consumption

The following crops were considered: citrus trees, coffee, and corn, bean and squash crops. Because of the lack of practice in the zone, the data for coffee growing could not be analyzed.

Citrus trees: The production of orange, mandarin and lime was considered. The KMO was 0.769. Squash: The KMO was 0.660. The total variance explained was with two principal variables, 86.076%. The first variable was: Currently, do you belong to an association or government program that is directed to the farming sector? The second variable was: What would you like the backing to be?

The South Huasteca Region has the highest production and sale of orange compared to mandarin and lime. Orange growing is one of the main sources of economic income for these families and they trade them to second parties that are devoted to cutting and selling directly to juice-makers that are near the *ejido*. Most of the population surveyed does not use fertilizer and the place where they have this crop is in the ejido itself and close to their homes. Most have at least ½ a hectare of land for this crop. In Mexico, 23 states cultivate and harvest citrus trees, and among the ones that stand out there are Veracruz, San Luis Potosí and Tamaulipas (Producción de Cítricos en México, 2022). The consumption of fresh citrus fruits contributes good fiber content, helps digestion, and improves the absorption of fats because it decreases the cholesterol levels (Gómez *et al.*, 2018).

Other agricultural products that are consumed in the Huasteca Region of San Luis Potosí are corn cobs, *xamit*, *atole* and byproducts of the corn crop (tortilla, corn for animal feed); this cereal is considered to be one of the most important in the world, and its main form of consumption is in tortillas (CEDRSSA, 2020). Bean: The population cultivates two species of beans. The first species is *Vigna unguiculata* (sarabanda/castelan bean) better known as *zarabanda* in the communities, and the second species is lentil. The families cultivate both species in the same place, where they have the orange orchards and the milpa; in most of the crops they do not use herbicides, the peasants carry out manual cleaning of the area (Ubiergo-Corvalán *et al.*, 2020). The families from *ejido* Chapulhuacanito use the Castelan bean and lentil, and they are both used to prepare food, primarily for tamales, empanadas and adobo.

Squash: The cultivation of *Cucurbita pepo* L. (calabaza/chu'jm) is practiced primarily within the *milpa* and it is consumed in different dishes (Ubiergo-Corvalán *et al.*, 2020).

Squash is cultivated in backyards with association to the *milpa*; the flowers, fruits and seeds are used for the elaboration of foods, desserts, and beverages.

CONCLUSIONS

A third of the population is classified in an area of high marginalization, and 70% of the community is indigenous. The backing given by the government does not have the objective of decreasing poverty; they are superficial and abrupt programs that make the population believe that with the economic help with resources in cash, materials and small animal species they will exit poverty. The families feel they have a safety support with their material goods and value the economic income provided by family members who have migrated from the region to other countries. The nutritional status of the population is lacking, primarily in the child population which presents anemia and malnutrition; there are no campaigns to improve the population's nutrition. Breeding chickens, turkeys and Creole pigs prioritizes the livestock production activity in the region. Auto-consumption and the commercialization of these species is a traditional productive activity that helps the family economy and solves dietary problems in the short term. The South Huasteca Region presents favorable conditions for citrus production, coffee production, and corn, bean and squash crops. However, the short-sightedness in strategies for cultivation and commercialization make these products only traditional. The culinary culture is rooted in the region and there are traditional dishes, where livestock production and agriculture actively influence the customs. It is necessary to create efficient programs that guarantee a better agriculture and livestock productivity with the purpose of improving the nutritional status of the population and generating economic resources that decrease poverty.

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Trade dependence of Mexico on barley (*Hordeum vulgare* L.)

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ABSTRACT
Objective: To determine the degree of trade dependence of the Mexican market on imported barley from 1994 to 2021.
Design/Methodology/Approach: The growth rates of the barley production variables in the domestic market were estimated, the relative trade balance was calculated, and the trade dependence was determined.
Results: The production variables had growth rates in the analysis period, the relative trade balance was −1, and the trade dependence was close to 0.
Study Limitations/Implications: There is no correlation between the barley market and the brewing industry in Mexico.
Findings/Conclusions: Mexico is a net importer of barley despite the positive growth rates of the production variables. Nevertheless, this grain does not have a trade dependence on the foreign market.

Keywords: Relative trade balance, trade dependence, growth rate, barley.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is considered the oldest cereal in the world and has two points of origin: Southeast Asia and North Africa (Ponce *et al.*, 2020). In 2019, it ranked fourth in sown area, after wheat, corn, and rice. The largest planted areas are in Russia, Australia, Ukraine, Turkey, and Spain, while Mexico ranks in the 27th place (Tumuri, 2019). The use of this cereal in Mexico dates to the Spanish conquest, when it was used as forage for horses (Coronel and Jiménez, 2011).

Barley is used as a raw material for malt production, and it is also an important source of health-promoting components (Bragachini *et al.*, 2008). The Mexican brewing industry uses it to produce alcoholic beverages. It is a temporary and profitable crop that has a comparative advantage in both the regional and the international markets (De la Rosa *et al.*, 2016).

To determine its competitiveness, the comparative advantages of a product associated with natural factors must be considered (Contreras, 2000). Additionally, this is a core issue for governments and companies, because it is related to better living conditions (Ferraris, 2009). A nation's competitiveness is the result of industrial productivity, sustained exports,

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and significant outflows of foreign investment (Porter, 2008). Market share is another useful competitiveness indicator (Mc Fetridge, 1995).

Competitiveness Indexes are values that measure the economic performance of a nation and reflect the variables that allow competitive performance (Murillo, 2005; Ibáñez and Troncoso, 2001). Comparative advantage forms the basis of exports (Ricardo, 1985) and understanding its nature is critical (Hosein, 2008), since this variable functions as a guide for trade and industrial policy (Huerta, 2009).

The theory of absolute advantage postulates that each country should specialize in producing the goods that they can make with greater efficiency under free trade (Smith, 1776). The absolute advantage proposed by Smith lacks two major elements that are basic for international trade nowadays: transportation costs and consumer preferences (Krugman *et al.*, 2012; Carbaugh, 2009; Appleyard *et al.*, 2006; Salvatore, 1997).

In Latin America, the importance of detecting sectors with advantage and disadvantage is essential for the optimal allocation of resources (Prebisch, 2008). The relative trade balance and the trade dependence must be calculated to analyze the competitiveness of the Mexican agricultural sector (Luquez, Gómez, and Hernández, 2021; Luquez, Gómez, and Hernández, 2022; Luquez, Hernández, and Gómez, 2022).

The objective of this research was to determine the degree of trade dependence of the Mexican market with respect to imported barley from 1994 to 2021. The research hypothesis was that the Mexican market is self-sufficient and does not depend on foreign barley markets, despite trade openness and the North American Free Trade Agreement (SE, 2019).

MATERIALS AND METHODS

The barley production variables were consulted in the Sistema de Información Agroalimentaria de Consulta (SIACON), while international trade statistics were obtained from the Food and Agriculture Organization of the United Nations (FAOSTAT).

The growth rates of the production variables were calculated, and the global competitiveness indexes were estimated: relative trade balance and trade dependence. The following concepts and formulas were used for this purpose:

Growth rate: the percentage increase or decrease that a given value has in a period (Brambila, 2011). The calculation procedure was:

$$r_{(1-n)} = \left[\left(\frac{V_n}{V_1}\right) - 1\right] * 100 \qquad (1)$$

Where: $r_{(1-n)}$: growth rate from year 1 to year n; n: number of years; V_n : value in year n; V_1: value in year 1.

A positive value of the growth rate implies that the variable grew in the period analyzed, while a negative value implies that it decreased.

Trade balance: a financial indicator that measures the relationship between exports and imports (WTO, 2015). It was calculated using the following formula:

$$BC = X - M \tag{2}$$

Where: *BC*: trade balance; *X*: exports; *M*: imports.

A trade surplus is recorded when exports are greater than imports in the trade balance. Otherwise (*i.e.*, if imports are greater than exports), there is a trade deficit.

Relative trade balance (**RTB**): an indicator that measures the relationship between the trade balance of a product and the total trade of the same product for a country in the world market or in a specific market. It is interpreted as an index of competitive advantage (García, 1995) and was calculated with the following formula:

$$BCR_{ij} = \frac{X_{ij} - M_{ij}}{\left|X_{ij} + M_{ij}\right|} \tag{3}$$

Where: BCR_{ij}: relative trade balance of country *j* with respect to product *i*; X_{ij}: exports of product *i* by country *j* to the world market; M_{ij}: imports of a product *i* by a country *j* from the world market.

If the RTB ranges from −1 to 0, the country is a net importer of the product and lacks a competitive advantage. If the RTB ranges from 0 to 1, the country is a net exporter of the product and has a competitive advantage.

Trade dependence: coefficient that calculates the relationship between the value of imports (M) and the value of apparent consumption (AC) during a given period. This indicator measures international competition for domestic demand (Ramírez *et al.*, 2016), using the following formula:

$$GI_{ij} = \frac{M_{ij}}{Q_{ij} + M_{ij} - X_{ij}} \tag{4}$$

Where: GI_{ij}: degree of penetration of product imports *i* in country *j*; M_{ij}: imports of product *i* from country *j*; Q_{ij}: domestic production of product *i* of country *j*. X_{ij}: exports of product *i* from country *j*.

If the coefficient is close to 0, the competitiveness of the sector or productive chain is greater, while, if it is close to 1, the competitiveness of the sector or productive chain is lower.

RESULTS AND DISCUSSION

The surface of Mexico where barley was sown and harvested increased in the analysis period, recording a growth rate of 138% and 177%, respectively. Specifically, a marked increase was observed from 1994 to 2003. From this date, the surface sown with barley has maintained a trend of small fluctuations (300,000 to 330,000 ha). For its part, the harvested surface showed large fluctuations, mainly in 2000, 2004, 2009, 2011, and 2013 (Figure 1).

During the analysis period, the barley yield in Mexico has been very unstable. For example, in 2003 and 2016, it reached 3.0 t ha^{-1} while in most years (since 1994), it has remained around 2. 5 t ha^{-1} showing a stable trend (Figure 2).

The total production of barley in Mexico recorded a >200% increase from 1994 (315,000 tons) to 2021 (>1,000,000 tons). However, important peaks in production were recorded, including increases in 2003, 2012, 2017, and 2018 in which >1 million tons were produced (Figure 3).

The Mexican market is not a major barley exporter: it reached the highest number of grain exports of the study period in 2014 (942 t) and an all-time low exportation level in 2010 and 2012 (169 t and 161 t, respectively). In 1996, Mexico imported more than 300,000 tons of barley —the largest volume imported in the period under analysis. However, the largest volume of cereal purchased in the last decade was 169,000 tons in 2015; in comparison, only 214 tons were purchased in 2018. Therefore, the trade balance of the product recorded a trade deficit during the period of analysis (Figure 4).

The relative trade balance ranges from −1 to −0.6 (Figure 5): Mexico is a net importer and lacks competitive advantages in the international barley market. The indicator usually has a value of −1, which proves that the production is not enough to supply the domestic demand.

Trade dependence was estimated between 0 and 0.4, which implies that the Mexican market is not dependent on the international barley market. Since 2000, this indicator has remained below 0.2 (Figure 6), confirming the previous observation. In 2017 and 2018, the value of this coefficient was practically null.

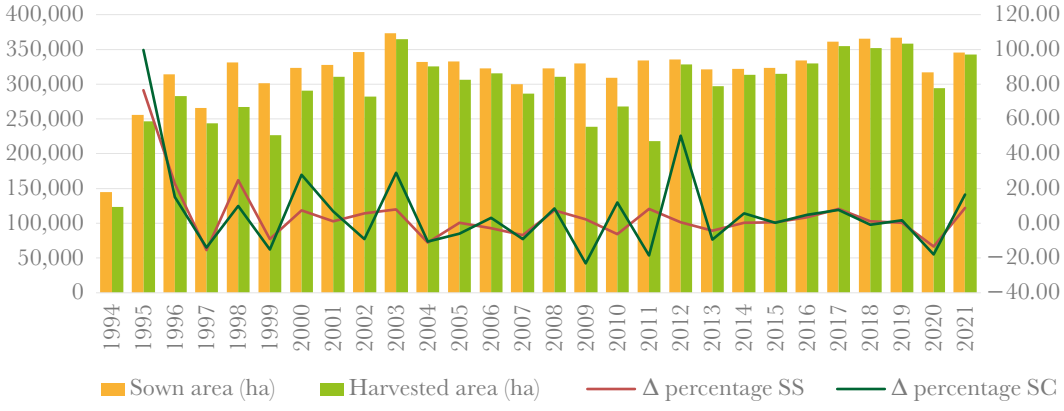

Figure 1. Behavior of the surface where barley was sown and harvested. Source: figure developed by the authors based on data from SIACON (2022).

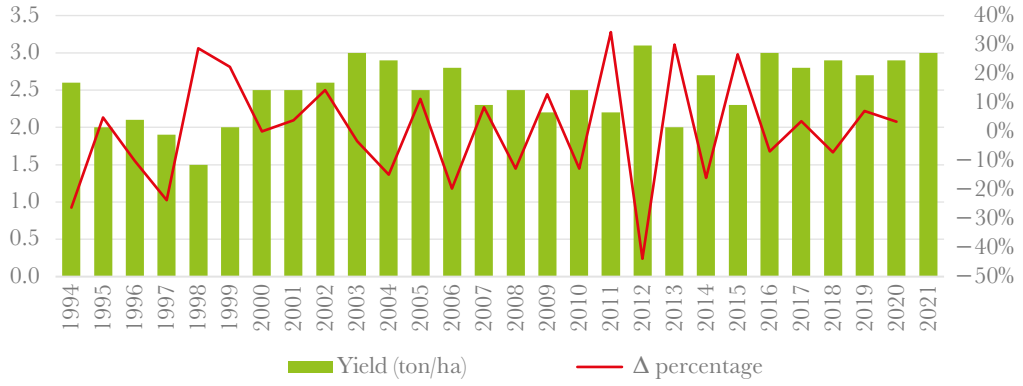

Figure 2. Barley yield in Mexico. Source: figure developed by the authors based on data from SIACON (2022).

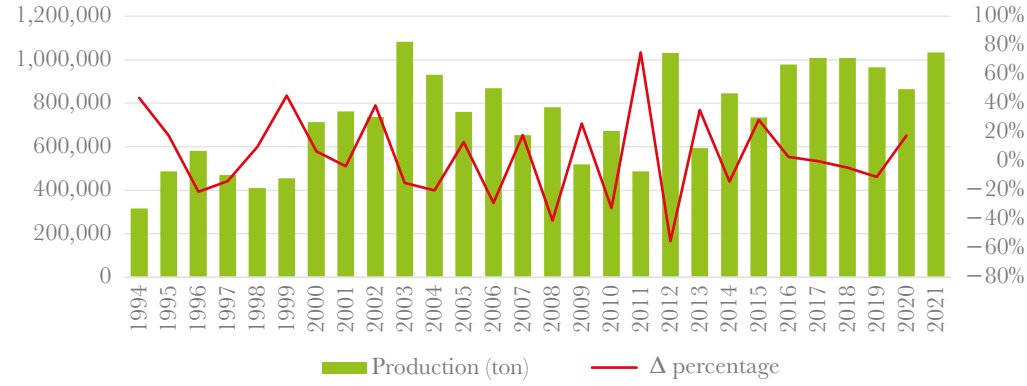

Figure 3. Volume of barley production in Mexico. Source: figure developed by the authors based on data from SIACON (2022).

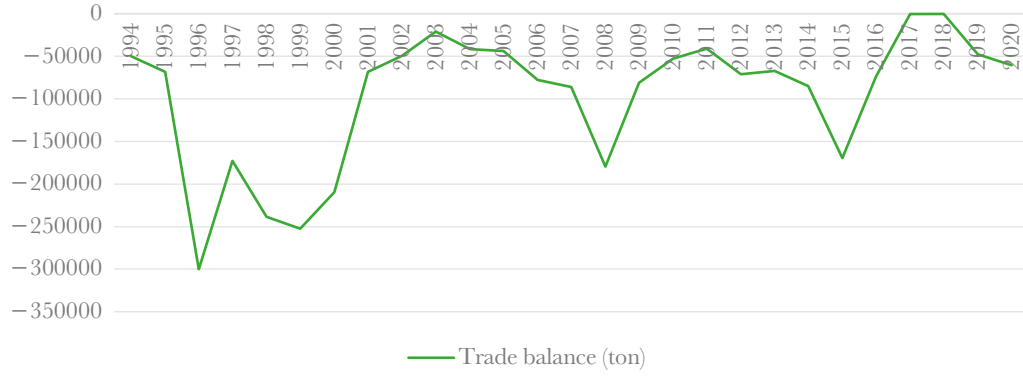

Figure 4. Trade balance of barley in Mexico. Source: figure developed by the authors based on data from FAOSTAT (2022).

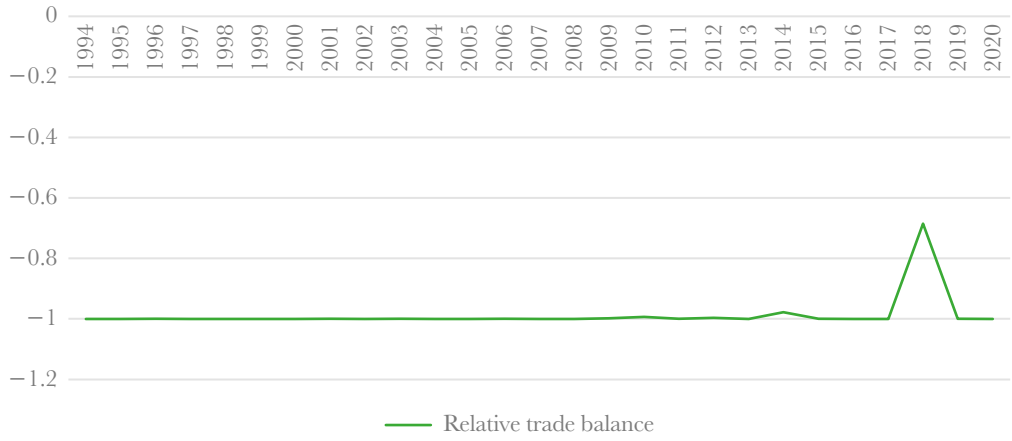

Figure 5. Relative trade balance of barley in Mexico. Source: figure developed by the authors based on data from FAOSTAT.

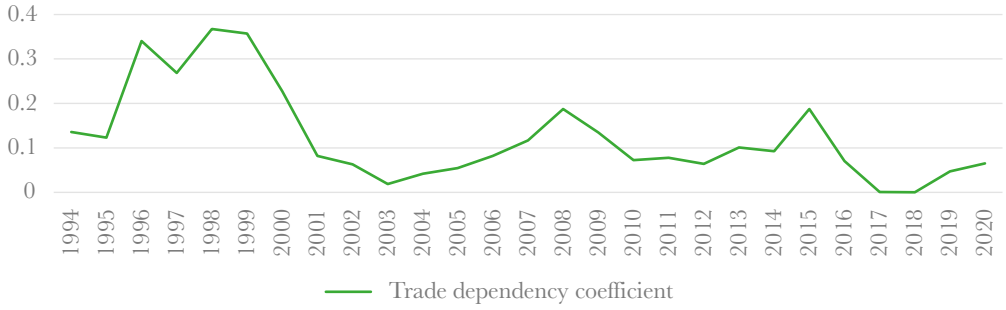

Figure 6. Trade dependence of barley in Mexico. Source: figure developed by the authors based on data from SIACON and FAOSTAT.

CONCLUSIONS

The surface in which barley was sown and harvested in Mexico increased in the period analyzed, the crop yield was stable, and the production volume tripled. However, exports were almost null, while imports have accounted for ∼15% of the production volume.

The competitiveness indexes show that Mexico is a net importer of barley; however, the Mexican market is not commercially dependent on the international barley market, since national production is enough to supply domestic consumption.

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Topic modeling analysis of Community Savings Groups: evidence from the combined literature

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ABSTRACT

Objective: To identify topics of study related to Community Savings Groups (CSGs) from the literature available.

Design/Methodology/Approach: Some phases of natural language processing were implemented. The data were obtained from scientific databases and gray literature. The analysis included 228 abstracts of papers, theses, working papers, and reports. The Latent Dirichlet Allocation model was used to identify the topics.

Results: Six topics have been the focus of the discussion about the existence and impact of CSGs in the last two decades.

Study Limitations/Implications: Texts without abstracts in English were excluded.

Findings/Conclusions: The topics found deal with various aspects on which CSGs have had an impact, such as health, empowerment, primary sector, violence, and other aspects related to existence. Additional evidence is required to consider CSGs as an effective and sustainable mechanism that facilitates well-being.

Keywords: Savings Groups, automatic literature review, impact, sustainability, participation.

INTRODUCTION

Scientists generally use Scopus, Web of Science, or PubMed to analyze the scientific literature on a given topic, because these databases contain high-impact publications (Falagas *et al.*, 2008). However, valuable information can also be found in gray literature (theses, working papers, or reports). Some systematic literature reviews use both sources (Sollis *et al.*, 2022). Overall, scientific databases are used for bibliometric analysis, seeking to identify authors, journals, impact of publications, or relationships between authors and topics, in order to identify knowledge gaps (Donthu *et al.*, 2021); however, this analysis ignores the knowledge provided by gray literature.

Combining both sources of information (*i.e.*, scientific and gray literature) is important in literature review. Topic modeling (TM) analysis —which is part of text mining— was used in the identification of topics in documents from both sources.

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TM is used to handle the large amount of information available as texts in sources such as Twitter, web pages, news, or books (Blei, 2012).

The most popular TM algorithm for the detection of topics is Latent Dirichlet Allocation (LDA), which is part of an Unsupervised Machine Learning (Griffiths and Steyvers, 2004; Kao and Luarn, 2020). TM makes use of artificial intelligence with natural language processing and machine learning. Previous studies used the LDA algorithm to discover topics in textual data. Rivera Delgado *et al.* (2021) analyzed 125 documents related to institutions and participants to find topics on the direct uses of geothermal energy and technological innovation systems in Mexico. Kao and Luarn (2020) focused on Twitter data to find social enterprise topics.

This study focused on the application of LDA to the Community Savings Groups (CSG) literature. CSGs are one of the informal financial institutions created by people excluded from the formal financial system (Amponsah *et al.*, 2023). CSGs are set up with the help of a facilitating institution (FI) which is generally a Non-Governmental Organization (NGO) that carries out CSG establishment projects. After a certain period (usually one year), CSGs are considered to be consolidated and its members are expected to be able to maintain the operation from that point onwards. In 1990, the CARE (Cooperative for Assistance and Relief Everywhere) NGO started the CSG movement in Mali; subsequently, other NGOs replicated that model with some modifications in other regions of Africa. After a decade, the CSGs —which had already spread to several regions of Latin America— were the subject of several researches. The objective of this research was to use the LDA to identify the topics of the publications made about CSGs.

MATERIALS AND METHODS

Documents about CSGs published until 2022 were searched in several scientific databases (Scopus, Web of Science, Google Scholar, PubMed, etc.), in university repositories, and reports from NGO dedicated the creation of CSGs. The abstracts of each document were considered, since they provide the maximum information contained in the document about a given subject (Griffiths and Steyvers, 2004). In total, 228 abstracts were retrieved and considered for the machine learning process.

The phases of natural language processing (NLP) were implemented in the R statistical package, using the tm and topicmodels packages. In the first phase, text processing (cleaning) was carried out through the following steps: text segmentation, tokenization, stop word, stemming, and lemmatization. In the second phase, a document term matrix (DTM) was developed. Defining the number of topics can be a subjective task; however, four available algorithms (CaoJuan2009, Deveaud2014, Arun2010, and Griffith2004) were implemented in the ldatuning package to obtain better results. This process suggests between four and seven topics. Finally, LDA was applied to the matrix (DTM) with the specification of six topics.

A post hoc analysis was implemented to assign names to the topics created to avoid a subjective proposal (Chang *et al.*, 2009). This algorithm is part of the lda package and it functions as the term frequency-inverse document frequency (TF-IDF), where the words with greater frequency in the documents are less important for the formation of topics.

RESULTS AND DISCUSSION

The word cloud was developed using words whose frequency was greater than 70 to determine which concepts were repeated the most in the publications. In addition, a bigram was used to present the relationship that exists between two concepts. The top word correlation has been previously observed to be: "Saving Group", "Saving Loan", "Village Saving", and "Loan Association" pairs, which are grouped under the heading that the literature provides for the CSG, after the word "and" was eliminated in the NLP. Figure 1 shows only the first 15 pairs of concepts —some of which are useful for the analysis of economic empowerment, women empowerment, food safety, etc.

Bigrams indicate relationships between two words. The topics were detected through the implementation of LDA with six topics, yielding satisfactory results. In LDA, each concept influences the formation of the topic, as represented by the Beta value. Figure 2 shows each topic and the Beta value for the concepts. The graph was limited to 10 concepts.

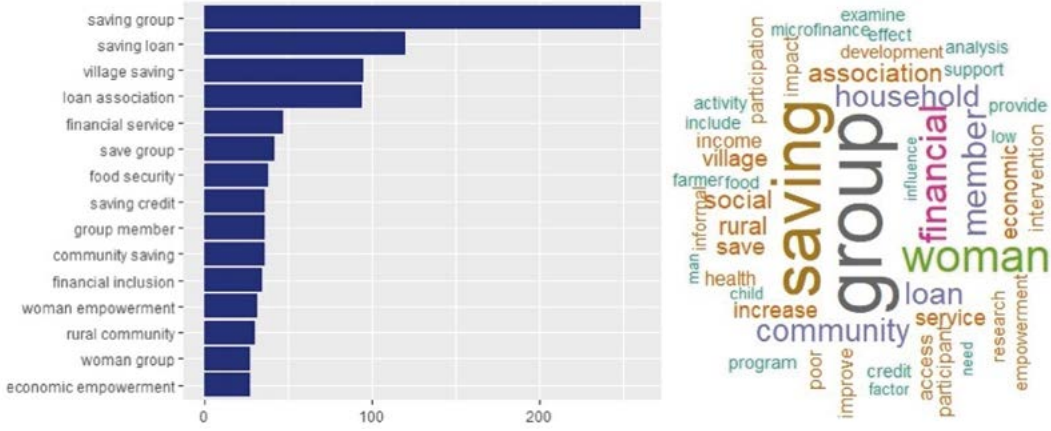

Figure 1. Bigram and word cloud.

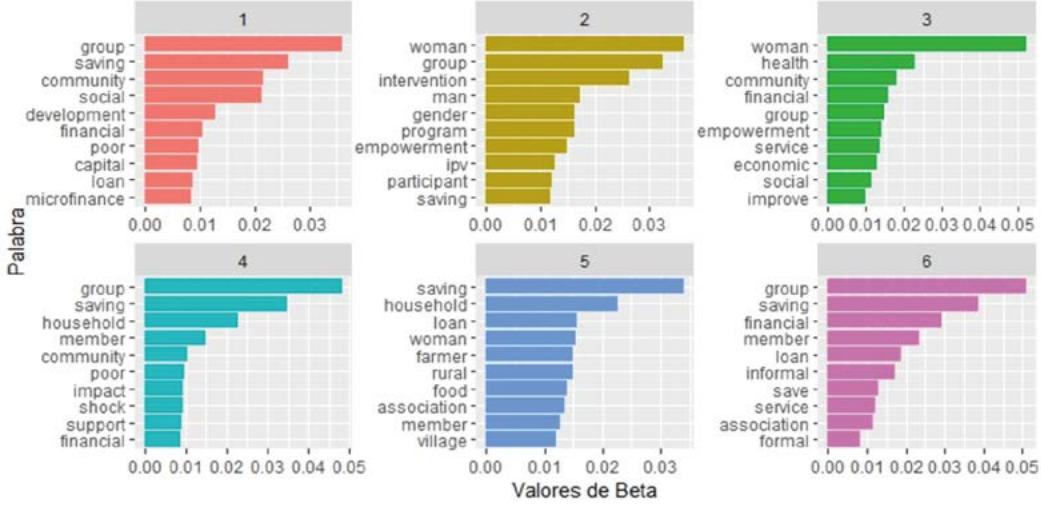

Figure 2. Result of the LDA model.

The names of the topics are defined according to the result of the post hoc test. Table 1 shows the first ten concepts presented in Figure 2 and five additional terms that were not presented in the same Figure.

Topic one takes the essence of CSGs as an alternative model for the financing of rural development in places where formal financial services are lacking. According to Ashe and Neilan (2014), CSGs constitute a revolution that will achieve development through the personal efforts of the poor. There are two types of objectives targeted by development finance: productive activities and infrastructure. CSGs, along with microfinance institutions, play an important role in the financing of activities that generate income in rural areas. Karlan *et al.* (2017) found that CSGs improve the businesses of the poor.

Topic two constitutes the importance of the gender approach in the study of CSGs, since the word "woman" has the highest Beta value in the graph. Several works found that CSGs empower women (Karlan *et al.*, 2017; Pamuk *et al.*, 2022). The CSGs constitute a mechanism that trains women on various topics. Some experimental works include men in workshops given at CSGs. For example, Dunkle *et al.* (2020) found that intimate partner violence (IPV) was reduced in couples who participated in workshops.

CSG training may vary depending on the interest of the NGO that facilitates its creation. Health is the third topic and it is frequently included in the workshops. PubMed is, in fact, one of the databases used to find papers about CSGs, which justifies including the health topic. While the previous topic involves the analysis of a single variable (*i.e.*, women empowerment and consequently the reduction of violence), this topic considers socioeconomic level and health simultaneously. The topic of maternal care is included in this group. Women's participation in a CSG is associated with four or more prenatal care visits, use of qualified midwives, and postnatal care no later than 48 hours after birth (Tura *et al.*, 2020).

Participation and impact on the resilience capacity of CSG members is another important topic for the analyses of these groups. The impact of the CSG can be detected in several aspects, both within the group and outside it (*i.e.*, participants and non-participants).

Table 1. Concepts and headings of the topics

ID	Additional concepts	Post hoc	Name of the Topic
1	save, rural, support, credit, member	Social, institutional, capital, urban, community, scheme	Scheme of Alternative Finance
2	effect, increase, hiv, session, violence	Intervention, ipv, man, woman, empowerment, gender	Impact on gender
3	improve, rural, save, examine, village	Woman, health, empowerment, care, maternal	Socioeconomic empowerment and health
4	child, increase, cope, participant, provide	Shock, cope, household, group, child	Participation and impact on resilience
5	income, participation, farm, agricultural, group	Farmer, food, farm, household, agricultural	Participation and impact on agricultural sector
6	sustainability, performance, institution, bank, access	Informal, sustainability, financial, group, performance, return	Sustainability and performance

Jahns-Harms (2017) found that, through the access they provide to savings and social support, CSGs increase the capacity to face crises resulting from inflation, illness, and poor harvest, among other causes. Other works found that CSG participants take less time to recover from a crisis than non-participants (Wagner *et al.*, 2022; Panman *et al.*, 2022).

The fifth topic is the participation and impact of the CSG in the agricultural sector and it is taken into consideration because the projects are usually implemented in predominantly agricultural territories. Pamuk *et al.* (2022) concluded that CSGs positively affect the adoption of climate-smart agriculture practices. Amponsah *et al.* (2023) found that participation in CSGs significantly increased the agricultural productivity and income of the participants. Another important aspect of this topic is the role that CSGs play in food security, although Lukwa *et al.* (2022) mention that this is not the main reason which drives the members to participated in these groups. Although this topic is included based on the algorithm, in fact it concerns the entire primary sector and there is evidence regarding fishing (Lieng *et al.*, 2018) and livestock breeding (Okello *et al.*, 2020).

Finally, the terms found for topic six suggest that the continuity or performance of the CSGs and their relationship with formal institutions (banks) should be analyzed. CSGs are informal institutions, although their operation is based on written rules. Sustainability is included in the research simply because CSGs must operate on their own when they are no longer assisted by the NGOs that favored their creation. Moret *et al.* (2021) found that CSGs realize changes to survive and the most important factors that enable sustainability are leadership, trust, and love.

In short, these topics reflect the points of view from which the CSGs have been analyzed, including their characteristics, objectives, the benefit they provide to their members (such as empowerment and reduction of violence), and their impact on various sectors of society. CSGs are not only focused on solving women's savings and credit problems; they also constitute a space with multiple purposes.

CONCLUSIONS

Community Savings Groups (CSG) are informal financing mechanisms created by people who do not have access to the formal financial system and are set up with the support of a facilitating institution. The CSG movement, which began in the 1990s, has been the subject of many publications. Summaries of theses, papers, working documents, NGO reports, books, and other sources were compiled to analyze the topics researched in those studies.

The impact of CSGs on health, childcare, agriculture, and women empowerment has been tackled by many studies. However, the main impact is expected to be economic —*i.e.*, granting access to financial resources to carry out productive activities. Many users are attracted to the considerable benefits on savings (passive interest rate) that CSGs offer as part of the strategies aimed at their own existence. Likewise, these groups have to maintain their operations (*i.e.*, they must continue in the long term after the departure of the NGO); therefore, few studies focus on analyzing this aspect.

Further research should be focused on the separate or comprehensive analysis of aspects of the topics determined in this work and even propose new models and more topics.

The CSGs themselves are constantly transforming and growing globally. For example, the Mexican government, through the Programa Sembrando Vida (PSV), promotes the creation, under a more comprehensive approach, of CSGs in the groups known as Comunidad de Aprendizaje Campesino (CAC). Consequently, new topics of interest may potentially arise, including the Government-CSG relationship, the impact on forestry, family well-being, and even sustainability.

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Typology of sheep farmers benefited by the Program for the Improvement of indigenous Production and Productivity

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ABSTRACT

Objective: To identify the typology and describe the sheep farmers benefited by the Programa para el Mejoramiento de la Producción y Productividad Indígena (PROIN: Program for the Improvement of Indigenous Production and Productivity) of the Instituto Nacional de Pueblos Indígenas (INPI: National Institute for Indigenous Peoples), in Campeche.

Design/Methodology/Approach: One-hundred ninety-nine sheep farmers registered as beneficiaries in the Program were interviewed. They belonged to 27 sheep farms (SF), located in seven municipalities. A questionnaire including socioeconomic and technical questions and 15 quantitative and qualitative variables was conducted. Variables were correlated and a principal components analysis was carried out to define types of farms. The variables that explained the highest variability in the data set were number of sheep, number of sheep sold per year, annual income from sheep sales, productive purpose of the sheep farming, and feeding system. These variables were then used to perform a cluster analysis in order to identify and cluster the sheep farms.

Results: Three groups of farmers were identified: Conventional (C, 74%) with 70 sheep and annual sales for $10,109.00; Transitional (T, 15%) with 169 sheep and annual sales for $36,680.00; and those in business (B, 11%) with 142 sheep and annual sales for $48,443.00. All the producers (100%) carry out extensive grazing. The breeds used by C and T are Pelibuey × Black Belly (78%), while B uses Pelibuey × Kathadin (21.7%).

Study Limitations/Implications: Implemented support strategies must differentiate according to the type of farm.

Findings/Conclusions: Three types of sheep farmers were identified: Conventional, Transitional, and Enterprise. Farmer types were differentiated by the number of sheep, sales, income, sheep production system, and feeding system they use.

Keywords: Management, sheep production, flock, production system, Farm types.

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INTRODUCTION

In Campeche, support programs for sheep farming are based on optimal agroecological conditions, the easy management of sheep, and the presence of Pelibuey and Black Belly breeds. These breeds are considered easy to raise because of their prolificity, rusticity (which makes them resistant to internal and external parasites), and adaptability to precipitation and high temperature conditions, these hair breeds are an alternative for production of food for self-consumption and commercialization (Calderón-Cabrera *et al.*, 2022).

The classification of sheep farmers enables their distribution into groups for their analysis and contributes to the decision-making process in the sector (Vázquez-Martínez *et al.*, 2018). In the case of small-scale sheep farming in private production systems, differences among the systems should be delineated to develop strategies for their development (Calderón-Cabrera *et al.*, 2022). Although Pérez-Bautista *et al.* (2021a) characterized the sheep farms benefited from the Comisión Nacional para el Desarrollo de los Pueblos Indígenas (National Commission for the Development of Indigenous People) in Campeche, there is still a lack of information about the socioeconomic and technological parameters under which they are grouped. The availability of the said information will contribute to the use of appropriate technology and the design of strategies suited to their socioeconomic characteristics. This information helps to improve productivity and encourages sheep farming. It can also be the basis for future research. Therefore, the objective of this research was to carry out a typology and characterize the types of sheep farmers benefited by the INPI, in Campeche.

MATERIALS AND METHODS

The study was carried out from October to December 2015 with the participation of 199 farmers from 27 sheep farms, with farms located in seven different municipalities of Campeche. The study area is located between parallels 19° 14' and 20° 00' N and 89° 50' and 90° 42' W, at 260 m.a.s.l. The climate is warm sub-humid with rainfall in summer (García, 1988), a mean temperature of 30 °C, and an annual rainfall of 1200-2000 mm.

Statistical analysis included data from all the 27 farms receiving funds from the INPI during 2014 and 2015, the data was provided from the database by the Comisión Nacional para el Desarrollo de los Pueblos Indígenas (CDI: National Commission for the Development of Indigenous Peoples) in the state of Campeche.

To characterize the farmers, a questionnaire with semi-structured questions was designed to gather information of the socioeconomic and technical status of farms. Socioeconomic characteristics included: number of members managing the farm, indigenous language, age, education, years of experience in sheep farming, importance in sheep-related activities, land tenure, sales, income from sheep farming, number of sheep owned, total farm area, area dedicated to sheep raising, breeds used, production purpose of the farm, characteristics of the job, facilities, and equipment related to sheep farming. Technical characteristics included the production focus of the farm, reproductive management, feeding management, health management, technical assistance, and water use. The questionnaires were performed throughout interviews. Direct observations were also made to describe the management and available equipment and infrastructure in the farms. The variables of the socioeconomic characteristics were used to classify the farms.

Pearson correlations were performed among all variables, to obtain the most associated variables and include them in a principal components analysis (PCA). The PCA was then performed to obtain the most significant variables and total variances that contribute to the total number of components. Subsequently, a cluster analysis was carried out through an average grouping based on Euclidean distances. The most relevant variables identified in the PCA (sheep sales, income per sale, number of sheep in the farm, production system, and feeding system) were taken into consideration to determine similar groups of farmers and define their characteristics. All analyses were carried out with the Infostat software version 2020 (Di Rienzo *et al.*, 2020).

RESULTS AND DISCUSSION

The sheep sale and income by sales variables recorded the highest correlation in the analysis (r=0.99), followed by the total number of sheep and sales income (r=0.54), and number of sheep and sheep sale (r=0.51). The PCA included two components: the first accounted for 53% and the second 29% of the total variance (together they represent 82% of the variance in the data). These components show the relationships that exist between the socioeconomic and technical variables: the most important variables in component 1 were sale of sheep and the income, while component 2, was the negative weight of the purpose of the production system opposed to the positive weight of the feeding system (Table 1).

Typology of Sheep farms

The three types of farmerss found had different socioeconomic and technical characteristics (Figure 1). Conventional (C) farmers represent 74% of the total and on average they have a maximum of 70 sheep, sell up to eight sheep per year, and their annual income is $10,109.00. Fifteen percent of the producers fall into the Transitional (T) category; on average they have 169 sheep, they sell 31 sheep per year, and they obtain an annual income of $36,680.00. Finally, 11% of the producers belong to the Business (B) category, they on average have 142 sheep, sell 40 sheep per year, and their annual income is $48,443.00 (Figure 2).

Socioeconomic characteristics of the types of sheep farms

Most sheep farmers (90%) in Campeche are literate and went to school during 2 years in average, similarly to farmers in the neighboring state of Yucatán (Góngora-Pérez *et al.*,

Table 1. Variables with the greatest influence on the two main components defining sheep farmer groups in Campeche, Mexico.

Variable	Component 1	Component 2
Number of sheep	0.41	−0.26
Sheep sales	0.55	−0.28
Sales income	0.56	−0.26
Productive purpose of the farm	−0.33	−0.62
Feeding system	0.33	0.63

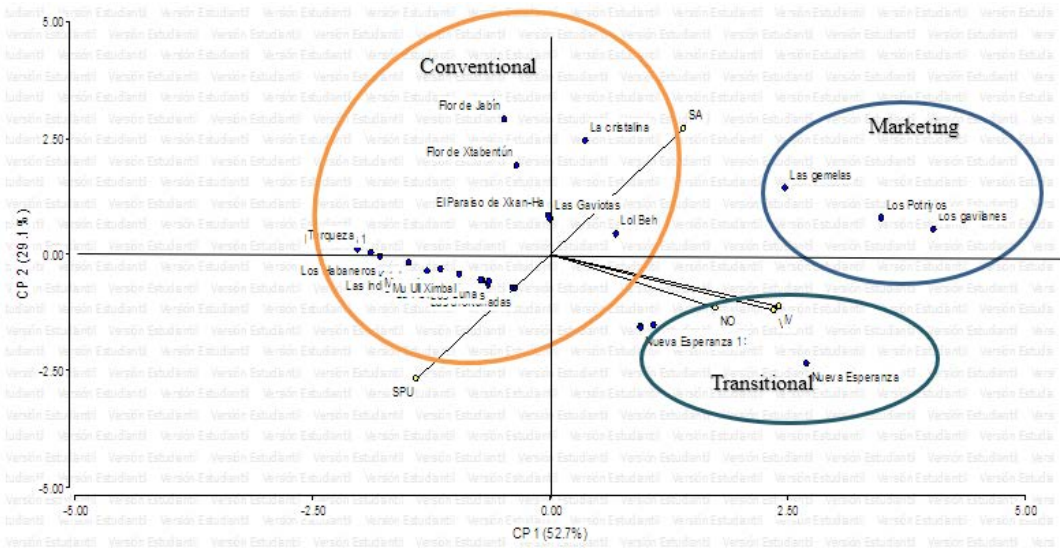

Figure 1. Values of the components 1 (PC 1) and 2 (PC 2) that identify the location of sheep farms into three groups, based on socioeconomic and technical variables.

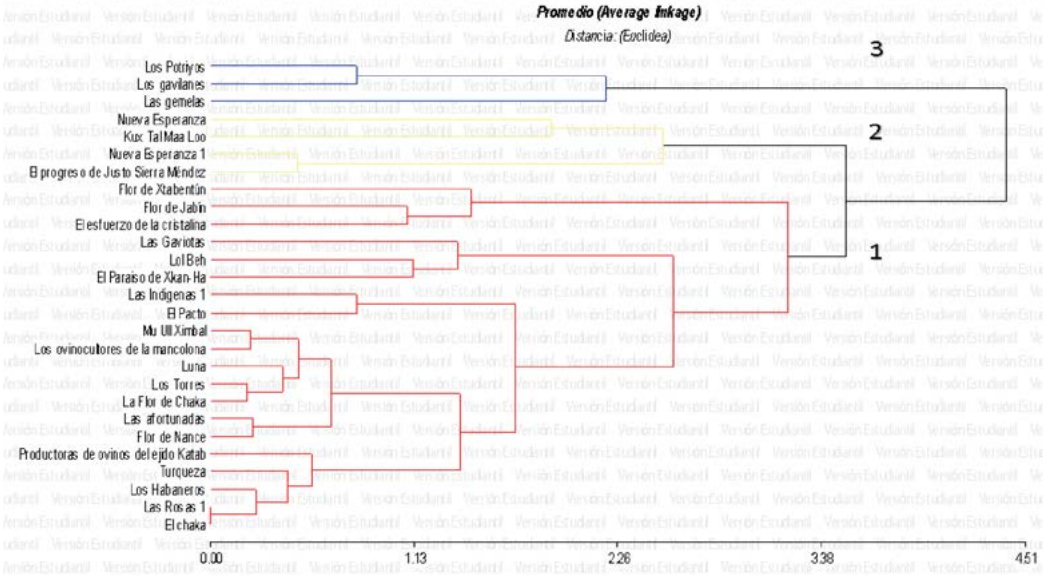

Figure 2. Dendrogram of the groups formed with similar characteristics in sheep production in Campeche, Mexico.

2010). Therefore, non-traditional training of this type of farmers must be implemented to understand and assimilate training regarding sheep farming.

The average age of the farmers was 37.5 (C), 38.4 (T), and 40.5 (B) years and they owned 70, 169, and 142 sheep, respectively. Candelaria-Martínez *et al.* (2015) reported similar results in eastern Yucatán, while Vázquez-Martínez *et al.* (2018) and Calderón-Cabrera *et al.* (2022) recorded lower values in the Puebla and Tlaxcala region and in the northeast-central areas of the State of Mexico, respectively. Candelaria-Martínez *et al.* (2015) sustains that this age range is appropriate for the adoption of technology and innovation.

Seventy-eight percent of the members of groups C and T use the Pelibuey × Black Belly sheep breed. The area dedicated to sheep production was 15 (C), 22 (T), and 24 (B) ha, which are sown with grasses of genera *Pennisetum* and *Briachiaria* and native grasses. Given that the support has only been granted in recent years, producers had 1-2 year experience in sheep farming (no more than 3 years). This time span is lower than those previously reported in Campeche (Dzib-Can *et al.*, 2006), less than 4, 6, and 7 years were recorded, depending on the level of technology (high, medium, and low, respectively). The three groups exclusively use family labor, and they have basic infrastructure and equipment: the barn, pens, drinkers, and feeders are built with native material, just like producers in Yucatán (Candelaria-Martínez *et al.*, 2015). Farmers in T and B groups have more equipment and infrastructure for flock management, while farmers in C lack enough equipment and infrastructure (Table 2). Therefore, they need support for the construction of basic infrastructure, which is key for the promotion of this type of production units (Martínez-González *et al.*, 2011).

All three groups lack the infrastructure required to produce or store forage and consequently animals lose weight during the dry season. This situation, coupled with the low number of trees and shrubs observed in the grazing areas (resulting from the establishment of exotic pastures), provides the opportunity to develop agricultural, forestry, and grazing systems with locally available tree resources, such *Guazuma ulmifolia* Lam (Partida-Hernández *et al.*, 2019) or breadnut (*Brosimiun alicastrum* Swarth (Rojas-Schroeder *et al.*, 2017). Likewise, it is proof that producers need to receive information that allows them to recognize this vegetation as a highly nutritious forage source.

Table 2. Infrastructure and equipment (%) owned by the groups of sheep farmers receiving financial support by the Instituto Nacional de Pueblos Indígenas, in Campeche, Mexico.

Infrastructure and equipment	Producers		
	Conventional (C) (n=20)	**Transitional (T) (n=4)**	**Marketing (E) (n=3)**
Backpack fumigator	30	43	75
Electric irrigation pump	10	10	20
Scale	14	20	50
Forage chopper	14	33	40
Chainsaw	14	28	40
Basic first aid kit	0	40	50
Feeders, water troughs and mineral feeders	100	100	100
Cyclonic wire mesh	20	30	50
Artesian well	20	25	43
Sheep individual pens	15	20	26
Sheep large pens Subdivided pastures	80	85	100
Sorting shuttle	20	20	20
Shelter	100	100	100

Most B and T farmers (80%) sell sheep and use their animals to increase their flock, while 75% of farmers in C are focused on the breeding and reproduction of their flocks, which indicates that they farms are growing. As in sheep farms in the State of Mexico (Calderón-Cabrera *et al.*, 2022), 90% of the sheep are sold directly at the farmers' homes. Sheep dealers and "*barbacoyeros*" (people who prepare and sell barbacoa) trade live sheep. This is considered an advantage, since farmers do not incur in transportation costs; however, the trading prices are low (Calderón-Cabrera *et al.*, 2022).

Technical characteristics of the sheep farm types

The reproduction system of studied farms involves natural mating throughout the year, with a 1:40, 1:55, and 1:65 male:female ratio for C, T, and B, respectively. These results fall within the ratio recommended by Cruz-Espinoza *et al.* (2021). Animals are allowed to graze (100% in C, 90% in T, and 70% in B) and are fed commercial balanced feed (25% in B and 10% in T) as well as crop residues (in C). Similar results have been reported by Dzib-Can *et al.* (2006) in Campeche and by Góngora-Pérez *et al.* (2010) in Yucatán. The stocking rate (animal units per hectare: AU ha^{-1}), is low in the three groups (0.14, 0.18, and 0.25 for B, T, and C, respectively), indicating the importance of training producers to improve the production, use, and conservation of forages.

Parasites are the main health problem faced by the three types of producers (Table 3), similar to what happens in Yucatán (Candelaria-Martínez *et al.*, 2015) and Hidalgo (Pérez-Bautista *et al.*, 2021b). Farmers do not follow the recommended calendars and doses of the medications. Therefore, technical assistance and training must be provided regarding this aspect of production.

A recently established slaughterhouse (with the capacity to slaughter 10,000 sheep per year and export carcass meat) may promote sheep meat production. The activity of sheep producers benefited by the INPI of the CDI in Campeche is incipient. Therefore, government programs, including technical assistance and training strategies —which are key for the consolidation of support programs— are needed to promote sheep farming (Martínez-González *et al.*, 2011).

Table 3. Primary health issues (%) detected in sheep flocks from farms supported by the Instituto Nacional de Pueblos Indígenas in Campeche, Mexico.

Health problem	Producers		
	Conventional (C) (n=20)	**Transitional (T) (n=4)**	**Marketing (E) (n=3)**
Keratoconjunctivitis	14	0	0
Hoof Rot	0	20	50
Parasitosis	71	60	75
Respiratory	0	0	0
Contagious ecthyma	0	0	25
Digestive	0	20	0
Other	28	0	0

CONCLUSIONS

The sheep farms of the groups benefited by the INPI in Campeche are differentiated by the size of the flock, total annual sales, and total annual income. In the classification, three types of farmers were identified: Conventional, Transitional, and those in Business. The Conventional group includes most farmers, followed by Transitional and Business. The characteristics of the available infrastructure and general management of the flocks show that, provision of sheep to farmers was not accompanied by training and adequate infrastructure support and that the effects of technical assistance are not yet perceptible.

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Developing a Social Vulnerability Index (SVI) for Risk Mapping

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ABSTRACT

Objective: To develop a Social Vulnerability Index (SVI) for the El Saltillo community, in Jilotepec, State of Mexico, with risk mapping purposes.

Design/Methodology/Approach: A Social Vulnerability Index (SVI) was developed based on sociodemographic indicators, housing characteristics, and the conditions of the production systems. The information sources for the SVI indicators were obtained from official Basic Geostatistical Area (AGEB) censuses and from an online survey carried out in the community under study. The SVI was cross-referenced with data from four previously published natural hazard studies for risk mapping purposes.

Results: The methodological proposal uses equal weight index statistical techniques to develop the SVI. Using online surveys is a clearly viable option for research studies that require to obtain more detailed data on housing characteristics, as well as the population's perception of certain changes in precipitation and temperature patterns that are happening in their community and the measures, they take to face these natural phenomena.

Study Limitations/Implications: Online surveys are relatively recent, which implies the need to design and implement validation and sampling mechanisms for the results.

Findings/Conclusions: Risk mapping enabled the territorial visualization and identification of the communal vulnerability conditions, which facilitates a conceptual approach to the social reality of the population and will allow the formulation of potential future scenarios of climate change and the implementation of public policies.

Keywords: Online surveys, climate change, natural risks and hazards, social vulnerability.

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INTRODUCTION

The impact of natural risks and disasters is directly related to the social vulnerability of the affected populations. The risks and dangers that threaten society and its environment have been approached from different scientific disciplines, including geography —which establishes most of the theoretical and methodological background for the study of risks and dangers and likewise contributes to the understanding of risk perception and phenomena. Principi (2020) points out that the human science of geography has extensive capacity and experience in risk studies from different approaches. Spatial analysis enables predictions about the spatial distributions of the constituent aspects of risk, threat, and vulnerability. Consequently, moving towards an applied geography —through the modeling of future spatial configurations— can be very helpful for decision-making in spatial planning, territorial planning, and rural development.

Since its appearance on earth, humanity has suffered from the attacks of nature in different forms: from storms that devastate buildings and crops, to the impact of droughts on the population. However, the frequency and severity of disasters has recorded such

an alarming increase in the last 50 years that the United Nations (UN) counts more than 2,000,000 deaths from 1970 to 2019, basically as a consequence of phenomena such as torrential rains, cyclones, floods, droughts, and earthquakes (UN, 2021). The National Center for Disaster Prevention (CENAPRED, 2021) points out that the damage in Mexico has increased both in terms of people affected (deaths) and in its economic cost. In the 2000-2018 period, the annual cost of natural disasters is estimated at $2,357 million dollars —a much higher figure than the $455.3 million cost for the 1980-1999 period. In this same period (2000-2018), 86.7% of the damages and losses had a hydrometeorological origin and the greatest impacts were recorded in the most vulnerable and highly marginalized localities.

Although risks and dangers have long been the subject of many studies throughout the world, there is currently no consensus regarding the definitions of such aspects as danger, vulnerability, exposure, response capacity or resilience, prevention, mitigation, etc. As Principi (2020) mentions, all the different lines of analysis agree that danger and vulnerability cannot be separated from risk.

On the one hand, risk can be defined as the combination of the likelihood of an event and its negative consequences —*e.g.*, deaths, injuries, disruption of economic activities, or environmental deterioration—, resulting from the interactions between natural or anthropogenic threats and environmental vulnerability (Baas *et al.* 2009). On the other hand, the National Center for Disaster Prevention of Mexico (CENAPRED, 2021) defines danger as the probability of occurrence of disturbances of a certain magnitude in a certain period and in a given location. This definition implies that danger is the exposure of the population to the occurrence (threat) of an event that may affect them or alter their daily activities.

The exposure level and fragility of society (and its activities) in the face of natural phenomena is known as vulnerability. Several definitions and theoretical approaches on the subject have been proposed. For example, Carreño *et al.* (2014) mention that vulnerability is composed of three dimensions: physical exposure and susceptibility, the fragility of the socioeconomic system, and finally the lack of resilience that would enable society to cope and recover. Principi (2020) defines vulnerability as "the capacity that the population has to face the occurrence or probability of occurrence of some danger and the possibility of recovery, linked to the characteristics of the population from a certain place, which can be modified by improvements in the quality of life." Turner *et al.* (2003) mention that, within the context of the system formed by the human population and the environment, vulnerability encompasses exposure, sensitivity, and resilience.

Vulnerability varies within social groups depending on space and time (multidimensional variance). However, it also varies at the individual, community, regional, etc. levels (study scale) and varies over time (dynamic). Nevertheless, it is also a precondition that can manifest during an event and every scientific discipline has a different way to measure its intensity. Considering the previous aspects, vulnerability can be applied in different fields of studies, such as natural disasters, sustainability, climate change, urban growth, agriculture and water availability, etc. Each scientific field can interpret vulnerability in a different way and impose its method of analysis.

From the point of view of social sciences, Ramos-Ojeda (2019) mentions that "social vulnerability (SV) raises questions about the planning and management of resilience, in addition to social disintegration and social instability issues, as well as the consequent poverty production processes; vulnerability is not synonymous with poverty but rather the result of defencelessness, insecurity, and exposure to risks, crises and stress." Kaztman (2000) defines social vulnerability (SV) as the "inability of a person or a household to make the most of the opportunities available to different socioeconomic areas, to improve their well-being situation or prevent its deterioration. The SV has its most important sources in the precariousness and labor instability phenomena linked to the operation of the market and the lack of protection and insecurity linked to the withdrawal of the State and the weakening of primary institutions.

Thomas-Bohórquez (2012), Navarro *et al.* (2020) and other researchers have pointed out that, as a consequence of the multiple variables that define social vulnerability, a direct definition and an immediate measurement are almost impossible. This situation has led to the development of indicators that —without losing sight of the specificity of the element that is measured— allow combined assessments that show, to a greater extent, the complex behavior of the variables involved. Therefore, indicators or vulnerability indices must be generated from a multidisciplinary perspective.

Several methodologies attempt to measure some type of social vulnerability. The most common are the Human Development Index (HDI), the Human Poverty Index (HPI), and the Gender Development Index (GDI). The present study calculates the Social Vulnerability Index (SVI) as defined by Natenzon *et al.* (2005): "a quantitative, statistical evaluation that enables the preliminarily identification of administrative units in which different degrees of social vulnerability are distributed in the territory, through a given set of indicators chosen for this purpose."

With respect to the development of SVI, Álvarez-Ayuso *et al.* (2006), Silva-Burgos *et al.* (2009), Thomas-Bohórquez (2012), and Arteaga *et al.* (2012) designed SVI considering the social, environmental, and territorial aspects of various regions and displayed some of the results in thematic maps.

Study area

The El Saltillo community belongs to the municipality of Jilotepec, State of Mexico, approximately 90 km northwest of Mexico City. El Saltillo has an area of 1,384 hectares, divided into 17 geostatistical units (AGEB), locally known as *manzanas* (block). It has 227 houses or production units and 760 inhabitants (INEGI, 2020). The community is purely rural, rainfed corn is the main crop in the area, houses are scattered throughout the territory, and land ownership is communal (*ejidos*).

MATERIALS AND METHODS

Social Vulnerability Index

The SVI in El Saltillo was designed at the Basic Geostatistical Area (AGEB) level —the smallest geographic unit from which data from different population and housing censuses can be obtained in Mexico. Two sources of information were used: 1) the

General Census of Population and Housing (CGPV2020, INEGI), for the microdata modality, at the AGEB level; and 2) an online survey applied to the inhabitants of the study location. An online survey was designed, given the technical and economic impossibility of carrying out the survey on site. To inform and invite the community to participate in the survey, a first contact was made with the *ejido* authorities who, through various WhatsApp groups, extended the population an invitation to participate in the online survey, through a Google Forms document titled "Percepción y adaptabilidad al cambio climático en la comunidad El Saltillo" ("Perception and adaptability to climate change in the El Saltillo community"). The following control mechanisms were used for the surveys: only one person per family was allowed to participate and the address was written down, including the block to which it belongs, because each block is equivalent to the Basic Geostatistical Area (AGEB) of INEGI. As a result, 96 surveys were completed (42.2% of the production systems), distributed among the 17 blocks or AGEB that make up the community.

Because the SVI is an expression of an unequal and unfavorable situation in the geographical space occupied by the population, the selected variables were grouped according to population condition and housing condition (taken from the CGPV2020) and production systems conditions (taken from the online survey) (Table 1).

Table 1 describes the indicators that were measured to develop the SVI. The indicators of the conditions types of the production systems are the average of the results of the online survey by units located in the same block or AGEB. The crop type (A) indicator was established according to the number of crops planted at the same time on the plot: 3 (monoculture), 2 (two crops), and 1 (more than two crops). The education level (B) indicator refers to the education level of the person who answered the survey: 3 (No Education

Table 1. Indicators used to develop the Social Vulnerability Index (SVI).

Indicator	Indicator	Unit of measurement
Population conditions	Total population	Persons
	Population aged 65 and over	%
	Population aged 15 and under	%
	Illiterate population	%
	Population with disabilities to see	%
Housing conditions	Houses without electricity	%
	Houses without computer	%
	Houses without cell phone	%
	Houses without internet	%
Production systems conditions	Type of cros	Index (A)
	Agricultural yields	t/ha
	Variety of livestock	Shannon diversity index
	Level of education	Index (B)
	Climate change adaptability actions	Number of adaptability actions

Source: Table developed by the authors based on data from the 2020 General Population and Housing Census (INEGI) and the "Perception and adaptability to climate change in the El Saltillo community" online survey.

and Only Basic Education), 2 (Secondary Education and High School), and 1 (Graduate and Postgraduate). Livestock variety was measured using the Shannon-Wieber index. The diversification of livestock species represents a process of sustainability for the productive system. It is a survival strategy in the study area: livestock species are considered as an investment in case of an economic need, although they also contribute to the family economy as both live animals or carcasses, as well as milk, eggs, and other non-meat products. At a high value or close to 1, species diversity is greater and vulnerability is lower. The Number of Adaptability Actions to Climate Change refers to the total number of actions taken by the inhabitants to adapt to or mitigate the negative effects of phenomena such as droughts and frosts. According to the perception of the inhabitants of the area, the increase in the frequency and intensity of these phenomena in the last 10-15 years has forced them to take measures to reduce damage to livestock, crops, and their own families.

The statistical management of the data to generate the SVI consisted of the weighting of the variables —a technique used to correct imbalances in sample types after data collection. Nardo *et al.* (2005) point out that "the weighting of variables is key when different dimensions measured on different scales must be subjected to a significant combination, implying a decision about what weight will be used in the model and what procedure will be applied to add the information." Gómez-Limón *et al.* (2010) point out that the preferences of society should be taken into account when social issues (such as sustainability) are involved; assigning different importance to each dimension or indicator included in the composite indicator is required to determine the extent to which weights influence the results.

A weighting factor is the assignment of a specific weight to each variable, based on its importance within the set of variables; however, as is the case with the data of this study, the compensation method was used to designate an equal weight or weighting to all variables. Munda *et al.* (2005) point out that the compensation method calculates weights as scale constants, without an ambiguous interpretation, requiring no significant judgment.

Therefore, the following formula was used.

$$EW = \frac{X_1 * P_1 + X_2 * P_2 + X_3 * P_3 + ... + X_n * P_n}{100}$$

Where: EW=equal weighting; X=indicator value; P=weight assigned to the indicator (the value (14) matches the number of variables used to develop the SVI).

The Equal Weighting formula was used to develop the Social Vulnerability Index (SVI) for El Saltillo and each block or AGEB was assigned a value or index.

Risks and Dangers

In the study of the threats posed by natural events, the danger indicates the potential occurrence of a phenomenon and the risk becomes an inherent part of human life, since risk is the result of the appropriation and modification of the geographical space by humanity

(as a species). Authors such as Aneas de Castro (2000) mention that "risk mapping research has increasingly revealed that danger is an event capable of causing severe losses, but danger likewise implies the existence of humans, who assess what can and cannot damage them; therefore, humans are the protagonists of the definition of natural hazards: their location, actions, and perceptions determine whether a natural phenomenon is dangerous or not."

Studies about the risks and dangers that threaten society and the environment have been extensively studied and analyzed. Global institutions are in charge of studying risks, dangers, and threats from very different perspectives. In Mexico, institutions such as CENAPRED and private and public universities, as well as state and municipal institutions, have worked intensively to understand both the origin and consequences of natural phenomena, aiming to reduce the exposure or vulnerability of the population. The present study compares the results of some of those studies with its Social Vulnerability Index, showing the different types of social vulnerability that are recorded in a particular space, in the form of maps.

The risk and danger studies considered in the present study (Table 2) are related to the results of the online survey applied in the community: according to the participants, phenomena such as droughts and frosts affect agriculture, livestock, and the general population to a greater extent.

As shown in Table 2, the most severe natural risks and hazards in the study area (municipality) have been subjected to hydrometeorological studies; however, within the same municipality, the effects on the population are different at a system of production level, depending on the level of vulnerability. Therefore, it is important to develop an Index that allows the identification of the areas of a given community where a natural phenomenon can cause greater damage and the visualization of the spatial distribution of the risk.

RESULTS AND DISCUSSION

According to the results of the online survey applied to the study community, climatic risks are identified as common and dangerous, while Herrero *et al.* (2020) state that "the risk of impacts due to climate factors is the consequence of the interaction of climate hazards or threats with vulnerability, since both events must take place simultaneously for the risk to exist."

Table 2. Risk and hazard studies considered for risk mapping.

Study	Source	Value-index	Classification
Drought hazard risk	CENAPRED, 2012	0.23	Low
Cold weather risk level	CENAPRED, 2012	0.63	Mid
Municipal vulnerability to climate change	INECC	0.13	Low
Agricultural drought vulnerability level	Espinosa-Rodríguez et al. 2022	0.75	Very high

Source: Table developed by the authors based on data from different sources.

Therefore, risk would be defined by the following formula:

$$Risk = Danger \times Vulnerability$$

Where: *Risk* is displayed in maps that visualize the spatial differences in a community; *Danger* is represented by the values described in Table 2 and *Vulnerability* is the Social Vulnerability Index (Table 3). High values belong to more vulnerable blocks regarding the conditions of their population, housing, and/or production systems. Using the quantile statistical method, the SVI values were classified into High, Medium, and Low social vulnerability levels.

Figures 1, 2, 3 and 4 show the risk mapping, combining the information from hazard maps (various sources) with the Social Vulnerability Index (SVI) developed for the present study.

Figures 1, 2, 3 and 4 enable the spatial visualization of the levels of vulnerability that exist in the same community. This information is necessary for the planning of rural development policies, because these differences increase the accuracy with which the various needs within the same population are measured, regardless of their size. The largest blocks (blocks 4, 6, and 11) have the largest population and consequently high levels

Table 3. Social Vulnerability Index.

Block	Social vulnerability index (SVI)		Social vulnerability to drought	Social vulnerability to cold weather	Social vulnerability to climate change	Social vulnerability to agricultural drought
	Val	Class				
1	0.089	Low	Low	Low	Low	Low
2	0.11	Low	Low	Mid	Mid	Mid
3	0.139	Mid	Mid	Mid	Mid	Mid
4	0.183	High	High	High	High	High
5	0.132	Mid	Mid	Mid	Mid	Mid
6	0.195	High	High	High	High	High
7	0.172	High	High	High	High	High
8	0.136	Mid	Mid	Mid	Mid	Mid
9	0.058	Low	Low	Low	Low	Low
10	0.098	Low	Low	Mid	Low	Low
11	0.192	High	High	High	High	High
12	0.075	Low	Low	Low	Low	Low
13	0.14	Mid	Mid	High	Mid	Mid
14	0.148	Mid	Mid	High	Mid	High
15	0.149	High	High	High	Mid	High
16	0.015	Low	Low	Low	Low	Low
17	0.148	Mid	Mid	High	Mid	High

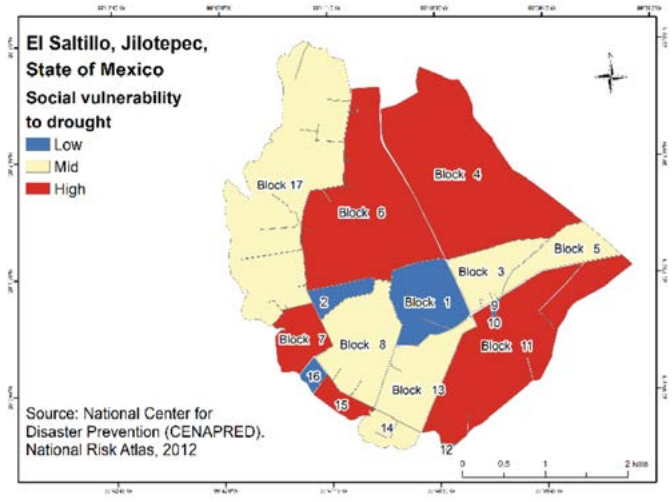

Figure 1. Level of social vulnerability to drought.

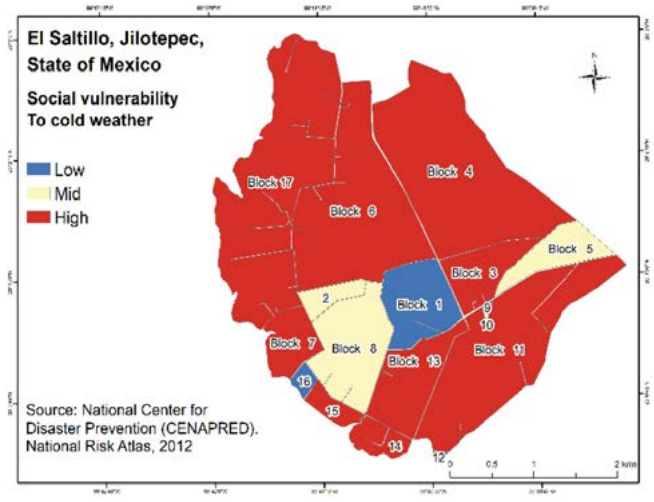

Figure 2. Level of social vulnerability to low temperatures.

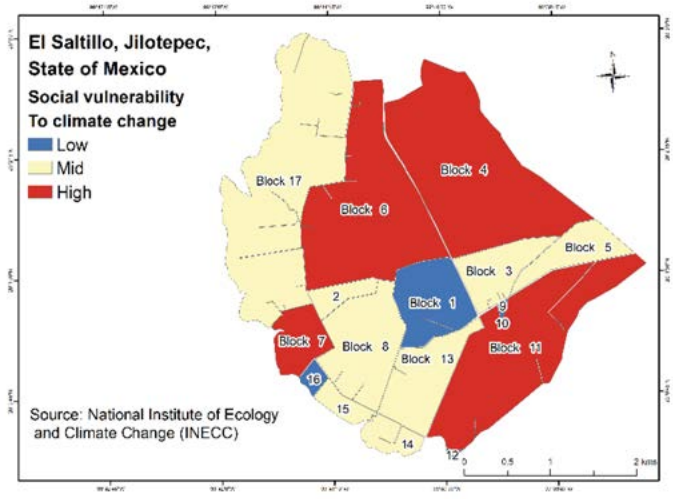

Figure 3. Level of social vulnerability to climate change.

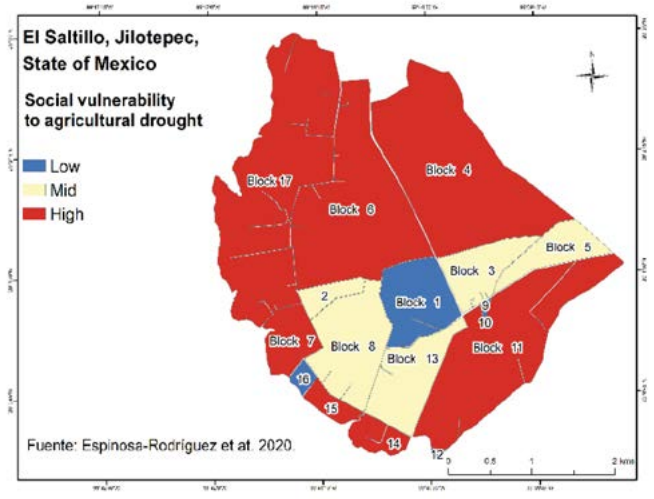

Figure 4. Level of social vulnerability to drought.

Source: Maps developed by the authors.

of vulnerability, both at the population level and in production systems. Block 1 has a low vulnerability because, as the administrative center of the community, it concentrates a greater number of services.

Regarding the population characteristics type indicators, Ruiz-Pérez *et al.* (2012) points out that "social vulnerability to natural disasters is highly dependent on various demographic factors; the characteristics of families and their homes will condition the fragility of the population in face of the effects of disasters, as well as their ability to cope with them." In this sense, outstanding aspects include a highly illiterate population (7-15%); only 3 blocks have 0% illiteracy, which is a challenge during a catastrophe. This limitation hinders resilience, as a result of its connection with the level of education of the

population: a population with a low educational level will hardly be well informed and will not be able to anticipate the danger or react to an emergency. Additionally, illiteracy also influences the sensitivity and levels of awareness against disasters. High values are also present among the older members of the population (65+ years old), as well as among the young population (<15 years old). These two parameters play a critical role in the ability to cope with a catastrophe and these two groups are considered highly vulnerable or not very resilient, due to their need for special food and/or medicine, mobility restrictions, and their dependence on other people.

In terms of housing characteristics, many houses lack electricity, home computers, and cell phones. However, the most acute problem is the lack of Internet access, which affects >50% of the houses. This is an indicator of the capacity of the population to be informed of the events that take place in the community or region; accurate and timely information can be a determining factor in the reduction of the negative effects of disasters. Cell phones and internet are indicators of the population's communication capacity: the greater the number of services, the lower the level of vulnerability.

Regarding the characteristics of the production systems —which were established through the online survey—, the existence of monocultures (basically native corn, grown under a rainfed system), coupled with the lack of implementation of agroecological practices, increases the overall vulnerability of the production system to phenomena such as drought or frost. Livestock variety is an aspect of the sustainability of the production system: high values indicate that this sector is essential for the local way of life. There is a high diversity of species of cattle, sheep, and poultry. Owning animals is an investment in case of an economic need, although some producers specialize in raising livestock to be marketed as carcass or live, as well in selling milk and other dairy products. Regarding the actions of adaptability to climate change, the population that answered the survey states that the intensity and frequency of phenomena such as droughts and frosts have increased in the last 10-15 years. Without describing them as effects of climate change, producers have been forced to implement some measures to address these changes, such as building of open ponds to store water for agricultural and livestock purposes, storing water for domestic use in cisterns or water tanks, improving stables with hermetic roofs and floors to avoid drastic temperature changes in the livestock, improving the construction conditions of the houses to make them warmer and cooler, and even increasing the efficient use of stored rainwater through the implementation of drip irrigation in the plots.

CONCLUSIONS

The information obtained from the Social Vulnerability Index (SVI) enable the research team to visualize the spatial distribution of the differential vulnerability levels in El Saltillo, despite the relatively small territory of this community. The identification of the areas with the largest vulnerable population shows that the conditions of the population exposed to risk are not homogeneous, since they have different qualities and abilities to face an extreme event.

The proposed methodology is based on the combination of different sources of information (2020 General Population and Housing Census, from INEGI, at the micro-

data level, and an online survey in the study community) and the application of a multi-criteria model to weight the variables involved in the design of a Social Vulnerability Index. Contrasted with values from natural risk studies (from different sources), the SVI allows the development of risk mapping to visualize the spatial differences of vulnerability.

The online survey application is an option for research works that require data about the characteristics of the homes, as well as the population's perception about some natural phenomena that are happening in their community. Therefore, the application of online surveys is a feasible and timely option which can be easily quantified, graphed, interpreted, and analyzed, although validation and sampling mechanisms must be implemented.

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Assessment and selection of flowering inducers to increase productivity of mango cv. Ataulfo (*Mangifera indica* L.)

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ABSTRACT

Objective: To assess new flowering inducers used to increase the fruit yield in mango cv. Ataulfo trees, to substitute paclobutrazol.

Design/methodology/approach: Ten-year-old mango cv. Ataulfo trees were used, homogeneous in terms of health. The treatments evaluated were prohexadione calcium, cytokinins, itaconic acid, phosphonitrate, potassium nitrate and paclobutrazol. The experimental design was completely random blocks with five repetitions; each experimental unit and repetition consisted of one tree. The number of inflorescences, percentage of flowering, number of fruits, fruit yield by hectare, and profitability of treatments were assessed. The data were analyzed through ANOVA and Tukey's means comparison ($p<0.05$).

Results: There were no significant effects of the treatments for number of inflorescences, percentage of flowering, and number of fruits; however, the homogeneous formation of inflorescences was found with itaconic acid. Prohexadione calcium (P-Ca) presented the highest fruit yield (19.32 t ha^{-1}), but it does not differ from paclobutrazol (10.34 t ha^{-1}). The highest profitability of the crop was obtained with prohexadione calcium, in which for each peso invested the amount of $1.51 was recovered.

Findings/conclusions: Prohexadione calcium can be an alternative for the use of paclobutrazol to induce flowering and increase the fruit yield of mango cv. Ataulfo in the Coast of Guerrero.

Keywords: itaconic acid, cytokinins, flowering promoters.

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INTRODUCTION

In Mexico, mango (*Mangifera indica* L.) is one of the most important fruit trees as a result of profits generated from the export of fruit to the United States. The state of Guerrero occupies the fourth place in surface planted with mango, with 26,917.50 hectares (ha) and a production of 395,477 tons (t) of fruit (SIAP, 2022). The municipalities with the greatest contribution to this production are Tecpan de Galeana, La Unión Isidoro Montes

de Oca, Cuajinicuilapa, Atoyac de Álvarez, Petatlán, Zihuatanejo de Azueta and Acapulco de Juárez. The Ataulfo cultivar occupies the second place in planted surface, after the Manila cultivar with 8,463 ha, which is preferred by producers due to the attractive color, flavor and aroma of the fruit.

One of the main problems affecting mango producers is the seasonality of the harvest which is between the months of March and July. This results in an excessive offer of the product and price reduction in the market, decreasing the sale prices and lowering the crop's profitability. This situation is given by agroecological limitations (high temperatures, drought, and rainfall outside of season, among others), as well as the inadequate management of the plantation (excessive use of agrochemicals and others), in the various producing regions of the state.

There are studies about flowering inducers in mango with positive results, such as potassium nitrate (Sandoval *et al.*, 2011), ammonium nitrate, paclobutrazol (Pérez *et al.*, 2011), alone or in combination with other inducers (Morales *et al.*, 2020). The use of paclobutrazol increased since it induces flowering even without inductive environmental conditions in the state of Nayarit (Pérez *et al.*, 2011).

Prohexadione calcium has promoted fruit flowering, mooring and production in temperate climate crops such as apple (Ramírez *et al.*, 2006), while in mango cv. Ataulfo, it has reduced the vegetative growth and increased flower budbreak under the edaphoclimatic conditions of Nayarit (Pérez-Barraza *et al.*, 2016). On the other hand, cytokinins have promoted greater flowering in fruit trees such as mango and Persian lime (Moreira *et al.*, 2002, Ambriz *et al.*, 2021). However, the inducers show different effects based on edaphoclimatic conditions, nutritional status of the tree, and others (Singh, 2013).

Because of this, the objective of this study was to assess and select new flowering inducers, which can substitute paclobutrazol to increase the productivity of the mango cv. Ataulfo crop in the coast of Guerrero.

MATERIALS AND METHODS

In 10-year-old mango cv. Ataulfo trees found in the locality of Coyuca de Benítez, Guerrero, the following products were assessed: prohexadione calcium (Apogee®), cytokinins (Citomax®), itaconic acid, phosphonitrate, potassium nitrate and the regional control used, paclobutrazol. The doses and dates of application are presented in Table 1.

Table 1. Products, doses, and dates of application.

Treatment	Dose	Application Method	Number of applications
Prohexadione Calcium	250 g L^{-1}	To the foliage	October 1, 16 and 31, 2019
Cytokinins	300 mL L^{-1}		
Itaconic acid	250 g L^{-1}		
Phosphonitrate	400 g L^{-1}		
Potassium nitrate	8 g L^{-1}		
Paclobutrazol	10 mL L^{-1}	Drained to the base of the stem	October 1 and 16, 2019

Pruning the buds was done in the month of September. The agronomic management consisted in applying fertilization, controlling fruit flies and trips, and managing the anthracnosis disease. The experimental design used was completely random with five repetitions. The experimental unit and repetition was constituted by one tree.

The variables evaluated were the following:

Number of inflorescences. Four branches located on each cardinal point were marked with red tape. A circular ring with one-meter diameter was placed on each of them, with which the number of inflorescences was quantified in six samples, from January to April.

Percentage of flowers. The percentage of flowers on each of the trees was estimated visually, and this was done in three sampling dates from February to the last week of March.

Number of fruits. In four cardinal points, the number of fruits with the size of a marble found within the one-meter diameter ring was quantified. This activity was carried out in four sampling dates, from the third week of February to the second week of April.

Fruit yield. Once the fruits reached physiological maturity, the harvest was carried out and they were weighed on a mechanical scale of 20 kg to obtain the yield per tree. The fruit yield per hectare was estimated with these values.

All the variables were transformed into square root, to fulfill the assumptions of normality. Later, they were analyzed through analysis of variance (ANOVA) and means comparison was done through Tukey's multiple range test ($p<0.05$). Likewise, the profitability for each treatment based on the treatment's total cost (TC), total income (TI), net income (NI) and profit per peso invested (PPI) were determined. To obtain the total income, the price of one kg of mango was multiplied by the production contained based on a hectare. The net income was calculated with the difference of the total income and the total cost. Finally, the profit per peso invested was determined by dividing the net income by the total cost.

RESULTS AND DISCUSSION

No significant differences were observed in the number of inflorescences of mango cv. Ataulfo in five sampling dates ($p>0.05$); however, itaconic acid promoted the highest number of inflorescences for the third sampling, compared to the absolute control (Table 2). In general terms, the highest numbers of inflorescences were present in trees treated with cytokinins and itaconic acid.

Regarding the percentage of flowering in mango cv. Ataulfo trees, there were no significant differences ($p>0.05$). In general, the trees treated with cytokinins and itaconic acid promoted more than 85% flowering, while with paclobutrazol it reached 60% (Table 3). In previous studies, cytokinins have promoted higher percentage of flowering in mango cv. Tommy Atkins trees and higher yield and fruit quality (Moreira *et al.*, 2002). Meanwhile, there are no reports about itaconic acid and its effects to induce flowering in the scientific literature, and therefore studies are required to determine the mechanism that takes place in order to promote flowering.

The treatments presented similar effects in the number of fruits per tree, except in the third sampling. However, the trees treated with cytokinins and itaconic acid presented the highest number of fruits (Table 4).

Table 2. Number of inflorescences of mango cv. Ataulfo in function of seven inducers.

Treatment	Sampling dates						Total
	January 24, 2020	February 8, 2020	February 22, 2020	March 7, 2020	March 25, 2020	April 14, 2020	
Prohexadione Calcium	2.20 a[x]	01.60 a	01.40 ab	11.00 a	16.00 a	1.60 a	33.8
Cytokinins	0.60 a	03.80 a	12.20 ab	59.80 a	11.20 a	0.00 a	87.6
Itaconic acid	0.80 a	03.60 a	19.20 a	50.20 a	0.00 a	0.00 a	73.6
Phosphonitrate	0.00 a	00.20 a	04.00 ab	20.20 a	0.00 a	0.00 a	24.4
Potassium nitrate	4.60 a	01.00 a	01.40 ab	12.80 a	7.00 a	0.00 a	26.8
Paclobutrazol	0.00 a	01.60 a	14.40 ab	36.60 a	1.40 a	0.00 a	54.0
Control	0.00 a	00.00 a	00.00 b	10.40 a	0.20 a	0.00 a	10.6

[x]. Means with the same letter are statistically equal.

Table 3. Percentage of flowering in mango cv. Atulfo trees with inducers.

Treatment	Sampling dates			Total
	February 22, 2020	March 7, 2020	March 25, 2020	
Prohexadione Calcium	12.00 a[x]	19.40 a	17.200 a	48.6
Cytokinins	27.00 a	59.20 a	8.000 a	94.2
Itaconic acid	17.60 a	67.40 a	0.600 a	85.6
Phosphonitrate	9.00 a	41.00 a	0.600 a	50.6
Potassium nitrate	9.20 a	13.00 a	13.800 a	36.0
Paclobutrazol	19.40 a	39.00 a	1.600 a	60.0
Control	2.00 a	21.00 a	1.000 a	24.0

[x]. Means with the same letter are statistically equal.

Table 4. Number of fruits on trees treated with flowering promoters.

Treatment	Sampling dates				Total
	February 22, 2020	March 7, 2020	March 25, 2020	April 14, 2020	
Prohexadione Calcium	4.80 a[x]	6.80 a	22.80 b	3.00 a	37.4
Cytokinins	0.00 a	25.60 a	78.20 ab	11.20 a	115.0
Itaconic acid	0.00 a	7.80 a	138.60 a	4.40 a	150.8
Phosphonitrate	0.00 a	4.40 a	47.60 ab	5.40 a	57.4
Potassium nitrate	7.60 a	0.00 a	43.20 ab	9.20 a	60.0
Paclobutrazol	0.00 a	2.00 a	85.00 ab	10.20 a	97.2
Control	0.00 a	0.00 a	32.80 ab	3.40 a	36.2

[x]. Means with the same letter are statistically equal.

A significant difference was found in the fruit yield of mango cv. Ataulfo trees treated with flowering inducers ($p<0.05$). The highest fruit yield was obtained with P-Ca, which was greater only than the absolute control (Table 5). In this regard, Pérez-Barraza *et al.* (2016) conclude that Prohexadione calcium reduces vegetative growth, increases and

Table 5. Fruit yield from mango trees treated with seven flowering promoters.

Treatment	kg/tree	t ha^{-1}
Prohexadione Calcium	193.24 a[x]	19.32 a
Cytokinins	123.60 ab	12.36 ab
Itaconic acid	106.24 ab	10.62 ab
Phosphonitrate	106.62 ab	10.66 ab
Potassium nitrate	93.34 ab	9.33 ab
Paclobutrazol	103.44 ab	10.34 ab
Control	47.16 b	4.16 b

[x]. Means with the same letter are statistically equal.

advances flowering and fruit production of mango cv. Ataulfo under the edaphoclimatic conditions in Nayarit. Therefore, P-Ca can be an alternative to paclobutrazol to induce flowering in the mango cv. Ataulfo crop under the edaphoclimatic conditions of the coast of Guerrero.

Regarding the profitability of treatments, it was observed that Prohexadione Ca (P-Ca) presents better results, since it has a production cost of $12,314.00 and a total income of $30,918.00 with a profit per peso invested of $1.51. Meanwhile, the other inducers have a similar profitability range, since their profit per peso invested ranges from $0.21 to $0.47 (Table 6).

Table 6. Profitability of the use of flowering inducers in the cultivation of mango cv. Ataulfo.

Treatment	CT	IT	IN	GPI
Prohexadione Calcium	12,314	30,918	18,604	1.51
Cytokinins	15,266	19,776	4,510	0.29
Itaconic acid	11,501	16,998	5497	0.47
Phosphonitrate	12,005	17,059	5,054	0.42
Potassium nitrate	12,270	14,950	2,680	0.21
Paclobutrazol	13,570	16,550	2,980	0.21
Control	8,575	7,532	−1042	−121.5

TC=Total cost, TI=Total income, NI=Net income, and PPI=Profit per peso invested.

CONCLUSIONS

Itaconic acid and cytokinins promote more than 85% of flowering in mango cv. Ataulfo trees in the edaphoclimatic conditions of the coast of Guerrero. However, new studies are required that allow a greater fruit mooring, yield, and crop profitability. Prohehadione calcium presented the highest fruit yield (19.32 t ha^{-1}) and crop profitability. Therefore, this product can be an alternative to the use of paclobutrazol in order to induce flowering and increase the mango cv. Ataulfo fruit yield in the coast of Guerrero. The suggestion is to conduct more assays with itaconic acid and cytokinins to define times of application and specific doses to induce flowering in all the mango varieties.

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Colegio de Postgraduados

Analysis of consumption preference of goat products in different regions of Mexico

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ABSTRACT

Objective: To characterize and determine the consumption preferences for goat products in different regions of Mexico.

Design/methodology/approach: An exploratory study was carried out through a survey addressed to 300 consumers. The sample was obtained through convenience sampling. The semi-structured questionnaire was divided into the following sections: sociodemographic information, willingness to consume, type of derivative products known, and frequency of consumption. The Kruskal-Wallis test was applied to determine significant variables.

Results: It was found that milk, cheese, and meat are the most relevant foods for goat consumption. These products are ideal for expanding the diversification of consumption in Mexican regions.

Limitations on study/implications: To deepen the analysis of the sociodemographic and consumption characteristics, it is necessary to consider a greater number of variables.

Findings/conclusions: Knowing the products that are consumed most frequently allows more effective and efficient strategies to be generated and, in turn, opens the pattern for consumption diversification.

Keywords: Goats, diversification, consumer preferences.

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INTRODUCTION

In Mexico, the efforts to improve productive and management aspects in goat production systems are limited (Tajonar *et al.*, 2022). This activity takes place more frequently in rural zones with high marginalization (Parrilla *et al.*, 2022), and its greatest influence is seen in arid and semi-arid zones, particularly under extensive production systems (*Servicio de Información Agroalimentaria y Pesquera* [SIAP], 2020).

These production systems are characterized by a low productivity and scarcity of natural resources (Salinas-González *et al.*, 2016). However, it is an activity of utmost importance for the low-income population, since it benefits around 1.5 million people (Ramos-Martínez *et al.*, 2020).

Another important aspect of these production systems lies in that they generate standing, meat and dairy livestock, which can be used for auto-consumption or for dietary diversification through products such as cheese and sweets (*Secretaría de Agricultura y Desarrollo Rural* [SADER], 2019).

However, there is a problem in that there is no specific information available about the inclusion of goat products in the diet of the Mexican population (Estévez-Moreno and Miranda-de la Lama, 2022). This makes the development of strategies to improve the production and management of productive systems difficult.

Likewise, according to Anzaldo-Montoya (2020), goat production is distant from social research, which is unpromising due to the role it has as an economic activity for marginalized families and with few alternatives, which is why permanence in the long term is uncertain (Barrera *et al.*, 2018).

Some strategies to improve this situation include the generation of byproducts or meat and milk derivatives, as well as promoting and raising awareness about the functional benefits of goat products (Ruiz *et al.*, 2019). Therefore, it is necessary to promote, diversify and recognize goat products (Castel *et al.*, 2010; Ruiz *et al.*, 2019), which will help to optimize the profitability of the production and at the same time, generate flows in the short and long term. The objective of this study was to characterize and to determine the consumption preferences of goat products in the different regions of Mexico.

MATERIALS AND METHODS

An exploratory study was conducted in the four main geographic regions of Mexico.

According to the National Institute of Statistics and Geography (*Instituto Nacional de Estadística y Geografía*, INEGI) (2023), they are distributed in the following way: 1) Central Region (Mexico City, Guerrero, Hidalgo, Estado de México, Morelos, Puebla, Tlaxcala and Oaxaca); 2) Central-West Region (Aguascalientes, Colima, Guanajuato, Jalisco, Michoacán de Ocampo, Nayarit, Querétaro, San Luis Potosí and Zacatecas); 3) North Region (Baja California, Baja California Sur, Chihuahua, Coahuila, Durango, Nuevo León, Sinaloa, Sonora and Tamaulipas); and 4) Southeast Region (Campeche, Chiapas, Quintana Roo, Tabasco, Veracruz de Ignacio de la Llave and Yucatán).

Data gathering and participants

In 2020, a digital survey based on Google forms was generated, designed and developed as an evaluation instrument. The survey was available online from May to July of that year (2020), and the link was distributed through social networks.

The data gathered were anonymous and personal identification information was not used. The participation was voluntary and the survey respondents had the opportunity to abandon the survey at any time. In addition, the analysis only included people over 18 years old.

For the sample size, a non-probabilistic technique called convenience sampling was used. It is based on the selection of those cases that are available and willing to participate, and also in the ease of access and the proximity of the subjects to the researcher (Otzen and Manterola, 2017). Therefore, the number of survey respondents was 300 people, from different regions in Mexico.

Development of questionnaires

The questionnaire had 12 multiple choice questions and it was divided into the following sections: (1) sociodemographic information (geographic region of residence, age, sex and willingness to pay for goat products); (2) willingness to consume; (3) type of derived products that are known and frequency of consumption.

Before implementing the final questionnaire, 10 pilot surveys were carried out to evaluate the clarity of the questions, the accuracy of the response options, and the general flow of the survey.

Statistical and data analysis

The data gathered were grouped to form categories and a contingency table was prepared that determined the different associations between the variables studied. The categorical and ordinal data were presented as percentages. The statistical analysis was conducted through the statistical package SPSS (2023), Statistics version 29.0.0.0 (241), and Excel (2023) version 16.69.1 (23011600). The Kruskal-Wallis test ($p \leq 0.05$), a non-parametric statistical test, was used to determine if there were differences between the means or the medians of the variables (López, 2013).

RESULTS AND DISCUSSION

Sociodemographic and consumption characteristics

The sociodemographic and consumption characteristics obtained from the surveys carried out are presented in Table 1. Most of the survey respondents belonged to the north region (59%).

The study found that goat production and consumption have greater presence in this region because it is an animal that has adapted adequately to the adverse conditions of the zone, and in addition, it is a species that is rooted in the population's culture (Andrade-Montemayor, 2017; Zapata-Campos and Mellado-Bosque, 2021; Torres-Hernández *et al.*, 2022).

Most of the participants were men, with the exception of the central-west region where there was a percentage of male participation of 31.8%.

The age of the survey respondents is predominantly 20 to 29, and 30 to 39 years old, which indicates that the consumption preferences towards products derived from goats happens especially in middle-aged people.

Most of the survey respondents consume this type of products and a high willingness to consume was found, since the percentage of those that were "highly willing" or "moderately willing" to consume them was higher than 60%.

Table 1. Sociodemographic and consumption characteristics evaluated by region.

	Participants			
	Center	**Central west**	**North**	**Southeast**
Variable (%)	25.0	7.3	59.0	8.7
Gender				
Man	50.7	31.8	59.3	76.9
Women	49.3	68.2	40.7	23.1
Age				
20-29	40.0	36.4	33.9	26.9
30-39	45.3	50.0	32.8	38.5
40-49	8.0	9.1	14.7	19.2
50-59	4.0	4.5	14.1	3.8
More than 60	2.7	0.0	4.5	11.5
Consumption of goat products				
Yes	69.3	63.6	65.0	73.1
No	30.7	36.4	35.0	26.9
Willingness to consume goat products				
Highly willing to consume	48.0	45.5	41.2	42.3
Medium	26.7	31.8	27.7	26.9
Indiferent	21.3	13.6	21.5	23.1
Low willingness to consume	2.7	4.5	5.6	7.7
Unwilling to consume	1.3	4.5	4.0	0.0
Price that consumers would pay for the purchase of goat products (Mexican pesos)				
$50-100	52.0	45.5	49.7	42.3
$101-200	36.0	36.4	36.7	50.0
$201-300	9.3	13.6	10.7	7.7
More than $301	2.7	4.5	2.8	0.0

The willingness to consume is justified based on the variability of products and byproducts from goat (SADER, 2019); also, from the versatility in the diets of Mexicans (Estévez-Moreno and Miranda-de la Lama, 2022).

The price that the survey respondents are willing to pay ranged between low values, with the strata of $50-100 and $101-200. This indicates that consumers are sensitive to the price, so there is not a high willingness to pay.

The geographic region influenced the variables presented. However, the sex of the survey respondent showed important significant differences. In this regard, the west region showed a higher participation of women (68.2%), which was reflected in a greater willingness to consume products derived from goat, with "highly willing" and "moderately willing" strata, which together represented a willingness to consume of 77.3%. Likewise, the price that would be paid for the acquisition of products was higher in the last two strata ($201-300 and more than $301).

Therefore, a Kruskal-Wallis test was conducted with the group variable "gender of the survey respondent" and it can be stated that the significant variables are given by age,

region and willingness to consume (Table 2). Understanding the socioeconomic variables allows generating schematic designs based on stratification (Ramos-Martínez *et al.*, 2020). Types of products consumed and frequency of consumption

Results from Figure 1 show that the goat products are present in the consumption of the survey respondents. These include cheese, meat, milk, ice-cream and soft toffee. Cheese was the product with highest presence, followed by meat and milk, indicating that Mexican people have a broad variety of goat products to satisfy their tastes and dietary needs. Some studies suggest that goat meat, milk and cheese have characteristics that make them potentially accepted and marketable foods (Aréchiga *et al.*, 2008). In the same way, they are a viable option in the high-quality food market (Tajonar *et al.*, 2022).

To evaluate the impact of the willingness to consume, a Kruskal-Wallis test was conducted (Table 3).

The results showed that the willingness to consume had a significant impact on all the foods registered, which suggests that consumers have a preference for certain products and that this willingness is a factor of great relevance to understand the behavior of survey respondents and their relationship with them.

Figure 2 shows the frequency of consumption there is in food products that were statistically significant, obtaining six different strata.

Table 2. Kruskal-Wallis test statistics with the grouping variable "Gender of the respondent".

	Age	Region	Willingness to consume
Kruskal-Wallis H	14.589	7.05	9.325
Asymp. Sig	<0.001	0.007	0.002

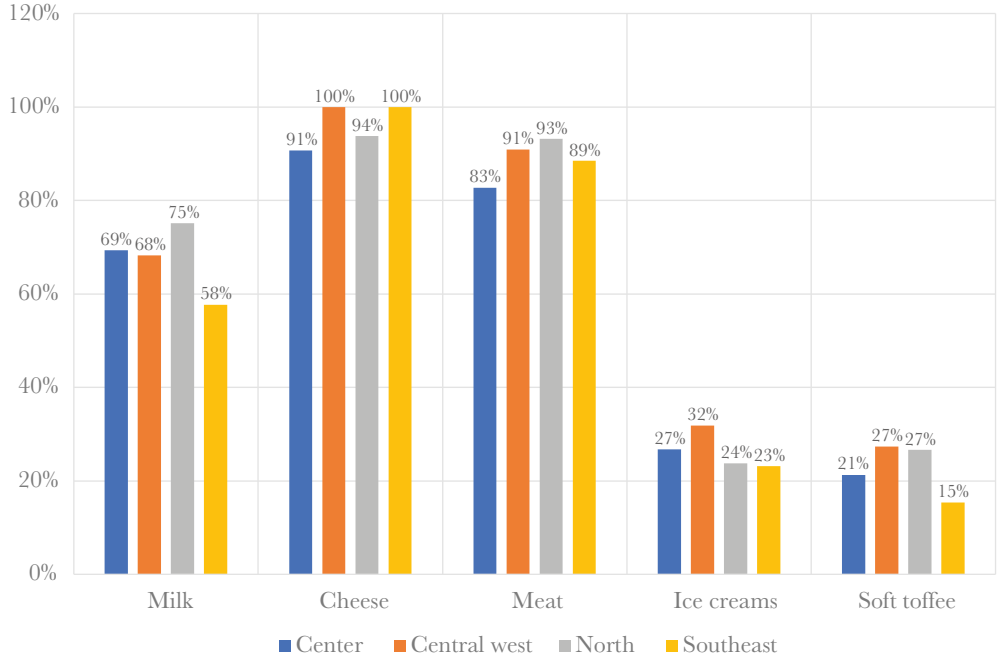

Figure 1. Goat products consumed by region and frequency of consumption.

Table 3. Kruskal-Wallis test statistics with the grouping variable "Willingness to consume".

	Cheese	Meat	Ice creams	Soft toffee	Milk
Kruskal-Wallis H	40.187	49.701	42.269	45.818	37.977
Asymp. Sig	<.001	<.001	<.001	<.001	<.001

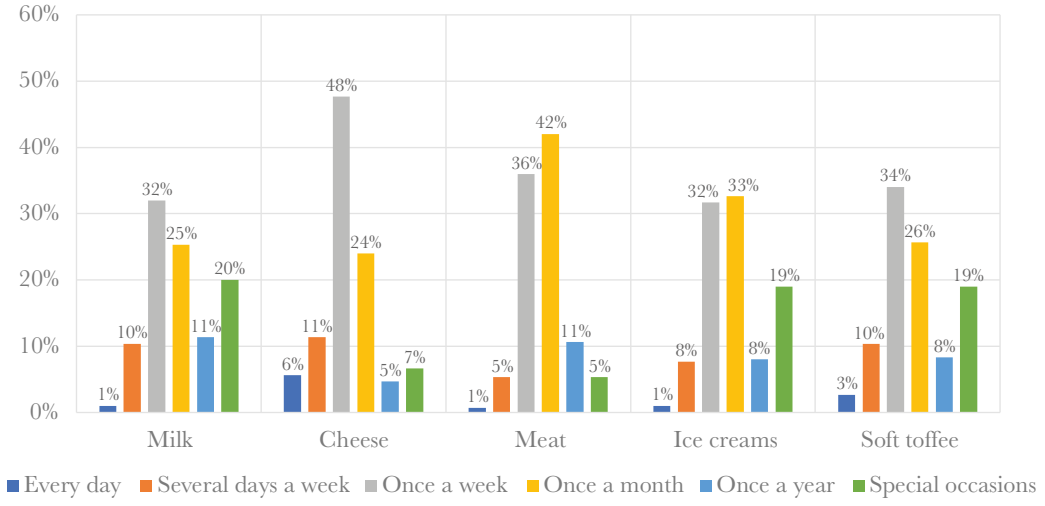

Figure 2. Frequency of consumption of goat products.

The frequency of consumption stratified into "every day", "many days per week", "once per week", and "once per month", together represent a percentage that can be considered as a strategic factor in the consumption of these products, which agrees with the results obtained from Figure 1; the ones of most importance are again cheese (84%), meat (84%), and milk (68%).

Taking into account these results, it is important to optimize the commercialization channels. Aréchiga *et al.* (2008) show that it is crucial to explore plans that increase added value, in order to improve the consumption and the production of goat livestock and their byproducts.

The goat products found, as well as the frequency of consumption, are ideal to amplify the diversification of consumption in Mexican regions. According to Miller and Lu (2019), production and consumption can be increased through management, cooperation, organization and access to markets.

Although some authors point to goat production being at a standstill, it is also considered that it has the potential of becoming an activity of high productivity and profitability, even under unfavorable conditions (Aréchiga *et al.*, 2008; Barrera *et al.*, 2018; Palomares *et al.*, 2021). In this sense, it is necessary to have effective strategies for the attainment of different objectives that lead to this purpose (Castel *et al.*, 2010; Ruiz *et al.*, 2019).

CONCLUSIONS

It was found that goat products are known and consumed in the different regions of Mexico. Cheese, milk and meat were the most important foods in the study, which points to these being ideal to increase the diversification of consumption.

On the other hand, to promote the growth of the goat industry and to contribute to the economic development through this type of products, it is essential to analyze the sociodemographic and consumption characteristics of potential clients, to determine which variables are significant, and what is their degree of influence. With this, more efficient marketing strategies could be developed.

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Economic valuation of a gallery landscape of ahuehuetes in Ciudad Mendoza Veracruz, using the AMUVAM method

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ABSTRACT

Objective: to determine the value, in monetary terms, of the landscape "Bosque de Galería de Ahuehuetes, in Mendoza, Veracruz", in order to have a reference for the purposes of planning and management of this environmental asset by the municipality.

Design/Methodology/Approach: the Analytic Multicriteria Valuation Method (AMUVAM) was used. A survey was made of 10 experts in the study area on the elements of the total economic value (VET) of the asset and the results were weighted to determine the importance of the components of the VET. The rent was determined based on the availability of the population to pay for the aesthetic enjoyment of the visit to the site; income updated by means of a Social Discout Rate (SDR) to environmental projects with a time horizon of more than 30 years.

Results: an estimation of 23,603,041.37 USD was obtained as monetary value. It was the result of the valuation of the landscape of this gallery forest in November 2022.

Study limitations/Implications: results were considered adequate. The main limitations of this type of studies are the time and economic resources needed in order to add other elements that could be considered beyond aesthetic enjoyment. Specific elements would allow to find an even more robust direct use value.

Findings/Conclusions: it can be noticed that the application of the method was adequate to determine the monetary value of this asset. Based on the determination of the willingness of people to pay for access to the aesthetic enjoyment of the analyzed landscape.

Keywords: valuation, environmental assets, landscape, total economic value.

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INTRODUCTION

The bridge between economics and environmental sciences allows generating tools for the preservation of the environment and under the premise that valuation is the first step to achieve this (Ayala and Moysén, 2016). Environmental assets (ecosystems) produce

Image by Carlos Aguilar at Pixabay

a number of Environmental or Ecosystem Services (ES), which are relevant to society. Currently, the situation of these assets and the services they provide is compromising due to the degradation caused by human activity. Environmental valuation becomes relevant as an effort to determine the value of ecosystems in relation to all the services they provide, not only those related to their direct use (Aznar and Estruch, 2015).

This type of valuation makes it possible to recognize in monetary units the value of environmental goods and services that often do not have a market that allows the application of a comparative methodology. Consequently, society assumes them as infinite, and therefore their valuation is sometimes non-existent or indefinite. Environmental valuation also helps to understand the consequences of the lack or alteration of a good, through the establishment of parameters of similarity between the ecological and the economic, although without considering the value as a sale price. The ultimate goal is to provide information for decision-making in understandable language (Ayala and Moysén, 2016).

From the point of view of Environmental Economics (Klink and Escolano, 1994), the resulting value of an ecosystem or environmental value is structured based on the several components of what has been called the Total Economic Value (TEV) (Figure 1) (Costanza *et al.*, 2017). TEV can be expressed as follows:

$$TEV = UV + NUV = DUV + IUV + OV + LV + EV$$

where: TEV = total economic value; UV = use value; NUV = non-use value; DUV = direct use value; IUV = indirect use value; OV = option (or quasi-option) value; LV = legacy value; EV = existence value.

It follows that in the TEV there are components for which there is a market value, as well as others that do not (non-market values) (Bonner, 2022). In this sense, the comprehensive valuation of environmental goods requires this determination of "non" market values. Due to several characteristics of ecosystems and those services they provide to society cannot be exchanged in any existing market. In the determination of non-market values, the use of various valuation methods is proposed. The valuation of environmental goods can be grouped into four sets: 1) those that use market prices; 2) those that use expenditures as

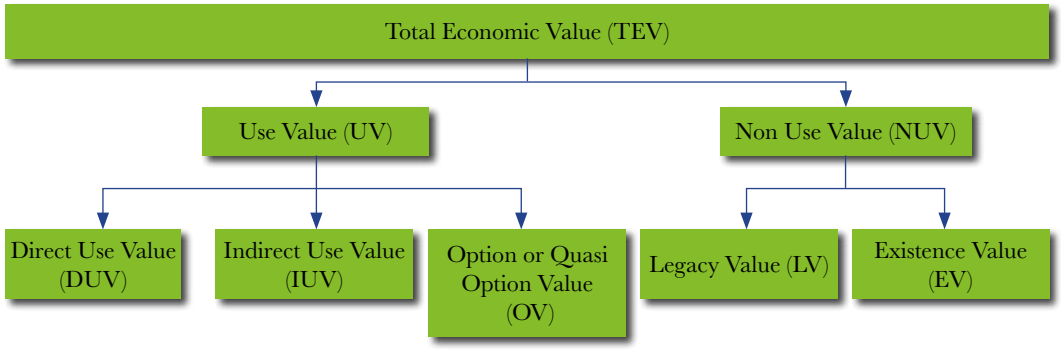

Figure 1. Components of the Total economic value (TEV).

an approximation of benefits; 3) those that use revealed preferences; and 4) those that use declared preferences (Eaton, 2017).

Aznar and Estruch (2015) proposed the use of multi-criteria valuation techniques; in particular, the technique called AMUVAM (Analytic Multicriteria Valuation Method) which is composed of the application of the hierarchical analytical process (AHP) and the application of the income update. This method allows, with the determination of criteria, alternatives, and the participation of experts, the weighting of the various components of TEV to generate a value in which all these components are represented, with their weighted contribution in the final value determined. To propose the valuation of a landscape, we cite the definition provided by the Council of Europe, which indicates that landscape "means any part of the territory as perceived by the population, the character of which is the result of the action and interaction of natural and human factors" (Consejo de Europa, 2000).

The space (territory) analyzed in this exercise can be perceived at least from sight, hearing, touch, and smell, so it constitutes a landscape according to that definition. Which is why this exercise is taken as the valuation of the gallery forest, through the perception of some ecosystem services that it provides which are components of the TEV. The general objective of this study was to determine the value, in monetary terms, of the landscape of the ecosystem called "Bosque de Galería de Ahuehuetes, in Mendoza, Veracruz", in order to have a reference for the purposes of planning and management of the natural good by the municipality. The specific objective was to apply the AMUVAM method as a broad framework for considering the variables related to the determination of the value of this ecosystem, based on the weighted contribution of each of the components of the TEV.

MATERIALS AND METHODS

This study is a case of application research. The study site was located in the so-called "Bosque de Galería de Ahuehuetes (a *Taxodium mucronatum* gallery forest landscape)", in Camerino Z. Mendoza, Veracruz, Mexico. It is an extent of the Blanco River of about 20 km long, and within there is the most visited section for scenic beauty and the physical possibility of access that it offers, which extends approximately over 5 km. Its main attraction is to see the Ahuehuete trees (*Taxodium mucronatum*), 30 to 40 m height and up to 4 m of diameter chest height (DCH).

To valuate this area, the multi-criteria assessment method called AMUVAM was applied (Aznar and Estruch, 2015). This procedure makes it possible to determine the weights and influence of the options and criteria that are established to arrive at a valuation of an asset, in this case, an environmental one. It is an alternative to other methods of valuation of environmental assets and liabilities that deliver a partial value of a broad spectrum of value that an environmental asset or ecosystem have. As mentioned before, AMUVAM is a method composed of the Hierarquical Analytical Process and the Income Update method.

Through the participation of a group of experts in (people who knows well) the area to be assessed, the technique makes it possible to determine the weight that each criterion

or component of the TEV has in its determination. Through a matrix process, where the weights determined by the experts are established by obtaining an Eigenvector for each evaluator. Then, with the aggregation of these vectors and their normalization, the participation of each of the component aspects in the final result of the TEV is weighed.

On the other hand, a process of updating the income values offered by the environmental good is applied, especially those of direct use value which, as already mentioned, are those for which there is a market. Therefore, those allow to obtain the price of what the environmental good produces; they can also be applied to those of indirect use, or even to other components of TEV. With this cost determination, after we calculated the weighting of each of the TEV components and considering this determined cost as a "pivot", the cost of each factor is determined. Finally, by summing them up, the value of the good in the present time is obtained.

For this reason, it is necessary to determine the update rate to be used, which in this case was the environmental rate or social discount rate (SDR). For this study, the use of a rate of 2.81%, calculated for Mexico by Aznar and Estruch (2015) in 2010, is proposed. It is worth mentioning that the Government of Mexico proposes in general, 12% for investment projects (SHCP, 2012), that is, almost 10% more than what Aznar and Estruch propose. According to several authors, this wide difference occurs because rates decrease as the time horizons of the analyzed projects increase (Castillo and Zhangallimbay, 2021; DGPI-MEF, 2011). The aforementioned authors support the need to visualize a decreasing rate in regard to time for environmental projects. As this project is considered to have a temporality of more than 30 years, the aforementioned rate of 2.81% was used.

For the case studied, it is proposed to determine the enjoyment of the landscape as a Direct Use Value (DUV) and the Willingness to Pay for access to it through Contingent Valuation (Penna and Cristeche, 2008; Sajurjo, 2001). This type of valuation attempts to construct a hypothetical market for a good that is not traded on the common market. This market is established through surveys applied to the population that uses the good, and tries to determine the willingness to pay for its use, or in other cases, to receive compensation for the loss of the good. In the first case, it is the maximum amount to be paid for it, and in the second, the minimum amount of money that would be accepted as its substitute.

Once the exercise is applied, the resulting average value is multiplied by the estimated population using the good, so that the total value of that use can be inferred. This value (rent) when obtained it becomes the pivot value, to which an updating rate is also applied and with the weighting of the TEV components, the resulting value of the asset is attained.

Here are the aspects that describe the general procedure in this application:

a. Establishment of the decision objective and description of the TEV elements.
b. Prioritization of the TEV components based on the importance and weight of each of the values, as well as the components of the use and non-use values.
c. Weighting of criteria and alternatives. At this stage, comparisons are made among all the TEV components. The scale proposed by Saaty (1980) is used, which rates

the importance of one aspect over another. This assessment or weighting is based on a survey applied to a selected group of actors or decision-makers who know the asset and understand the importance of one value or element over another (AHP).

d. Construction of paired matrices that determine the weights of each TEV component. This is done for each expert. The geometric mean of the weights that each person made for each component is obtained. The values are then normalized by the sum.
e. Application of contingent valuation and determination of DUV. This was developed through the application of a survey to a sample of the population that uses or is related to the good. It was estimated that 40 people would visit per day in the site visited directly (5 km); which generates a total of 14 400 annual visitors. Based on this data, and for the purposes of determining the sample size, with a margin of error of 8% and a confidence level of 95%, the number of 149 respondents was reached for this determination. The final interviewees were 177 people to determine their willingness to pay for access to this environmental asset, for the purpose of enjoying the landscape. The sample size was determined using the following formula:

$$N = \frac{\frac{Z^2 * p(1-p)}{e^2}}{1 + \left(\frac{Z^2 * p(1-p)}{e^2 N}\right)}$$

where, N = sample size; e = margin of error; p = probability of error; Z = z-score

f. Data analysis. They were performed with the Statistical Analysis System (SAS). Frequency tables were used with response ranges regarding the willingness to pay for access per person each time the site is visited.
g. Determination of the total number of users of the good (20 km). The frequency of visits observed in the field was considered. In this sense, an influx of 40 people per day was estimated in the section visited directly (5 km). This generates a total of 14 400 visitors per year for this section. For the rest of the property, this is 15 km, half of the influx (20 visitors per day) was considered for each 5 km section. So, the grand total of estimated visitors resulted in 36 000 per year.
h. Update of the DUV (rent), a rate of 2.81% was considered, suggested by Aznar and Estruch (2015) and applied to cash flow (rent); in this case it was the value of the willingness to pay (on the part of the total estimated visitors) for the enjoyment of the area.
i. Determination of which of the components becomes the pivot element. From this, the contribution of each TEV component, and its total result are determined.
j. Weighting of the TEV components and determination of the value of the good in monetary units; in this case, Mexican pesos.

RESULTS AND DISCUSSION

Description of the components of the TEV, for this landscape

Direct Use Value (**DUV**). In this case, aspects of direct use value are not clearly identified, since there is no obvious market for materials such as wood or fruit harvesting, for example. It is a gallery forest that occurs on the banks of the Rio Blanco; this is, a curtain of trees on each side of the riverbank, along an extent of about 20 km. Direct use was considered as the enjoyment of the landscape.

Indirect Use Value (**IUV**). Nitrogen fixation, rainwater harvesting, soil stabilization, natural barrier to the growth of urban development in the area.

Option Value (**OV**). It is an environmental and cultural resource. The species *Taxodium mucronatum* ("Ahuehuete") is a living monument, due to the long time it takes to grow. At the study site, there are specimens of considerable size. It is hypothesized that many people would prefer its conservation for these and other reasons.

Legacy Value (**LV**). Given the described characteristics of the OV, in this case, it is also considered important to conserve this resource for the next generations. So that they have reference to the specimens that were established long before and that bear witness to the passing of the history of the region.

Existence value (**EV**). This ecosystem has a long list of animal and plant species that survive despite the impact of the urban development of the municipalities it crosses. It is also an edge that contains to an important extent the increase of the urban sprawl, so it is important to guarantee its existence in the future.

The group of experts assembled to carry out the paired matrices was composed of four researchers in environmental and agricultural sciences, two members of civil society, two regular visitors to the site and two environmental managers.

It is important to clarify that, in the application of the paired matrices to the 10 experts and verification of the consistency ratios suggested by Saaty (1980), the answers of three experts (6, 7 and 10) were not consistent, so they were discarded for the weighting analysis of the TEV values.

Paired matrices applied to the experts resulted in these values in Table 1, which shows the Eigenvectors used and the aggregation of values obtained from the interviews.

The prioritization verified in this table was used for the determination of the VET values. In this case, from the willingness to pay for the visit to the site for scenic enjoyment (DUV).

Survey Results

After analyzing the surveys, the following frequency table was obtained (Table 2). It can be observed that most of the respondents (68.36%) were in the range of less than 2.5[1] USD per admission per person, per visit. For the purposes of this valuation, the value of 1.25 USD was taken as the average of that range of values for the calculation of the income obtained.

[1] An exchange rate of $19.50 Mexican pesos (MXN) per U.S. dollar (USD) was considered.

Table 1. Eigenvectors and aggregation values obtained.

	Eigenvectors experts							Aggregation	
	1	**2**	**3**	**4**	**5**	**8**	**9**		
DUV	0.0499	0.0740	0.0343	0.0289	0.0663	0.1924	0.0714	0.0615	0.0678
IUV	0.4096	0.2676	0.6139	0.4192	0.1605	0.1302	0.5202	0.3148	0.3474
OV	0.1728	0.0525	0.1131	0.0840	0.1694	0.1924	0.1361	0.1211	0.1337
EV	0.1626	0.2883	0.1257	0.2911	0.3335	0.2425	0.1361	0.2114	0.2333
IV	0.2051	0.3175	0.1131	0.1768	0.2704	0.2425	0.1361	0.1973	0.2177
$\sum$	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9061	1.0000

Table 2. Frequency table obtained in SAS® (through the FREQ procedure).

Price rango (USD$)	Frequency	%	Cumulative frequency	Cumulativo (%)
10.25-12.82	3	1.69	12	6.78
5.1-10.25	9	5.08	9	5.08
2.5-5.1	34	19.21	46	25.99
<2.5	121	68.36	167	94.35
Nada	10	5.65	177	100.00
Frequency Missing = 1				

Considering that the total number of visitors is 36,000 per year for all the river, and the value determined by the survey (a willingness to pay 1.25 USD per person) as the income, the determined rent results in the following:

$$36{,}000 \times 1.25 = 45{,}000 \text{ USD}$$

That amount would correspond to the determination of the value of direct use (DUV) which will be used as the pivot value.

Update of the rent obtained

To the amount determined in the previous section as rental income we assigned a rate of 2.81% (Aznar and Estruch, 2015).

$$VIU = \frac{45{,}000 \text{ USD}}{0.0281} = 1{,}601{,}423.49 \text{ USD}$$

Calculation of TEV considering DUV as a pivot value

Applying the determined weights and with the DUV as a pivot, it is obtained that the TEV of the ecosystem services of the landscape of the Ahuehuetes Gallery Forest amounted to 23,603,041.37 USD (November 2022).

Table 3. Prioritization of TEV values, values per component and the total determined.

Priorization of components of TEV		Values by TEV components (USD)
DUV	6.78%	1,601,423.49
IUV	34.74%	8,200,648.37
OV	13.37%	3,155,065.32
EV	23.33%	5,507,690.24
LV	21.77%	5,138,213.95
∑	100.00%	23,603,041.37

It is important to note that the result obtained does not correspond to the value of the environmental asset analyzed. But to a proxy indicator of the values that this landscape might reach as a necessary element for planning and management. The value determined is based solely on the aesthetic enjoyment of the landscape and yields a considerable figure, which shows the importance of this activity in monetary terms. The results obtained were based on only one element, which is scenic enjoyment. It seems that an even higher value might be achieved if a study with more time and resources were to include some additional elements in the annual cash flow (rental income) that would complement the DUV. As well as, estimating visitors in a more accurate way can vary the results.

CONCLUSIONS

The value obtained corresponds to the rental income obtained because of the asset, with a proposed update rate in a horizon of more than 30 years. But if it is considered that the useful life of the environmental asset is in perpetuity, then its value is invaluable.

The results show an adequate applicability of the AMUVAM method in the valuation of environmental assets. It is perceived that in the exercise, other aspects of DUV such as wood or others, might be considered and added to the aesthetic enjoyment, which would generate a value estimated even higher. Also, determining more precisely the number of visitors to the entire river would certainly change the results upwards.

The aggregation of more aspects related to DUV, as suggested above, requires more human and financial resources to determine it within a greater scope. However, the figure obtained clearly denotes the importance in monetary terms of the valued environmental asset.

Environmental valuation requires a longer time to run and at a higher cost than a valuation of other types, such as real estate. Since it requires, for example, techniques such as the application of surveys to a representative sample of the population that uses the asset, which requires more time. On the other hand, it demands a deeper and more detailed research on the qualities and aspects that compose TEV. It is important to consider this point for study-planning with this type of valuation.

As far as we are concerned, this valuation is an important contribution to the recognition of the value of this environmental asset, based on one indicator set in monetary terms.

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Determination of the main agricultural crops for the Metropolitan Puebla-Tlaxcala area using the Papadakis Methodology

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ABSTRACT

Objective: This study aimed to identify potential areas for establishing the main agricultural crops in the Puebla-Tlaxcala Metropolitan Area (ZMPT).

Design/methodology/approach: From April to June 2022, the classification process for identifying the main crops in the ZMPT was conducted. This process utilized monthly climatic data from the Mexican Institute of Water Technology (IMTA), analyzed through the Papadakis methodology (1970). Subsequently, the results were mapped using the Weighted Overlay (WO) tool in ArcGIS v.10.2.

Results: The Papadakis methodology identified 10 seasonal crop types, particularly for summer and winter. The WO tool categorized potential areas into five classes: optimal, highly suitable, acceptable, and unacceptable for the establishment of several crops.

Limitations on study/implications: This study has limitations due to incomplete and scarce databases and the complexity and cost associated with the software used. However, the implications for agriculture include the potential to enhance and diversify agricultural production by identifying optimal areas for establishment, especially in Urban-Periurban Agricultural areas (UPAs).

Findings/conclusions: This study successfully identified the main crops cultivated in the ZMPT and highlighted potential areas for their establishment. The generated cartographic information enables the strategic distribution of productive agricultural systems, particularly in UPAs, to adapt to regional climate fluctuations in the short, medium, and long term. Besides, an adequate distribution in the implementation of productive agricultural systems, particularly in UPAs, depending on fluctuations in the climatic conditions of the region.

Keywords: self-consumption, Climate change, Urban growth, Spatial modeling.

INTRODUCTION

Natural resources such as soil, climate, vegetation, and topography, among others, collectively constitute the concept of land, which serves as the foundation for establishing agriculture in rural areas (FAO, 2023). Studying it as a landscape element is the result of environmental factors that work together; therefore, it requires an understanding of most of the biophysical characteristics (Delgado-Calvo-Flores, Sánchez Marañón & Delgado Calvo-Flores, 1987).

On the other hand, soil is the physical space where human activities take place. Besides being a landscape element, it enables food production and serves as a refuge, space, and habitat, providing various elements for survival (Burbano-Orjuela, 2016). This resource is considered the substrate that supports and supplies nutrients to plants, while also participating in the hydrological cycle by allowing water filtration into groundwater, among other ecosystem services (Montanarella, 2015).

In the early 1980s, human population growth led to a drastic increase in food supply and, consequently, agricultural production, promoting negative effects associated with changes in land use for poorly planned productive activities. This decrease in productive capacity created the international need to develop standard soil classification systems (IUSS & WRB, 2007).

To harness the productive potential of the soil, it is imperative to manage territories to make decisions that are not overly complex to interpret, even for specialists from other disciplines unrelated to soil science (Perucca & Kurtz, 2016). The physical, chemical, biological, economic, and social evaluation of the soil constitutes a solid tool for sustainable management based on its inherent potential and productive capacity (Miranda *et al.*, 2021). This approach offers the possibility of implementing rational and sustainable use of this resource (Vargas & Ponce de León, 2008), as both soil and climate are the most relevant environmental factors that seasonally determine crop production in different regions around the world, as exposed in various agrometeorological studies (Mehrdad, 2017). Additionally, FAO (2022) recommends that this evaluation should be approached in a multidisciplinary method, considering environmental, social, economic, and cultural factors that impact agricultural systems.

Therefore, currently, the challenge is to produce more food while impacting fewer natural resources, especially soil, in order to mitigate the devastating effects on agrobiodiversity. This is because there are only about 100 species of plants and animals worldwide that are of agricultural and livestock importance for food production, with between 12 and 15 of them sustaining global production. Crops like rice, wheat, corn, and potatoes provide over 60% of the calories consumed by humans (Alemán, 2019). Recently, various more precise techniques for planning, implementation, and data analysis have been developed to improve the accuracy of results, thus promoting the prevention of the loss of germplasm with the potential to increase agricultural system productivity (Storck, Steckling, Roversi & Lopes, 2008).

As a result, the classification of agricultural soils will depend largely on the characteristics and quality of their mappable unit in comparison to agroecological needs for sustainable soil management in the short, medium, and long term, while minimizing environmental

degradation. In this context, the task of classifying, evaluating, analyzing, and identifying soils to determine their productive potential could be carried out using the Papadakis method, mapped through the WO tool within a Geographic Information System (GIS). However, no quantitative or qualitative developments have been made in this regard (Flores, 1997). Therefore, this study aimed to identify potential areas for the establishment of the main agricultural crops in the ZMPT.

MATERIALS AND METHODS

Study area

The ZMPT is located in the central part of Mexico, specifically in Puebla and Tlaxcala states, between the coordinates 18° 50' and 19° 25' N 97° 55' and 98° 40' W. It covers an approximate area of 2,204.34 Km^2. This area is composed of 38 municipalities, with 20 belonging to Tlaxcala and 18 to Puebla. It exhibits temperate, semi-cold, cold, and semi-humid climates, with annual precipitation ranging from 800 to 1500 mm. The average annual temperature varies between −2 °C and 18 °C (Periódico-Tlaxcala, 2013; Figure 1).

The information was collected from 18 weather stations owned by the IMTA, from which databases containing records of 20 years or more were obtained. These stations are distributed throughout the entire study area (Figure 2). The data from these stations were extracted using Eric III v.2 (IMTA, 2009), a tool that streamlined data retrieval from the National Historical Data Bank of the National Meteorological Service, stored within the CLICOM database of the same institution. To do this, the suitable stations distributed in the ZMPT were selected (Table 1).

To identify the main crops in the ZMPT, monthly average climate data, including the lowest, minimum, and maximum temperatures, precipitation, and vapor pressure from IMTA databases, were analyzed using the Papadakis method (1970). The climate classification required determining parameters such as winter and summer characteristics, temperature regimes, humidity, as well as climatic types, adaptability, and limitations for

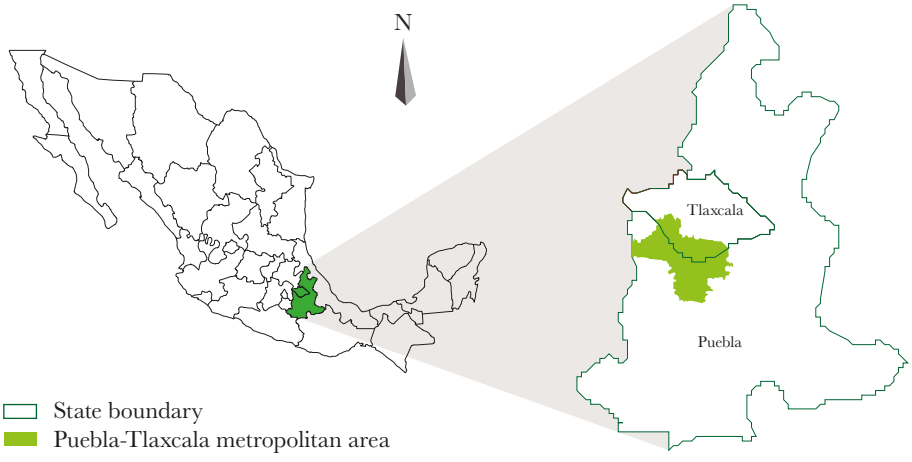

Figure 1. Location of the study area (ZMPT).
Source: Own elaboration with information from INEGI, 2021.

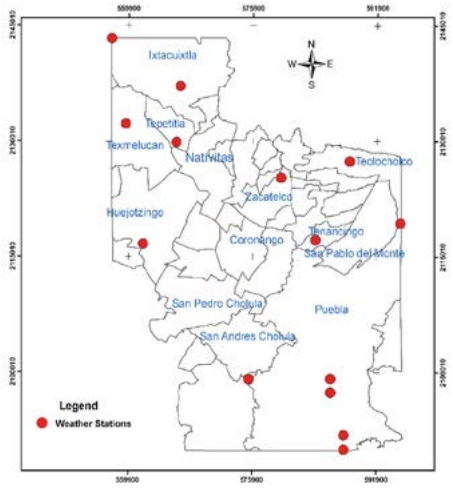

Figure 2. Distribution of IMTA meteorological stations in the ZMPT.
Source: Own elaboration using locations in the Mexican Republic. Scale: 1:50,000 from INEGI, 2018.

Table 1. Selected climate stations distributed across ZMPT, with records of 20 years or more.

Key	Initial year	Final year	Total Recorded years
21016	1943	2007	64
21023	1943	2006	63
21034	1943	2006	63
21035	1952	2006	54
21046	1925	1998	73
21164	1978	1996	18
21071	1954	2001	47
21148	1977	2003	26
21078	1961	2006	45
21089	1969	1990	21
21163	1978	2000	22
21214	1982	1995	13
29040	1974	2004	30
29041	1974	2005	31
29050	1980	2002	22
29056	1992	2002	10
29161	1990	2004	14
29169	1994	2002	8

important crops. This method comprised two phases: a) climate information analysis, involving the integration of the climatic system with crop requirements to ascertain their agricultural potential, and b) spatial analysis conducted through interpolation using the Spline tool of ArcGIS® (ESRI, Inc., 2019). This interpolation method estimates values

through a mathematical function that minimizes the global curvature of the surface, resulting in a smooth area that accurately fits the input points.

With the interpolation product, WO was performed, which included a set of methods applied to determine the optimal locations for crop establishment through suitability modeling. In this technique, a common value scale was applied to various inputs that differed from each other to generate a comprehensive analysis. A weighting factor derived from the Papadakis classification was applied, taking into account factors such as relative humidity, precipitation, and extreme maximum and minimum temperatures.

RESULTS AND DISCUSSION

The results from the climate stations display the extreme values of precipitation, relative humidity, maximum temperature, and minimum and extreme temperatures in the ZMPT (Table 2).

Interpolation results provide an average approximation of the prevailing climate type in the ZMPT, from which maps of maximum, minimum, absolute average temperatures, precipitation, and relative humidity were obtained.

Data suggested the presence of average maximum temperatures ranging from 23.8-32.4 °C, which were located in the northern and central parts of Puebla, including San Martín Texmelucan, Huejotzingo, and Domingo Arenas. In contrast, values ranging from 18.6-23.8 °C were recorded in the eastern part of San Pedro Cholula, the western part of Puebla, San Andrés Cholula, San Miguel Xoxtla, Tetlatlahuca, San Jerónimo

Table 2. Extreme values were obtained from the IMTA climate stations in the ZMPT.

Station	Precipitation	Relative humidity	Maximum temperature	Minimum temperature	Extreme temperature
21016	143.5	69	29.3	6.20	2.1
21023	94.7	69.5	26.80	4.57	0.4
21034	185.1	69.5	26.46	0.91	−3.9
21035	195.6	69.5	26.46	4.88	1.24
21046	165.9	69.5	27.36	3.10	−0.78
21071	140.8	69.5	28.19	4.76	0.78
21078	126.1	69	28.16	3.97	−0.31
21089	70.6	69	26.34	−0.52	−6.75
21148	183.8	69.5	23.87	2.95	−0.21
21163	204.5	69.5	16.25	2.45	−2.5
21164	204.4	69.5	16.25	−0.57	−3.64
21214	160.9	69.5	19.97	0.68	−2.3
29040	129.9	69	27.60	1.6	−3.48
29041	133.9	69	26.02	0.63	0.62
29050	165.9	69	19.5	3.2	−0.11
29056	249.7	69.5	27.5	3.1	−0.37
29161	149.9	69	25	2.8	−0.68
29169	185.8	69	26.8	3.3	−0.22

Zacualpan, San Juan Huactzinco, San Lorenzo Axomanitla, Zacatelco, Coronango, and Cuautlancingo. Temperature ranges of 13.53-18.67 °C corresponded to San Pablo del Monte, Acuamanala de Miguel Hidalgo, Mazatecochco de María Morelos, Tenancingo, Santa Catarina Ayometla, Ixtacuixtla de Mariano Matamoros, Tepetitla de Lardizábal, Santa Ana Nopalucan, Tlaltenango, and Juan C. Bonilla. On the other hand, the threshold of 5.9-13.5 °C was concentrated in the central and western parts of Ocoyucan. The lowest temperatures of −6.1-5.9 °C were found in the eastern part of Puebla (Figure 3).

In contrast, the average minimum temperatures showed that ranges of 20.2-33.2 °C were distributed in the south of Ocoyucan and Puebla. Values of 12.10-20.2 °C were observed in the east of Ocoyucan, southeast, and central Puebla. Thresholds of 7.3-12.1 °C were located in the east of San Martin Texmelucan, Huejotzingo, Domingo Arenas, and the west of Puebla. On the other hand, values of 3.97-7.28 °C were present in Tepetitla de Lardizábal, Ixtacuixtla de Mariano Matamoros, Santa Ana Nopalucan, Nativitas, San Miguel Xoxtla, Tlaltenango, Juan C. Bonilla, San Gregorio Atzompa, Tenancingo, San Pablo del Monte, and others. Similarly, the ranges of −1.9-3.9 °C were distributed in the west of Ocoyucan (Figure 4).

On the other hand, the average minimum extreme temperatures were located in the center of Puebla and Ocoyucan. Thresholds between 11.9-21.5 °C were situated to the east of Ocoyucan and the south of Puebla. Values of 6.7-11.9°C were recognized to the west of Puebla, Amozoc, and the center of Ocoyucan. Ranges of 3.6-6.8 °C were focused in the center and east of Huejotzingo, San Martín Texmelucan, Nativitas, Tepetitla de Lardizábal, Tlaltenango, San Miguel Xoxtla, Santa Apolonia Teacalco, and others. Figures between −9.5-0.7 °C corresponded to the southeast of Puebla (Figure 5).

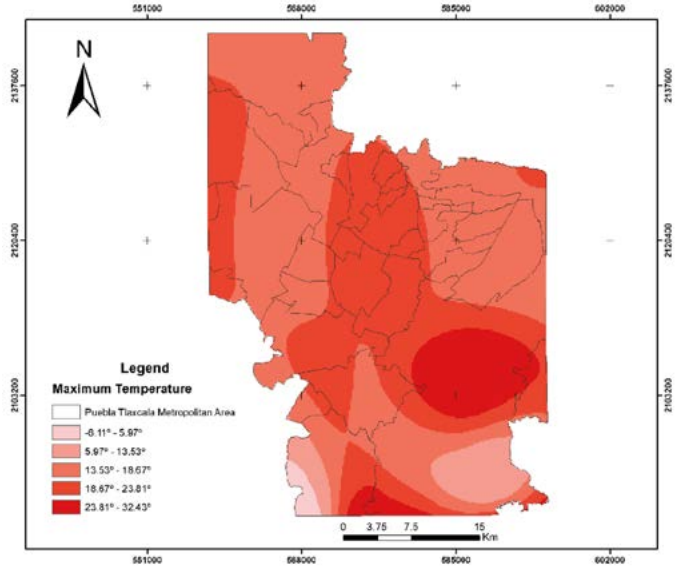

Figure 3. Cartographic results of the Spline interpolation method for average maximum temperature recorded in the municipalities of the ZMPT.
Source: Own elaboration with information from SMN and INEGI climate stations (INEGI, 2021).

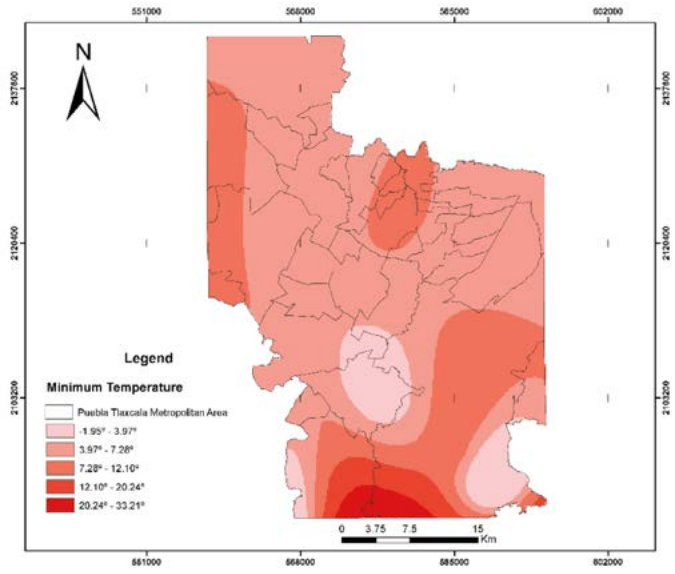

Figure 4. Cartographic results of the Spline interpolation method for average minimum temperatures recorded in the municipalities of the ZMPT.
Source: Own elaboration with information from SMN and INEGI climate stations (INEGI, 2021).

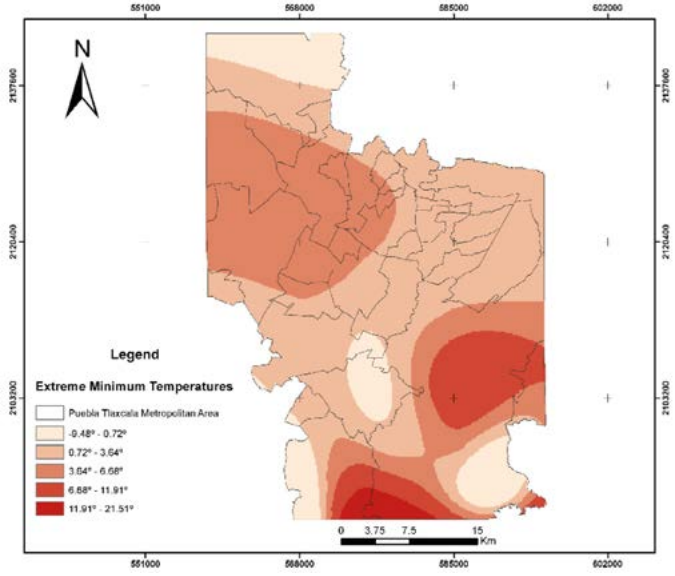

Figure 5. Cartographic results of the Spline interpolation method for average minimum extreme temperatures recorded in the municipalities of the ZMPT.
Source: Own elaboration with information from SMN and INEGI climate stations (INEGI, 2021).

On the other hand, average precipitation showed values between 98-137mm, which occurred in the west of Ocoyucan, southeast of San Andrés Cholula, Puebla, and Amozoc. Ranges of 73-98 mm were observed in the east of Tlaltenango, northwest of Puebla, Huejotzingo, Papalotla de Xicohtencatl, Santa Catarina Ayometla, Zacatelco, San Miguel Xoxtla, Coronango, Juan C. Bonilla, and others. Thresholds of 52-73mm were present in the northwest of Puebla, San Martin Texmelucan, east of Huejotzingo, southeast of

Puebla, Domingo Arenas, south of Ocoyucan, Ixtacuixtla de Mariano Matamoros, north of San Pablo del Monte, Santa Ana de Nopalucan, Santa Apolonia Teacalco, Nativitas, Tepeyanco, San Jerónimo Zacualpan, Tetlatlahuca. Parameters between 20-52 mm were recorded in the north of Ixtacuixtla de Mariano Matamoros, south of San Pablo del Monte, Mazatecochco. Similarly, values of 35-20 mm were reported in the center of Puebla and southeast of Ocoyucan (Figure 6).

Finally, average relative humidity ranges from 58.382% to 58.520% were located in the center of Huejotzingo, north of San Pablo del Monte, Papalotla de Xicohtencatl, Cuautlancingo, Santa Catarina Ayometla, and the south of Tlaltenango, Coronango, and Xicohtzinco. The range of 58.278-58.382% was observed in San Andrés Cholula, the center of Puebla, San Pablo del Monte, Nativitas, Tepetitla de Lardizábal, San Martin Texmelucan, Santa Ana Nopalucan, and more. Humidity thresholds between 58.140% and 58.278% were found in the south of Cuautlancingo, San Pedro Cholula, Tenancingo, the center of Huejotzingo, San Pablo del Monte, Papalotla de Xicohtencatl, Cuautlancingo, the south of Tlaltenango, Coronango, Santa Catarina Ayometla, and Xicohtzinco. Values between 57.9% and 58.1% were concentrated in the center of Huejotzingo, Ixtacuixtla de Mariano Matamoros, north of San Pablo del Monte, Papalotla de Xicohtencatl, Cuautlancingo, Santa Catarina Ayometla, Tlaltenango, Coronango, and Xicohtzinco. Humidity scales from 57.8% to 57.9% dominated the south of Ixtacuixtla de Mariano Matamoros, the north of Zacatelco, Huejotzingo, the east of San Jerónimo Zacualpan, Teolocholco, Santa Ana Nopalucan, Tepetitla de Lardizábal, Nativitas, San Martin Texmelucan, Tepeyanco, Santa Apolonia Teacalco, and more (Figure 7).

The results from Papadakis highlighted the main crops with productive potential that adapted to the prevailing climatic conditions in the ZMPT (Table 3).

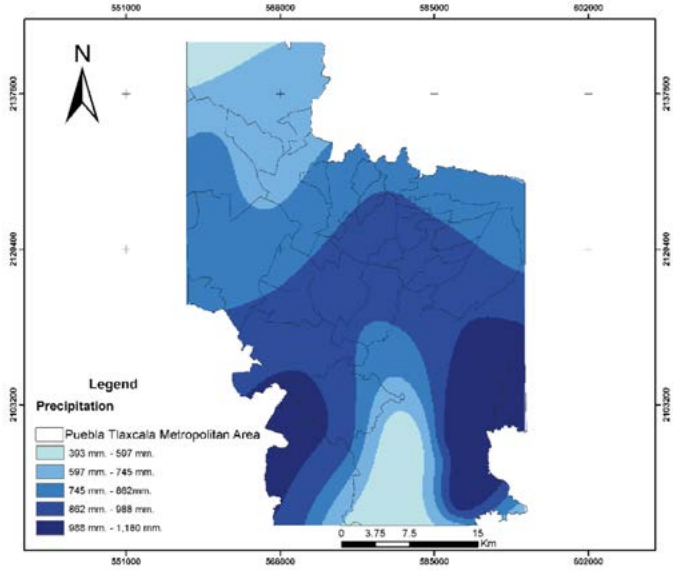

Figure 6. Cartographic results of the Spline interpolation method for average precipitation recorded in the municipalities of the ZMPT.
Source: Own elaboration with information from SMN and INEGI climate stations (INEGI, 2021).

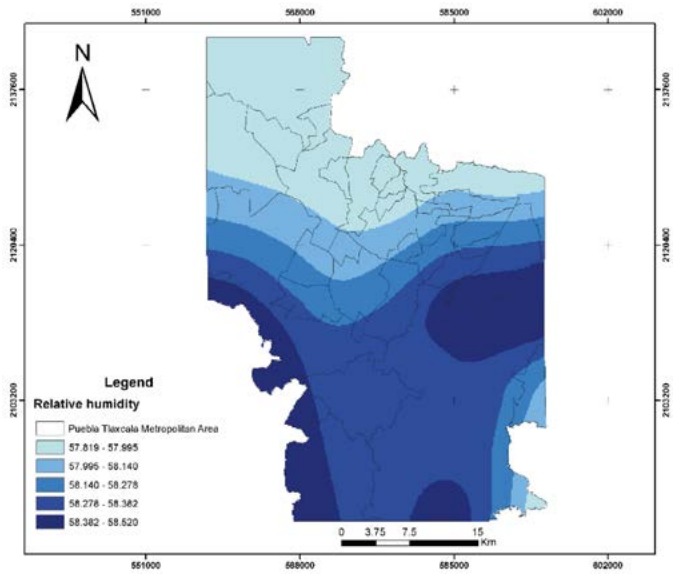

Figure 7. Cartographic results of the Spline interpolation method for average relative humidity recorded in the municipalities of the ZMPT.
Source: Own elaboration with information from SMN and INEGI climate stations (INEGI, 2021).

Table 3. Papadakis results, emphasizing the main crops with productive potential adapted to the recorded climatic conditions in ZMPT.

Key	Possible crops	Annual Precipitation (mm)	Annual Max. Temperature	Annual Min. Temperature	Annual Extreme Temperature
21106	Summer cereals: maize, sorghum, millet, rice.	724.3	29.3	6.20	2.1
21023	Winter cereals: wheat, oats, barley, rye.	464	26.80	4.57	0.4
21034	Summer cereals: maize, sorghum, millet, rice.	899.4	26.46	0.91	−3.9
21035	Summer cereals: maize, sorghum, millet, rice.	960.5	26.46	4.88	1.24
21046	Summer cereals: maize, sorghum, millet, rice.	827	27.36	3.10	−0.78
21071	Winter cereals: wheat, oats, barley, rye.	1400.9	28.19	4.76	0.78
21078	Summer cereals: maize, sorghum, millet, rice.	766.2	28.16	3.97	−0.31
21089	Summer cereals: maize, sorghum, millet, rice.	439.5	26.34	−0.52	−6.75
21148	Summer cereals: maize, sorghum, millet, rice.	830.4	23.87	2.95	−0.21
21163	Summer cereals: maize, sorghum, millet, rice.	876.7	16.25	2.45	−2.5
21164	Sugar beet and potato.	1026.9	16.25	−0.57	−3.64
21214	Winter cereals: wheat, oats, barley, rye.	891.6	19.97	0.68	−2.3
29040	Winter cereals: wheat, oats, barley, rye.	684.4	27.60	1.6	−3.48
29041	Summer cereals: maize, sorghum, millet, rice.	696.1	26.02	0.63	0.62
29050	Summer cereals: maize, sorghum, millet, rice.	802.8	19.5	3.2	−0.11
29056	Summer cereals: maize, sorghum, millet, rice.	955.8	27.5	3.1	−0.37
29161	Summer cereals: maize, sorghum, millet, rice.	780.3	25	2.8	−0.68
29169	Summer cereals: maize, sorghum, millet, rice.	885.0	26.8	3.3	−0.22

Similarly, the Papadakis results obtained suggested some management recommendations for the crops with productive potential identified in this study for the ZMPT (Table 4).

The results of the WO displayed the optimal locations for establishing certain crops with productive potential in the ZMPT. This location was successfully mapped, allowing the identification of five categories (optimal, very suitable, suitable, acceptable, and unacceptable) of soil suitability or potential for these crops.

The information generated through the WO indicated that summer cereals had an Optimal Potential in two municipalities, while Very Suitable was present in 12 municipalities. Suitable was located in nine municipalities, and Acceptable was also registered in eight (Figure 8).

For winter cereals, the Optimal Potential was recorded in 11 municipalities, Very Suitable in more than 11 municipalities, and Acceptable in only one (Figure 9).

For Sugar Beet, the Optimal Potential was observed in one municipality, Very Suitable in 12 municipalities, Suitable in 28 municipalities, and Acceptable in only one (Figure 10).

Regarding potatoes, the Optimal Potential was located in eight municipalities, and Suitable in more than 22 municipalities (Figure 11).

Likewise, the results of the SP allowed the estimation of the total areas by category for the establishment of productive potential crops in the ZMPT (Table 5).

Table 4. Papadakis results highlighting some management recommendations for the main crops with productive potential adapted to the recorded climatic conditions in ZMPT.

Key	Crops	Description
21106 21046 21078 21148 21163 29040 29041 29056 29161 29169	Summer cereals: maize, sorghum, millet, rice.	The cool nights in these climates make them favorable for summer cereals, which are grown during the frost-free season. This type of climate is most suitable for maize.
21023 21034 21035 21071 21089 21214	Winter cereals: wheat, oats, barley, rye.	Winter cereals (wheat, oats, barley, rye) can be sown in both spring and autumn, but in many subdivisions, irrigation is required. In some cases, even spring-sown crops require irrigation, and with proper irrigation and fertilization, good yields can be obtained.
21164	Sugar beet and potato	Potatoes are frequently damaged by frost but are still cultivated; irrigation is essential. For cryophilic grasses, irrigation is necessary, and legumes require either irrigation or the selection of suitable species, as their yields are considerably limited. Sugar beets can be grown using varieties that do not easily flower and are frost-resistant.
29050	Potato, Sugar beet	Potatoes yield well, but depending on the climate and planting time, irrigation is usually required. Sugar beets can grow well, but their production could be costly.

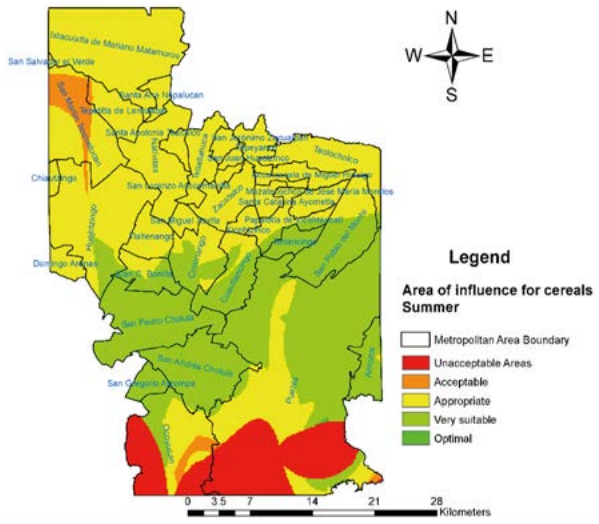

Figure 8. Cartographic results of the Weighted Overlay (WO), showing the optimal locations for establishing productive potential summer cereals based on the five categories of soil suitability or potential in municipalities of the ZMPT.

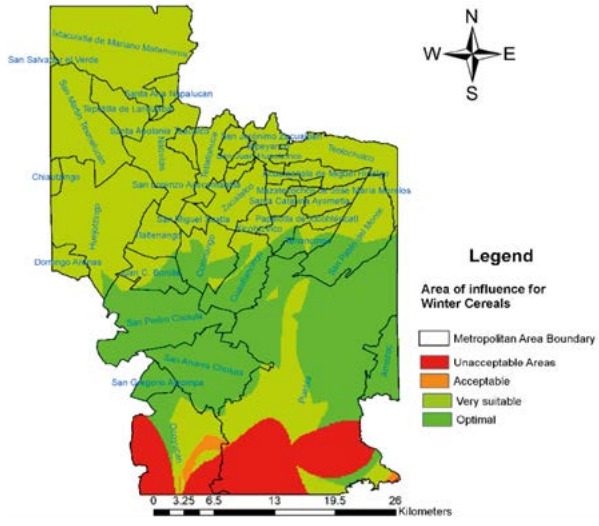

Figure 9. Cartographic results of the Weighted Overlay (WO), showing the optimal locations for establishing productive potential winter cereals based on the five categories of soil suitability or potential in municipalities of the ZMPT.

On the other hand, some authors (Velasco, 2010; Bautista-Capetillo, 2017; Mehrdad, 2017; Mendoza-Cariño *et al.*, 2021) conducted various studies on agroclimatic zoning using the Papadakis method to identify areas with potential for crops, focusing on specific climatic conditions in each area. These studies were based on climatic records collected over periods of at least 10 years or more, using information from 25 to 133 stations. The aim of these studies was to improve production in the study areas. In the case of the provinces of Kermanshah and Hamadán in Iran, characterized by their semi-arid and dry climate, the possibility of rainfed crops, specifically winter crops such as wheat, oats, citrus, cotton,

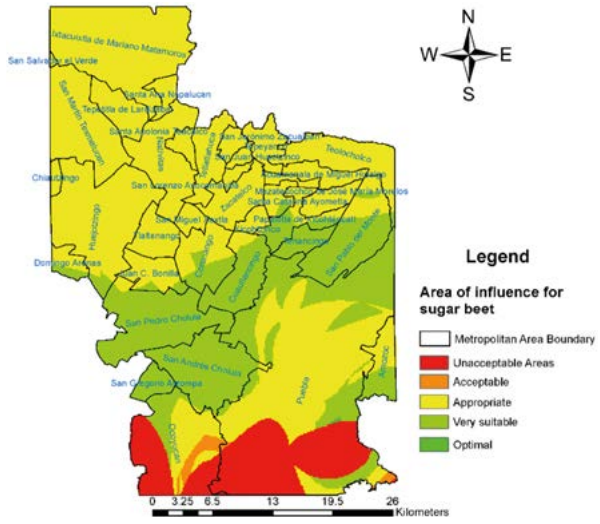

Figure 10. Cartographic results of the Weighted Overlay (WO) showing the optimal locations for establishing productive potential sugar beet based on the five categories of soil suitability or potential in municipalities of the ZMPT.

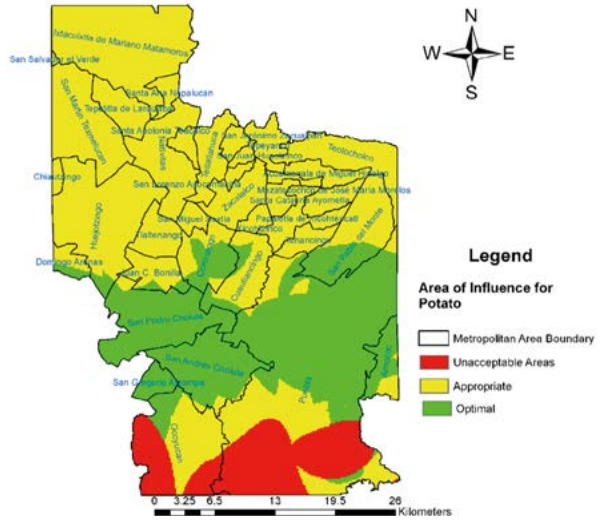

Figure 11. Cartographic results of the Weighted Overlay (WO) showing the optimal locations for establishing productive potential potatoes based on the five categories of soil suitability or potential in municipalities of the ZMPT.

Table 5. Results of the Weighted Overlay (WO) displaying the total areas by category for the establishment of productive potential crops in the ZMPT.

Type of crops	Unacceptable Areas ha.	Acceptable Areas ha.	Suitable Areas ha.	Very Suitable Areas ha.	Optimal Areas ha.
Winter cereals	138.88	9.9	829.35	481.86	0
Summer cereals	138.88	35.53	760.30	524.77	0.51
Sugar Beet	138.88	10.39	892.09	418.21	0.42
Potato	138.88	0	885.32	435.79	0

and others, was identified. Meanwhile, in Nayarit state, Mexico, areas with potential for summer crops, including rice, corn, millet, sorghum, as well as bananas and sugarcane, were identified. For the semi-arid zone of Zacatecas, Mexico, areas suitable for maize, beans, and soybean crops were identified. It is important to note that these studies covered large geographical areas and were mainly conducted at the state level in Mexico.

In this way, these studies align with the present research in managing some crops, particularly wheat, oats, rice, corn, sorghum, potatoes, and soybeans. However, the present study succeeded in identifying areas with productive potential for some crops such as rye, barley, and potatoes in the ZMPT using the Papadakis method and WO. For the first time in this region of Mexico, it was demonstrated that sustainable crop management is possible. This allows for the implementation of UPA systems to diversify agricultural production in areas seemingly unsuitable for it. These findings were mapped in a Geographic Information System (GIS), suggesting that the recommendations generated from our results for these crops are more precise and robust. It was possible to determine the months with the highest precipitation, crucial for rainfed agriculture in the study area.

Furthermore, this study differs from previous research because it focused on zoning urban and periurban areas, which is essential for food production in resource-limited settings. It enabled the identification of optimal zones for specific crops based on their productive potential, primarily driven by climatic factors. Additionally, the number of weather stations considered in this study is a distinguishing factor. While we used a smaller number of weather stations, we had more extensive data records over the years. Despite the differences in the number of stations and years, the trends identified in this study appear to be equally robust because we focused on the ZMPT, particularly in urban and periurban areas. The recommendations for crop establishment can contribute to producing what is needed for self-consumption and even for sale on relatively smaller land areas than those evaluated by other authors. This is a significant contribution because this study generated fundamental information that can enhance food security in this specific region of Mexico.

It is important to highlight that these mentioned studies share some similarities with the approach of this study. Their focus was on identifying climatic groups, primarily considering temperature, unlike the current study, which concentrated on identifying potential areas for agricultural crops based on climatic aspects.

CONCLUSIONS

Potential areas for the establishment of certain agriculturally productive crops in the ZMPT were successfully identified. The Papadakis methodology, along with WO and its cartographic projection in GIS, constitutes a set of tools with significant potential to promote good practices in UPA systems in relatively small land areas. This allowed us to determine the appropriate months for crop establishment, particularly in rainfed systems. As a result, this will foster sustainable agriculture that contributes to local food security through self-consumption and the generation of some economic development through the commercialization of these crops in local and regional markets.

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Colegio de Postgraduados

Characterization of production units of cured foods in the Isthmus Region, Oaxaca, Mexico

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ABSTRACT

Objective: To characterize the family production units (FPUs) that produce and market cured foods in the Isthmus Region.

Design/methodology/approach: The approach was descriptive and correlational. The methodology used was proposed by Chayanov (1925), which proposes the assessment of six factors. A survey was applied and 75 variables were evaluated, Spearman's correlation and chi-square test were carried out, and contingency tables were generated with the most significant variables.

Results: With a higher the level of studies of the head of the family, the number of members was greater and women participated more in decision-making. The production of cured foods is a tradition inherited from one generation to another, and 73% learned the activity from a family member. The workforce is family-based and only family members are involved in 95% of the FPUs.

Limitations on study/implications: The vastness of the region makes it difficult to cover other municipalities and insecurity makes it difficult to obtain information.

Findings/conclusions: The family structure at the FPUs is nuclear. The woman directs the elaboration of cured foods, so it is considered that she plays an important role in conserving artisanal production.

Keywords: Artisanal activity, traditional knowledge, cured foods.

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INTRODUCTION

The state of Oaxaca is among the states of highest index of marginalization and poverty in Mexico; Reyes (2021) and Mariscal *et al.* (2019) mention that it is one of its main characteristics. It is reported that 61.7% of the population is in poverty and 70% of its territory is rural, with agricultural activities predominating as the basis of its economy (Consejo Nacional de Evaluación de la Política de Desarrollo Social, CONEVAL, 2020).

The importance of the study is because the FPUs in rural communities establish strategies to obtain foods and at the same time they contribute to sustaining the family economy (Ramírez *et al.*, 2015; Zepeda *et al.*, 2021). These FPUs generate a large variety of artisanal products for auto-consumption or commercialization, based on their traditions (Abril *et al.*, 2019; Ávila, 2021); it is necessary to understand this, which gives importance to the present research. It is of great interest to know the functioning of these FPUs and the family-based employment generated within the social and economic dynamics, and the way in which they are integrated in order to understand their strategies (Muñoz *et al.*, 2019; González and Sacco, 2015).

Bustos (2009) considers that artisanal production consists in elaborating products with basic raw materials and non-industrialized processes. In this regard, Gallego and Hernández (2021) state that artisanal production is strengthened with collective work.

In the FPUs, women's knowledge and experiences in terms of food conservation can have a positive impact on the development of the community and to attain better living conditions (López *et al.*, 2015; Yong *et al.*, 2017). The objective of the study was to characterize the family production units devoted to the production and commercialization of fruit-based cured foods in the Tehuantepec Isthmus, Oaxaca.

MATERIALS AND METHODS

Area of study. The research was conducted in the region of the Tehuantepec Isthmus, Oaxaca, made up by the districts of Juchitán and Tehuantepec, which make up 22 and 19 municipalities, respectively (Sistema de Información Cultural, SIC, 2022). According to the National Council for Culture and Arts (*Consejo Nacional para la Cultura y las Artes*, CONACULTA, 2010), the region is inhabited primarily by Zapotec people, although it houses small communities of Mixe, Zoque, Chontal and Huave peoples.

Foundation of the research. The study has a mixed, descriptive, transversal and correlational approach, with the direct generation of information in the units of analysis (Hernández *et al.*, 2010).

Methodology. The methodology used was proposed by Chayanov (1925), characterizing the FPUs based on six factors:

1. Profile of the FPU. It generally describes the size of the family, its structure and composition by sex or age. Variables evaluated: number of members in the family (NMF), who is the head of the family (WHF), occupation of the head of the family (OHF), diversification of activities (DA).
2. Cultural traits. It refers to the ethnic group of the family, the language they speak, and the conception of the productive activity as tradition. Variables evaluated: language (L), ethnic group (EG), religion (R), cured foods are part of the culture (CPC), family tradition (FT).
3. Profile of the producer (a). It describes general data about the producers, age, sex, marital status, religion, language, among others. Variables evaluated: who directs the production (WDP), age of producer (AP), degree of studies (DgS).
4. Acquisition of knowledge. It describes how knowledge, techniques and the production process are transmitted in the FPUs. Variables evaluated: from whom did the producer learn (FWPL), transmitted knowledge (TK), time directing the activity (TDA), years working with their supplier (YWS).
5. Family workforce. It characterizes the origin of the workforce and the participation of family members in the FPU's activities. Variables evaluated: workforce (WF), work in society (WS), family participation (FP).
6. Tools, inputs and raw material. It characterizes the use of tools, inputs and raw materials used in production. Variables evaluated: use of tools (UT), raw materials required (RMR), fruit purchase (FP), and inputs used (IU).

Research technique. The survey was used, with a questionnaire structured by 75 questions, where the six factors mentioned before were considered. According to Hernández *et al.* (2010), the survey is supported by a questionnaire that is generally applicable in different contexts.

Unit of analysis. The unit of analysis was the FPUs of cured foods. To identify the FPUs, a census was conducted within the municipalities selected: Santo Domingo Tehuantepec, Salina Cruz, Ciudad Ixtepec and Santa María Jalapa del Marqués, which are the municipalities with the highest and lowest number of inhabitants. According to the National Statistics, Geography and Information Institute (*Instituto Nacional de Estadística, Geografía e Informática*, INEGI, 2022), there were 19 FPUs registered, yet 38 were found when the survey was applied, twice as many as those officially recorded; the decision was made to apply the questionnaire to the entire population.

Information analysis. A database was integrated in the Excel 2013 software, and statistical analyses were carried out with the SPSS® Statistics software version 2019. Spearman's correlation tests were applied, as well as the chi-square independence test and frequency tables.

RESULTS AND DISCUSSION

Profile of the FPUs

Of the FPUs, 45% are made up of two people, 26% three, 18% four, and 11% five people. They present a nuclear family structure, similar to the FPUs that produce pozole corn in Tlaxcala where the number of members and the structure is similar (Román *et al.*, 2019).

Regarding WHF, it is reported that it is the father in 61% of the FPUs, the mother in 26%, and 13% manifest that both. Ramírez *et al.* (2015), in the community of Vícam, Guaymas, Sonora, reports a similarity where 22% of the FPUs that produce grains and vegetables have a woman as head of the family.

Regarding the OHF, 32% are employees, 29% pensioners, 21% housewives, 8% merchants, 5% bread makers, and 5% farmers. This indicates that the income is generated from various sources, the same as a FPU from Pueblo Nuevo, Acambay, Estado de México, where Magdaleno *et al.* (2014) report that 59% of the heads of the family diversify their sources of income.

Concerning the DA in the FPUs, 50% of the FPUs carry out two or more activities, as it happens with bean producers in Zacatecas, farmers in Tanhuato, and FPUs focused on livestock production and soy crops in Cerro Largo, Uruguay, which perform two or more activities to complement their income (Ramírez *et al.*, 2022; Román *et al.*, 2020; Gonzáles and Sacco, 2015).

Cultural traits of the FPU

In relation to language, 100% of the FPUs speak Spanish and only 26% Spanish and Zapotec. The EG that predominates is Zapotec in 79%, the rest manifests not belonging to an EG. This is because according to CONACULTA (2010), the Zapotec are one of the five ethnic groups that inhabit the region and have greater presence in the state. The religion that predominates is the Catholic with 92% and the rest Baptist.

Regarding whether CPC of the PFUs, 100% considers that yes, 90% also considers FT and the rest doesn't. It is generalized as a characteristic activity of a region and inheritance of their ancestors. Gallego and Hernández (2021), in the municipality of Magdalena Sonora, report that the FPUs devoted to the elaboration of fruit conserves and quince caramel consider this activity as family and cultural tradition inherited from their ancestors.

Profile of the producer

In the production of cured foods, the variable WDP is the woman (100%), and this highlights the importance of the feminine gender to preserve the activity as part of family culture and tradition. Data reported by Ortiz and López (2015) in the community of Nariño, Colombia, indicate that women's participation predominates in the elaboration of handcrafts made of porcelanicrón, migajón, ceramics and pottery, and this highlights the importance of the feminine gender in artisanal activities.

The AP varies from 29 to 79 years, 71% is concentrated in the range of 50 to 79 years. This age range is similar to that reported by Mariscal *et al.* (2019) in FPUs devoted to agriculture and livestock production, in Santa Gertrudis, Zimatlán, Oaxaca, where the age ranges from 18 to 75 years and 24% are over 65 years old, and this is because of the lack of interest by the young population and the need of older adults to conserve their culture, tradition and to generate income.

The DgS varies from six to 16 years, with an average of 8.2 years, where 47% have six years of study, 40% nine, and 8% and 5% with 12 and 17 years, respectively. Galindo *et al.* (2000) report that, of the farmers from Zacatecas, 48.7% have primary education and this is because the families destine few resources to education.

Knowledge acquisition

In the variable FWPL, 73% are of a family member and the rest of people outside the family. In TK, 68% manifests they have transmitted their knowledge and 32% that they have not yet done so. Gallego and Hernández (2021) mention that FPUs of fruit conserves and quince caramel in Magdalena Sonora agree with the form of knowledge transmission in the Isthmus region, which happens generation to generation.

The TDA of the women producers vary in a range of 2 to 50 years with average of 21, which indicates the vast experience of the farmers. As it happens in Los Ríos Ecuador, where Morales *et al.* (2018) identified that farmers have considerable experience in cacao production, this piece of data can also be related with the time that farmers (YWS) have been working with a single supplier because they have more experience time in the acquisition of their raw materials.

Family workforce

The WF used in 95% of the FPUs is contributed by the family, meaning that the main workforce is family-based, as it happens in coffee-producing FPUs in Chiapas, where 84% of them resort to family workforce with the main purpose of self-employment (Vázquez *et al.*, 2022). Similar data are reported by Flores *et al.* (2021) in Puebla, in the extraction of totomoxtle where they use family workforce because it is a livelihood strategy. Referring to

the WS, each FPU carries out the activity individually, there is not a group or society of women producers due to the lack of initiative and because they think that they work better that way.

This factor is considered one of the most important characteristics of the FPUs, since Chayanov (1925) manifests that family workforce represents the main source of income.

In relation to the FP, it stands out that the children (55%) and husband (53%), grandchildren (11%), siblings (8%), aunts (8%) and nephews (5%) contribute their workforce, even when the person does not inhabit the FPU. The same happens in the municipality of Arismendi, Nueva Esparta, Venezuela, in the production of arepa de vieja, since in both cases family members participate who commute to the place where the FPU is located to contribute their workforce (Gómez, 2008).

Tools, raw material and inputs

In UT 100% of the FPUs used simple tools, such as pails, trays and forks, where both the tools and the elaboration process are manual; according to Flores *et al.* (2021), it is a characteristic of small-scale artisanal producers.

The RMR are the traditional fruits, plum (100% of the FPUs) and quince (84%). Some FPUs have diversified their production, 31% use also mango and 21% peach. The raw material is used directly without any process; this is similar to the raw material used to elaborate stick handcrafts in Santa Catarina del Monte, Texcoco (Rivera *et al.*, 2008), since the production process requires it. For FP, 90% acquire it with farmers from the region and from Santa María Ecatepec, municipality that belongs to the Sierra Sur region; the rest produce the fruit they use.

In the IU variable, 100% of the FPUs purchase sugar, sugarcane alcohol, and water. Both the FPUs of cured foods and the FPUs of citrus trees, avocado and corn from Yucatán perform as demanders when they purchase inputs and offerors in the sale of their products (Ávila, 2021).

Correlation of variables of the different factors

The AP variable shows negative correlation with NMF ($r=-0.724^{**}$), which means that with a lower AP the NMF will be higher, because these FPUs are still made up by parents and children. The AP also has a positive correlation with TDA which means that with higher AP more TDA ($r=0.505^{**}$). This agrees with Morales *et al.* (2018), who report in the province of Los Ríos, Ecuador, that the older cacao producers are there are more years of experience.

Chi-square independence test

The AP variable has a high dependency ($P\leq0.01$) with DgS, which means that young women producers have more years of study, similar to what Díaz *et al.* (2020) reported, in corn, bean and tomato FPUs in Ejutla de Crespo, Oaxaca, where there is high dependency between years of study and age range. Something similar happens with artisans of the Central Valleys in Oaxaca, where Mejía *et al.* (2018) identified that 84% of artisans are older than 41 years and 89% only study primary and secondary school.

The TDA variable showed high dependency on the YWS variable ($P \leq 0.01$), and this indicates that with women producers with higher TDA, the possibility of changing supplier is lower. Something similar happens with producers of stick handcrafts in Santa Catarina del Monte, Texcoco, who support their suppliers of raw materials, since in their community they do not have this resource (Rivera *et al.*, 2008).

CONCLUSIONS

Of the families in the FPUs, 45% are made up of two people, primarily by the parents, and the remaining 55% with three or four members; in general, the structure is nuclear.

Spanish is spoken in all the FPUs; the Zapotec ethnic group predominates (79%), but only 26% speaks Zapotec.

The woman is the one who directs the production of cured foods, where 71% is in an age range between 50 and 79 years, indicating that it is an activity of generally adult people and that the woman plays an important role to conserve the artisanal production of cured foods, and this activity is inherited from their ancestors; 73% acquired the knowledge from a family member, reason why it is considered part of the culture of the FPUs.

The main workforce is family-based and in 95% of the FPUs only the family intervenes, significant piece of data according to the methodology used for the characterization.

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Cost-efficiency in the production of strawberry plant CP-Jacona under two techniques

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ABSTRACT
Objective: to estimate the production price of strawberry "mother" plant of the CP-Jacona variety in both TIS and TS, and to compare these prices with the price of the imported "mother" plant.
Design/Methodology/Approach: micropropagation methods have been used as an effective means for the mass production of pathogen-free plants, in small spaces and relatively short periods of time. In particular, *in vitro* Temporary Immersion Systems (TIS) applied to the production of strawberry "mother" plants have been shown to offer technological and quantitative benefits, as well as a higher proliferation rate, compared to the *in vitro* Traditional System (TS). Despite the benefits of TIS, these systems have not been evaluated in terms of the price at which the "mother" plant can be produced and whether it is a profitable option to supply strawberry producers. The traditional method of financial analysis was applied.
Results: the price of the CP-Jacona variety plant obtained from the third production period through TIS was lower than the price of the imported Festival or Camarosa varieties.
Findings/Conclusions: both the high production rate and the low rate of loss from handling in TIS were fundamental aspects to obtain lower prices than those of imported varieties.

Keywords: Efficiency-cost, micropropagation, bioreactors, temporary immersion systems.

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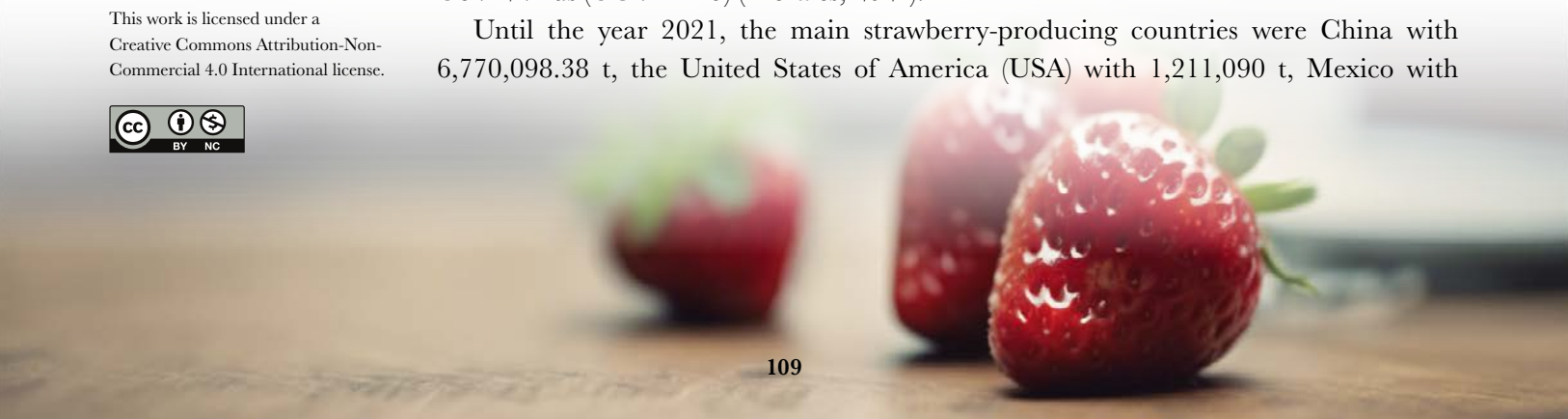
INTRODUCTION

Strawberry is a fruit of high demand at the global level due to its nutritional properties, delicious flavor and versatility in the kitchen. It is rich in vitamins, antioxidants, and essential minerals, and at the same time it is low in calories and fat. In addition to its nutritional value, the strawberry fruit is considered a functional food with multiple benefits for health. The accumulated evidence proves that there are antioxidant, anti-inflammatory, anti-hyperlipidemia, anti-hypertensive, and anti-proliferative effects that counteract the problems caused by chronic diseases (Basu *et al.*, 2014). In addition, the high demand is explained by its availability during most of the year, its use in the food industry and, in recent times due to a significant increase in face of the generalized worry about the SARS-CoV-2 virus (COVID-19) (Morales, 2021).

Until the year 2021, the main strawberry-producing countries were China with 6,770,098.38 t, the United States of America (USA) with 1,211,090 t, Mexico with



669,195 t, Turkey with 542,890.63 t, and Egypt with 470,913.1 t, which contribute more than 76% of the total volume of global production. In addition, the main exporting countries until 2021 were Spain with 316,413.06 t, Mexico with 182,540.49 t, USA with 137,495.29 t, Greece with 68,427.36 t, and the Netherlands with 65,592.36 t; Mexico stands out as the third producer and second exporter of strawberry in the world (FAOSTAT, 2022).

In the country, during the fall-winter agricultural cycle of the year 2020, there were a total of 9,342 ha of strawberry, with production of 425,007 tons. The main producing states are: Michoacán (66.86%), Baja California (31.21%) and Baja California Sur (1.50%), states that generate 99.57% of the total national production of strawberry (SIAP, 2020).

Micropropagation methods play an important role for the mass production of pathogen-free strawberry plants, at low cost, in reduced spaces, and in short periods of time. In addition, they allow ensuring the compliance of specific safety, genetic and quality standards that are required for the certification of the plant material. The strawberry crop is established using the asexual multiplication of runners obtained from "mother" plants. Thus, in a hectare with around 80,000 strawberry plants, and with an average of 7 daughter plants for each "mother" plant, approximately 11,428 "mother" plants per hectare are required annually, which can be used during a period of four years (Rodríguez *et al.*, 2012; Fondo Sectorial de Investigación, en materia agrícola, Pecuaria, Acuacultura. Agrobiotecnología y Recursos Fitogenéticos, 2012). In the case of strawberry production for export, producers in Mexico import varieties of "mother" plants from the USA such as Festival, Camino Real, Sweet Charly, Camarosa and Albión. This practice has been conducted since the 1950s causing not only the technological dependency on such plant material, but also for producers to face high prices representing up to 26.3% of the total production costs (Olmos *et al.*, 2015). In the presence of this situation, producers have stated the need to have more inexpensive and productive national varieties, with quality fruits that can compete in flavor and consistency with the imported strawberries (Barrera and Sánchez, 2003).

Research institutions such as Colegio de Postgraduados, in collaboration with Universidad Michoacana de San Nicolás de Hidalgo, have developed the varieties CP-Zamorana, CP-Jacona, CP-Roxana and CP-Paola, designed for the producing zone in Michoacán, the most important in the country (Rodríguez *et al.*, 2012). For its part, the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, in collaboration with the Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional, have developed the varieties Buenavista, Cometa, Nikté and Pakal. The varieties cited have been developed as a more inexpensive alternative for strawberry producers in the country, and at the same time, allowing the reduction in technological dependency on the United States (Dávalos *et al.*, 2011).

Under the premise that the CP-Jacona variety presents similar characteristics to the varieties imported in terms of high yields, presence of large fruits, excellent flavor, early maturity, lower degree of acidity, and high percentage of exportable fruit (Calderón *et al.*, 2009; Bolaños *et al.*, 2008), this study suggests that the production price of this variety is

similar or even lower in comparison to imported varieties such as Festival or Camarosa. Based on interviews carried out with private businesses, the import prices of these varieties ranged between $25.00 MX and $36.00 MX during 2022. Thus, the import price will be compared to the production prices of "mother" plant obtained under the *in vitro* Traditional System (TS) and the Temporary Immersion System (TIS). In this regard, it is expected that the use of these micropropagation systems will have an impact on the reduction of production costs due to the high production scale. By its nature, the number of plants that can be obtained through in vitro plant micropropagation is unlimited, the space required is minimal, and the time when the process can be conducted is relatively short in comparison to the traditional commercial propagation method (Domínguez *et al.*, 2008).

Micropropagation through the TS is an alternative used successfully since the 1970s, and it allows efficiency in the propagation of crops, obtaining material of high genetic and phytosanitary quality; on the other hand, TIS was created in 1995 by the CIRAD (La Recherche Agronomique Pour Le Développement, 2009) and have the characteristics of semi-automatization of some micropropagation stages, in addition to a reduction in the loss of plant material as a result of more control over the process (Castillo *et al.*, 2020).

The TS allows a numerous production of plants; however, in the multiplication phase, due to the use of specialized labor and gelling agents such as microbiology growth culture medium (agar), the costs increase significantly (Pérez *et al.*, 1998; Adelberg *et al.*, 2007). TIS is a viable alternative in comparison to the TS, because of high micropropagation rate and by the substitution of the gelling agent by a programmed immersion system. Still, although the use of bioreactors reduces production costs in obtaining plants in 50 to 60% (Domínguez *et al.*, 2008, Winkelman *et al.*, 2006), the initial investment costs can be significant.

In general, plant micropropagation consists of 6 phases: selection of plant material, preparation of the culture medium, disinfection of plant material, establishment, multiplication, rooting, and acclimation. In this study, since it is a comparison of costs between TS and TIS, it stands out that acquiring plant material represent an important cost in both systems. That is, the installation and acquisition of laboratory equipment such as laminar flow hood, agitator, sterilizer, represent a high cost in both systems, as well as the essential micronutrients for the *in vitro* micropropagation. In the TS in particular, inputs such as the gelling agent (agar), containers for the propagation and multiplication, and the workforce are important costs for the production system, while the acquisition and installation of bioreactors is the main cost in TIS.

According to the certification program from California, the phases of propagation take place during the first 5 conventional clone generations from the "mother" plant (nuclear stock) (Dávalos *et al.*, 2011).

It is important to highlight that the "mother" plant imported to Mexico is a plant in the last sequence of propagation (certified plant). The "mother" plant generated in Colegio de Postgraduados is a plant that, according to the propagation sequence (Table 1), is from "nuclear stock" since it is only multiplied in *in vitro* medium for one month, to later be transported to greenhouses for the acclimation stage, and finally, to be sold to nursery keepers who will propagate it for the next 2 years to generate a

"registered plant" that will be distributed to strawberry producers. One of the main benefits for strawberry producers to receive "registered plants" is that they will obtain higher strawberry yields, plant of better quality, longer life in plantations, and/or higher strawberry productivity.

MATERIALS AND METHODS

The research was done during the years 2021-2022 in Colegio de Postgraduados, Campus Montecillo, with information from the Graduate Studies Program in Genetic Resources and Productivity-Fruit Growing. The "mother" plant that is used in the production area was generated from 2,000 annual explants for each of the systems, extracted from the strawberry "mother" plant of the CP-Jacona variety, to later become established in an *in vitro* medium in TIS and TS, in the temporary immersion laboratory of the general laboratory area, which is a basic laboratory with level 2 biosafety, in a risk 2 group, according to the classification of the World Health Organization (WHO) and which has dimensions of 125 m^2.

In the acclimation stage, dome trays with 100 cavities were used in a greenhouse of 2500 m^2, which is a curved-roof greenhouse with an intermediate level of technology and approximate value of $200,000.00 MX, property of Colegio de Postgraduados Campus Montecillo.

Taking into consideration that comparing the prices of the imported "mother" plant with those of the national "mother" plant will be carried out, the source of information is described next. The sale prices in Mexico of the imported strawberry "mother" plant, of varieties Festival or Camarosa from USA and the European Union, were obtained through interviews with private businesses, and they range between $25.00 MX and $36.00 MX. In the case of the prices of the national "mother" plant, they were obtained from the production costs of the "mother" plant both for the *in vitro* traditional system (TS) and for the *in vitro* Temporary Immersion system (TIS). The information of costs was obtained from interviews with experts in the topic and private companies that supply biotechnological equipment. Based on these costs, a profit was estimated from the CETES (Certificados de la Tesorería de la Federación, Treasury Certificates) rate at 364 days in the period 2021-2022, which was 11.13%.

For each system, the real Total Costs (TC) were determined, subdivided into Variable Costs (VC) and Fixed Costs (FC); they were counted for a period of 10 years, which is the

Table 1. Stages and categories of plant according to the certification program from California, USA.

Year	Propagation Sequence	Propagation Sites
1	Nuclear Stock	Greenhouses
2	Multiplication of nuclear plant	Greenhouses
3	Foundation plant	Nurseries
4	Registered Plant	Nurseries
5	Certified Plant	Nurseries

Source: Taken from Dávalos *et al.*, 2011.

depreciation period given for the fixed asset costs, with the exception of the laboratory and the greenhouse, based on the "Guide for estimated useful life and depreciation percentages" published in the DOF on August 15, 2012. The National Consumer Price Index (NCPI) from December 2022 was considered to carry out the calculation of real costs and revenues.

Next, the Unitary Cost (UC) is calculated in each of the systems, and this will allow understanding the convenience in the use of a specific system based on the period and number of plants obtained.

Later, the potential revenues (Y) of each system were calculated. For the calculation of said revenues, the costs generated in each of the systems will be taken into account, to which will be added the benefits that should be generated if those costs were invested at a CETES rate (i), and the result will be the expected income in each system (Equation 1).

$$Y = \left(Benefits + costs \right) \tag{1}$$

Based on the potential revenues, the price per "mother" plant is obtained, as well as the number of "mother" plants generated in each of the systems, and with this, the convenience of acquiring the imported "mother" plant versus the national one will be determined.

RESULTS AND DISCUSSION

To begin with the calculation of the Costs and Revenues, it is essential to understand the productivity in each of the systems; this study starts in the year 2022 and suggests a projection until the year 2031. Based on previous studies conducted by the Postgraduate Program in Genetic Resources and Productivity-Fruit Growing, TIS generate 5.8 plants per explant, while the TS generates 2.3 plants per explant.

Although one of the advantages in both in vitro systems (TS and TIS) is spatial efficiency, it is true that space is not a limited resource, and this is why some of the main limitations in this study are the size of the laboratory and the nursery. In this regard, the establishment of 2,000 explants annually in each of the systems is suggested, which will increase annually at a rate of 5.8 explants in the case of TIS (10 explants are established by bioreactor), and 2.3 in the case of TS (one explant per assay tube), with losses from manipulation of 2% and 4%, respectively, for the systems mentioned (Table 2).

Based on this level of productivity and the limitations of the research, the "mother" plant produced was destined to supplying plants in nurseries (50%), while the rest was destined to the micropropagation process (50%) (Table 3).

In both systems, the FC and VC vary and increase since they depend on the level of production. In the case of TIS, the FC associated to bioreactor modules of 1 liter capacity stand out, which increase annually in function of the productivity requirements. Other important FC are those related to micronutrients, acquiring plant material, and substrates such as agrolite or peat moss. It is important to mention that because of the automation present in TIS, production costs are reduced because less labor is employed and no gelling agents are required (Table 4).

Table 2. Annual production of "mother" plant in TIS and TS.

Year	Traditional System		Temporary Immersion System	
	Explants production	Mother plant production	Explants production	Mother plant production
2022	2,000	4,416	2,000	9,957
2023	2,208	4,875	4,978	24,784
2024	2,438	5,382	12,392	61,693
2025	2,691	5,942	30,847	153,567
2026	2,971	6,560	76,784	382,260
2027	3,280	7,242	191,130	951,522
2028	3,621	7,995	475,761	2,368,528
2029	3,998	8,827	1,184,264	5,895,740
2030	4,413	9,745	2,947,870	14,675,676
2031	4,872	10,758	7,337,838	36,530,693
Total	32,493	71,744	12,263,864	61,054,422

Source: Prepared by the authors, 2023.

Table 3. Destination of production.

Year	Traditional System		Temporary Immersion System	
	Plant nursery	Micropropagation	Plant nursery	Micropropagation
2022	2,208	2,208	4,978	4,978
2023	2,438	2,438	12,392	12,392
2024	2,691	2,691	30,847	30,847
2025	2,971	2,971	76,784	76,784
2026	3,280	3,280	191,130	191,130
2027	3,621	3,621	475,761	475,761
2028	3,998	3,998	1,184,264	1,184,264
2029	4,413	4,413	2,947,870	2,947,870
2030	4,872	4,872	7,337,838	7,337,838
2031	10,758		36,530,693	
Total	41,251	30,493	48,792,558	12,261,864

Source: Prepared by the authors, 2023.

Table 4. Principal real costs during the propagation period in TIS (in MX pesos base 2022).

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
National consumer price index	**7.90%**	**6.27%**	**3.89%**	**3.28%**	**3.09%**	**3.03%**	**3.01%**	**3.01%**	**3.01%**	**3.01%**
Plants	9,957	24,784	61,693	153,567	382,260	951,522	2,368,528	5,895,740	14,675,676	36,530,693
Total cost	1,435,631	845,955	1,271,203	2,396,816	4,430,667	9,935,928	23,274,875	55,688,433	143,928,441	321,661,221
Unit cost	$144	$34	$21	$16	$12	$10	$10	$9	$10	$9

Source: Prepared by the authors.

For the case of the TS, the most important costs are the acquisition of plant material, agar, workforce (WF), and the use of containers for micropropagation (Table 5).

In that regard, while the Total Cost (TC) in the propagation period is lower in the TS compared to the TIS, the Total Unitary Cost (TUC) is lower in TIS than in TS. As a result, the Average Total Unitary Cost (ATUC) is lower in TIS compared to TS (Table 6).

To calculate the potential income (Y), the costs per system were taken into account, to which the benefits were added that would be generated under the assumption that the amount corresponding to the costs had been invested in CETES (i) (Table 7).

Finally, the price of the "mother" plant of imported varieties which ranges between $25.00 MX and $36.00 MX was compared with the estimated price in each system. For this purpose, the expected income was divided by the number of plants produced in each of the systems, which resulted in an average price per "mother" plant of $170.00 MX and $10.00 MX for TS and TIS, respectively (Table 8).

It can be appreciated that starting on the third period (year 2024), the price in TIS is lower compared to the imported varieties; however, this system has the disadvantage that

Table 5. Principal real costs during the propagation period in the TS (in MX pesos base 2022).

year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
National consumer price index	**7.90%**	**6.27%**	**3.89%**	**3.28%**	**3.09%**	**3.03%**	**3.01%**	**3.01%**	**3.01%**	**3.01%**
Plants	4,416	4,875	5,382	5,942	6,560	7,242	7,995	8,827	9,745	10,758
Total cost	1,844,963	1,061,835	1,028,603	1,238,787	980,323	959,498	951,184	1,120,237	904,689	889,835
Unit cost	$418	$218	$191	$208	$149	$132	$119	$127	$93	$83

Source: Prepared by the authors, 2023.

Table 6. Total unitary cost (in MX pesos base 2022).

		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	ATUC
TIS	TUC	$160	$38	$23	$17	$13	$12	$11	$10	$11	$10	$10
TS	TUC	$464	$242	$212	$232	$166	$147	$132	$141	$103	$92	$170

Source: Prepared by the authors, 2023.

Table 7. Income Budget (in MX pesos base 2022).

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Temporary immersion system income	$1,595,273	$940,025	$1,412,560	$2,663,342	$4,923,358	$11,040,804	$25,863,041	$61,880,987	$159,933,284	$357,429,949
Traditional system income	$2,050,123	$1,179,912	$1,142,984	$1,376,541	$1,089,335	$1,066,194	$1,056,956	$1,244,808	$1,005,290	$988,784

Source: Prepared by the authors, 2023.

Table 8. Price of the "mother" plant (in MX pesos base 2022).

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Temporary immersion system price	$160	$38	$23	$17	$13	$12	$11	$10	$11	$10
Traditional system price	$464	$242	$212	$232	$166	$147	$132	$141	$103	$92

Source: Prepared by the authors, 2023.

its costs are higher compared to costs in TS, so the investor should evaluate adequately both the amount to be invested and the size of the market to be supplied.

Based on the results obtained, the following advantages are confirmed when implementing TIS compared to TS: 1) Automatization of its processes (Preil, 2005; Ziv, 2005), which allows providing more uniform growing conditions during the micropropagation process (Adelberg, 2007); 2) greater productive efficiency (Delfino *et al.*, 2020); 3) lower loss caused by manipulation (Quiala *et al.*, 2012; Cruzat, 2009; Pérez *et al.*, 1998); 4) reduction between 50% and 60% in production costs per plant (Winkelman *et al.*, 2006), as consequence of the mechanization of some of the micropropagation stages (Castillo *et al.*, 2020); and 5) lower price in TIS compared to the imported varieties.

CONCLUSIONS

This study shows that the price of the plant variety CP-Jacona estimated from the third production period through TIS was lower than the price of the imported varieties, Festival or Camarosa. The reasons that explain this result were due to both the high production rate and the low rate of losses caused by the plant manipulation. On the other hand, despite the lower prices obtained through TIS compared to the TS, TIS require greater amounts of investment which need to be assessed.

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Microhistological References of Plants Available for Ungulates in Sonora, Mexico

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ABSTRACT
The microhistological technique is the most popular methodology used to determine the wild and domestic ungulates diet; its success depends on the development of a reliable reference catalog.
Objective: To describe and analyze the epidermal structures of the plants available for wild and domestic ungulates in Sonora, Mexico, using the microhistological technique.
Methodology: A comprehensive collection of the plants available for wild and domestic ungulates was carried out at UMA Rancho Noche Buena, in order to subsequently identify their genus and species. Plant structures were analyzed with the modified microhistological technique, scraping the beam and underside cuticle of leaf plants. In addition, at least one photograph was taken to characterize them.
Results and Discussion: The epidermal structures of 95.95% of the analyzed plants were observed with the microhistological technique and its modification. The distinctive structures of 74 plant species were identified, in order to describe the main characteristics of each species. A catalog of microhistological references was developed from the data collected; it included information about the morphology and arrangement of structures such as: epidermal cells, stomata and trichrome. A difference was found between the beam and underside of the leaves in 23% of the species.
Conclusion: A reliable microhistological reference catalog should consider possible differences between the beam and underside of the leaves of plants.

Keywords: Scraping, beam, underside, leaves.

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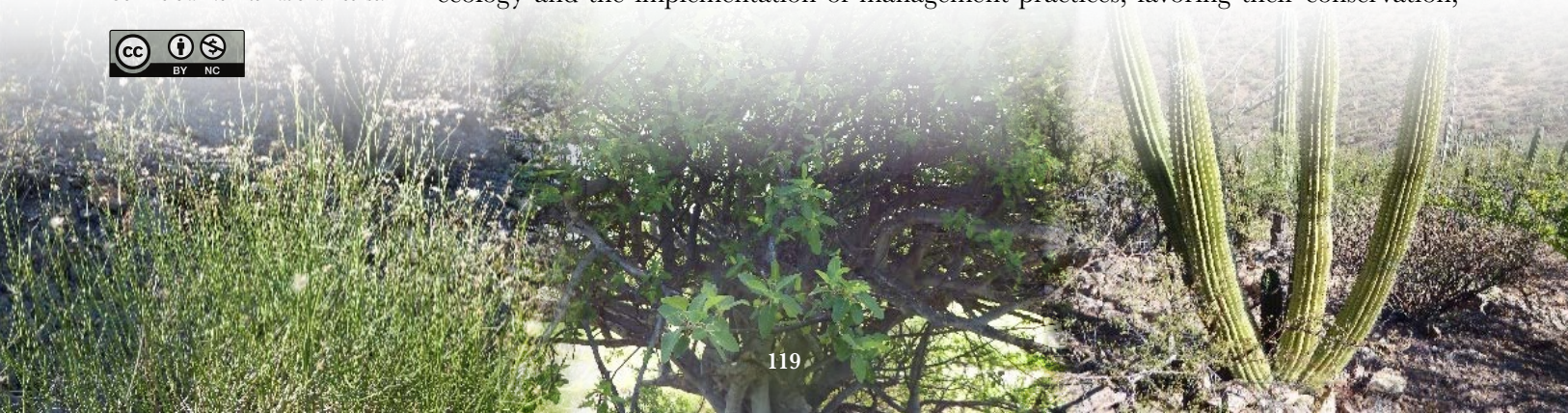
INTRODUCTION

Hunting in northern Mexico is one of the most successful wildlife management activities in the country (Valdez *et al.*, 2006). A large number of ranches in Sonora (categorized as Wildlife Conservation Management Units [UMAs]) have benefited economically from the sale of hunting licenses. Various herbivores —especially mammals, such as bighorn sheep, mule deer, white-tailed deer, and collared peccary— are hunted each year, providing an important economic benefit for the state (Guajardo-Quiroga and Martínez-Muñoz, 2004). In many cases, the sustainable use of these animals involves knowledge of their ecology and the implementation of management practices, favoring their conservation,



as well as knowledge of their food resources. Different techniques were used to determine the herbivores diet, including behavioral observation, NIRS, stable isotopes, and DNA. However, one of the most popular techniques was microhistology, proposed by Baumgartner *et al.* (1939) and modified by Sparks and Malechek (1968) (Garnick *et al.*, 2018). It is based on the identification and quantification of digestion-resistant epidermal tissues found in the stomach, rumen, or excreta contents (Holechek *et al.*, 1982). On the one hand, its main advantages are its low cost and non-invasiveness; on the other hand, its main disadvantage is the time investment required to train the personnel that will develop the reference catalogue (Holechek, 1982; Garnick *et al.*, 2018).

The catalogue or references is a set of images (photographs or drawings) and descriptive notes of leaf epidermal structures; they are representative of each plant found in the habitat of the herbivore under study (González and Améndola, 2010). The possible differences between the beam and underside of the same leaf should be taken into consideration, since they are sometimes recorded as if they belonged to different species. A comprehensive and representative catalogue of the plants available in the habitat is one of the essential components of the technique and it helps to determine diets with a high level of accuracy (Alipayo *et al.*, 1992; Cuartas and García-González, 1996; Garnick *et al.*, 2018). Epidermal scraping (González and Améndola, 2010) is one of several procedures used to obtain the epidermal tissues to be analyzed (Catán *et al.*, 2003; Castellaro *et al.*, 2007; González and Améndola, 2010; Arellano *et al.*, 2019). It keeps intact the structures used to characterize and describe the epidermal conformation of the leaves of each plant species. Moreover, two additional advantages are that it requires few inputs and that its application is relatively simple.

The aim of this study was to describe and analyze the plants available to wild and domestic ungulates in Sonora, Mexico, using the microhistological technique.

METHODOLOGY

Description of the study area

The Management Unit for Wildlife Conservation (UMA) Rancho Noche Buena is located in the southern Sonoran Desert, 120 km northwest of Hermosillo and 14.2 km away from the Sea of Cortez (29° 12' 19.45" N, 112° 0' 22.80" W). Its 16,800 ha are the natural habitat of bighorn sheep, mule deer, white-tailed deer, and collared peccary, although cattle has been introduced to the area. Climate is classified as BWh(x'), the average temperature is 22.3 °C (coldest, −1.5 °C; hottest, 47 °C), and the average rainfall varies from 172.9 to 193.9 mm (López *et al.*, 1999; García, 2004; SMN, 2019). The predominant vegetation is arbosufrutescent scrub, sarcocaulescent scrub, and crassicaule scrub. The most relevant species are *Carnegie gigantea*, *Pachycereus pringlei*, *Cylindropuntia* spp., *Olneya tesota*, *Parkinsonia microphylla*, and *Bursera microphylla* (López *et al.*, 1999; León *et al.*, 2018).

Sample collection and preparation of the reference catalogue

From August to October 2018, an extensive plant collection was carried out at UMA Rancho Noche Buena. Taxonomic identification of the collected material was then carried

out with the support of Mr. Diego Valdez Zamudio (ScD), a specialist in the vegetation of Sonora and in the literature regarding the flora of northwestern Mexico (Shreve, 1951; León *et al.*, 2018; SEINet, 2019).

The reference catalogue was developed following the methodology described by González and Améndola (2010). Leaves were hydrated for one day and the epidermis —both on the beam and the underside— was scraped with a razor blade and then rinsed with 12% sodium hypochlorite. The epidermal tissues obtained were then mounted on a slide with glycerin jelly and placed on a 24×40 mm slide. The samples were labelled, stored, and left to settle for two weeks. Three preparations were made for each species. Once the mounting medium had solidified, representative areas of each of the epidermal tissues were located using a Leica® microscope with a 10x objective; based on those tissues, the epidermal structures of each species was described. Photographs were taken of the representative areas using a Nikon D5600 camera (Annex 1).

Description of epidermal structures and data analysis

Characterization took into consideration the easily identifiable structures (cells, stomata, trichomes) and special structures, as well as the differences between the beam and underside of the same species (Peña and Habib, 1980; González and Améndola, 2010). Epidermal cells were catalogued according to the combination of factors specific to both the cells that make up the regular epidermis and other cells or structures, such as stomata, trichomes and glands. In the case of epidermal cells, their arrangement (irregular or regular), shape (puzzle piece, polygonal, irregular, or rectangular), and size (small, medium, or large) were taken into account. Cell wall specificities such as thickness (thick, medium, or thin), levels of undulation (faint, short, or deep), and texture (smooth, striated, or granular) were also considered.

Stomata were classified according to their shape (oval, elongated oval, round, or rhombic), size (small, medium, and large), orientation (random and unidirectional), and arrangement (actinocytic, anisocytic, anomocytic, cyclocytic, diacytic, exposed, hexacytic, implanted, unexposed, paracytic, pentacytic and tetracytic). Trichomes were classified according to their type (simple unicellular, unicellular with two branches, unicellular with bulbous base, glandular unicellular, simple bicellular, simple multicellular, multicellular stellate, multicellular vesicular and glandular). The following special structures were recorded: asperidia, cork cells, silica cells, crystals, druses, glands, papillae, raphidia and tannins.

RESULTS AND DISCUSSION

The catalog of microhistological references of vegetation at UMA Rancho Noche Buena was developed using the epidermal tissues of 74 species from 25 taxonomic families (Table 1 and Annex 1). The highest number of species were recorded for Fabaceae, Euphorbiaceae, and Cactaceae, with 11, 8, and 7 species, respectively. The microhistological structures of 71 species (95.95%) could be observed without any difficulty; on the contrary, certains structure were difficult to observe in the following three species (4.05%): *Abutilon incanum*

and *Solanum hindsianum* (due to the high density of trichomes) and *Bebbia juncea* (because the size and structure of leaves prevented the scraping).

As a result of the characterization, 86.5% of the species were determined to have an irregular cell arrangement, 12.2% a regular arrangement and 1.4% could not be observed. The shape proportion of the cell walls were classified as follows: 42.5% irregular (17.2% with short undulations, 14.9% with faint undulations, and 10.3% with deep undulations), 41.4% polygonal (32.2% with straight cell walls and 9.2% with faint undulations), 11.5% rectangular (6.9% with short undulations, 2.3% with faint undulations, 1.1% with straight cell walls, and 1.1% with deep undulations), 2.3% oval, and 2.3% not observed. Cell texture was 54.1% smooth, 29.7% granular, 12.2% striated, and 4.1% not observed. Regarding this same collection, epidermal cell size was considered as medium (43.4%), small (34.2%), large (19.7%), and not observed (2.6%). Finally, cell walls were determined to be thin (56.8%), thick (39.2%) and not observed (4.1%).

Regarding their shape, stomas were oval (61.0%), elongated oval (16.9%), round (15.6%), rhombic (2.6%), and not observed (3.9%). In terms of their size, stomas were medium (37.7%), small (32.5%), large (26.0%) and not observed (3.9%). Regarding their orientation, 71.6% of the stomas were random, 23% were unidirectional and 5.4% were not observed. The stomatal arrangement was 29.6% tetracytic, 20.4% anisocytic, 11.2% paracytic, 9.2% pentacytic, 7.1% exposed, 6.1% hexacytic, 5.1% cyclocytic, 4.1% unexposed, 2.0% actinocytic, 2.0% diacytic, 2.0% implanted and 1% anomocytic.

Trichomes were recorded in 68.9% of the species. In proportion to their type, trichomes were unicellular simple (45.6%), simple bicellular (12.3%), simple multicellular (10.5%), multicellular stellate (8.8%), unicellular with two branches (7.0%), unicellular glandular (5.3%), multicellular glandular (5.3%), vesicular (3.5%), and unicellular with bulbous base (1.8%).

Special structures were observed in 71.6% of the species, divided as follows: 25.7% druses, 21.4% tannins, 12.9% raphidia, 11.4% papillae, 10.0% cork cells, 8.6% silica cells, 4.3% glands, 2.9% crystals and 2.9% asperidia.

In 23% of the species, differences between the beam and the underside were observed. These differences accounted for 55.6% of the cell shape, 11.1% greater abundance of trichomes on the underside, 11.1% more abundant trichomes on the upper side, 11.1% stomata only on the underside, 5.6% trichomes only on the underside and 5.6% in cell size.

Characterization allowed to identify patterns for different plant families and species. The most representative characteristics of family Poaceae were regular cell arrangement, rectangular cell shape, unidirectional stomata, and the presence of asperidia, silica cells, and cork. Family Cactaceae was characterized by polygonal cell shape, unidirectional stomata, and absence of trichomes. For their part, most of the species of family Fabaceae had simple unicellular trichomes and tannins. Finally, Zygophyllaceae had unicellular simple trichomes and papillae, while Malvaceae had a high density of stellate trichomes.

The modification proposed by González and Améndola (2010) for the development of the reference catalog proved to be a reliable tool for the identification of epidermal structures (cells, stomata, trichomes, special structures, and beam/underside differences) and for the characterization of plant species at UMA Rancho Noche Buena.

Table 1. Comparison matrix of the epidermis of vegetation at UMA Rancho Noche Buena, Sonora, Mexico.

Family	Species	Cells					Stomas				Trichomes	Special Structures	Beam/underside difference
		Arrangement	Shape	Texture	Size	Cell wall	Shape	Size	Orientation	Arrangement	Type		
Acanthaceae	*Justicia californica*	I	Po	L	P	Gr	O	M	A	Di y Ani	Bs	Dr	
	Ruellia californica	I	Ip	L	M	D	Oa	M	A	Di	Us		
Aizoaceae	*Trianthema portulacastrum*	I	It	Es	G	D	O y Red	G	A	Tet		Dr	
Amaranthaceae	*Amaranthus palmeri*	I	It[1] Ip[2]	L	P	D	O	P	A	Ani y Tet			Fc
	Tidestromia lanuginosa	I	Ip	L	G	D	O	M	A	Ano	Us	Ra	
Asteraceae	*Ambrosia dumosa*	I	Ic[1] It[2]	L	P	D	O	P	A	Ani	Ps	Gl	
	Bebbia juncea	I	Po	N	M	N	N	N	N	N	Ps		
	Encelia farinosa	I	Ic	L	P	D	O	M	A	Tet	Us y V	Gl	Te
	Pectis rusbyi	I	Ip	L	G	D	Oa	G	U	Tet		Ra	
	Trixis californica	I	It	Gra	M	Gr	Oa	G	A	He	Ps		
Boraginaceae	*Cordia parvifolia*	I	Po[1] Ic[2]	L	P	D	O	M y G	A	Tet	Ud		Fc
Burseraceae	*Bursera laxiflora*	I	Po	Es	M	D	O	M	A	He		Dr	Ee
	Bursera microphylla	I	Po	L	P	D	O	M	A	Pen			
Cactaceae	*Carnegiea gigantea*	I	Po	Gra	M	Gr	Red	G	U	Ci			
	Cylindropuntia fulgida	I	Po	L	P	Gr	O	M	U	Ci		Dr	
	Cylindropuntia thurberi	I	Po	L	P	D	Red	M	U	Ci		Dr	
	Ferocactus wislizenii	I	Po	Es	G	Gr	O	G	U	Par			
	Lophocereus schottii	I	Ic	Es	G	Gr	O	G	A	Par			
	Pachycereus pringlei	I	Po	Es	P	Gr	O	G	A	Ci		Dr	
	Stenocereus thurberi	I	Po	Gra	M	Gr	Oa	M	U	Par			
Euphorbiaceae	*Croton sonorae*	I	Ic	L	P	D	O	P	A	Tet	Pe y Us	Dr	
	Ditaxis lanceolata	I	Po	L	M	Gr	Oa	M	A	Par y Tet	Ud	Dr	Th
	Euphorbia eriantha	I	Po	Gra	M	D	O	P	A	Ani y Tet	Ps	Ra	Ts
	Euphorbia hyssopifolia	I	Ic[1] Ip[2]	Gra	M	Gr	O	P	A	Ani y Tet	Bs	Dr, Pa y Ra	
	Euphorbia prostrata	I	Pt[1] It[2]	Gra	G	Gr	O	P	A	Ani		Dr	Fc
	Jatropha cinerea	I	Po	Es	M	Gr	O	M	A	Tet	Us	Dr	
	Jatropha cuneata	I	Po	Gra	M	D	O	M	A	Tet			
	Sebastiania bilocularis	I	Po	L	P	Gr	Red	M	A	Par y Tet		Dr	
Fabaceae	*Caesalpinia palmeri*	I	Ic	Es	G	Gr	O	P	A	Tet	Us		

Table 1. Continues...

Family	Species	Cells					Stomas				Trichomes	Special Structures	Beam/underside difference
		Arrangement	Shape	Texture	Size	Cell wall	Shape	Size	Orientation	Arrangement	Type		
Fabaceae	*Dalea mollissima*	I	Ic	Gra	P	D	O	P	A	Tet	Us		
	Ebenopsis confinis	I	Po	Gra	M	D	O	P	A	Ac	Us	Dr y Ta	
	Eysenhardtia orthocarpa	I	It^1 Ic^2	Gra	M	Gr	Oa	P	A	Ani y Tet	Us	Dr y Ta	Ee
	Mariosousa willardiana	I	Pt	Gra	M	D	Oa	P	A	Par		Ta	
	Mimosa laxiflora	I	It	L	M	D	O	P	A	Par y Ani			
	Olneya tesota	I	Po	Gra	P	Gr	O	P	A	Ani y Tet	Us	Ta	
	Parkinsonia microphylla	I	Po	Gra	P	D	O	P	A	Tet	Us	Ta	
	Phaseolus grayanus	I	Ip	L	G	D	O	M	A	Par	Us		
	Prosopis juliflora	I	Po	Gra	M	Gr	O	P	A	Par	Us	Ta	
	Senna covesii	I	Po	Gra	M	D	O	G	A	Par y Ani	Us	Ta	
Fouquieriaceae	*Fouquieria splendens*	I	Po	L	P	Gr	O	G	A	Pen y He		Pa	
Krameriaceae	*Krameria erecta*	I	Pt	L	M	D	O	G	U	Tet y Pen	Us	Ta	
Linaceae	*Linum lewisii*	I	Ic	L	M	D	Red	P	U	Ani	Ud		
Loasaceae	*Mentzelia pumila*	I	Ic^1 Po^2	L	P	D	Re y O	G	A	Pen y He	Ub	Ra	Fc
Malpighiaceae	*Callaeum macropterum*	I	It	Es	M	D	Oa	G	A	Tet	Ud	Dr	
	Galphimia angustifolia	I	Ic	Gra	G	D	Oa	G	A	Tet		Ta	
Malvaceae	*Abutilon incanum*	N	N	N	N	N	N	N	N	N	Pe		
	Hibiscus denudatus	I	Po	L	M	D	Oa	M	N	N	Pe	Gl	
	Melochia tomentosa	I	Po	L	P	D	O	M	A	Ani y Tet	Pe y Ug		
Nyctaginaceae	*Allionia incarnata*	I	It	Gra	M	Gr	O	M	A	Ani y Tet	Pg	Ra	
	Boerhavia coccinea	I	Pt^1 It^2	Gra	G	Gr	O	G	A	Ani y Tet	Ug	Ra y Cr	Fc
	Boerhavia coulteri	I	Pt^1 Ic^2	Gra	M	Gr	Red	G	A	Tet	Ug	Ra	Fc
Passifloraceae	*Passiflora arida*	I	Ic	L	P	D	Red	P	A	Pen y He	Us	Ta	
	Passiflora quercetorum	I	Ip	L	M	D	O	M	A	Ani y Tet	Us	Dr	Th
Plantaginaceae	*Pseudorontium cyathiferum*	I	It^1 Ip^2	L	P	D	O	P	A	Ani	Pg		Fc
Poaceae	*Aristida ternipes*	R	Rc	L	P	Gr	Oa	M	U	Im	Bs	Cc	
	Bouteloua aristidoides	R	Rc	L	M	Gr	Red	M	U	Im	Bs y Us	Cs	
	Bouteloua barbata	R	Rc^1 Rp^2	Gra	M^1 P^2	D	O	P	U	Im	Us	Cs, Cc y As	Fc y Tc
	Cathestecum erectum	R	Rc	L	P	D	O	M	U	Im	Bs	Cs y Pa	

Table 1. Continues...

Family	Species	Cells					Stomas				Trichomes	Special Structures	Beam/underside difference
		Arrangement	Shape	Texture	Size	Cell wall	Shape	Size	Orientation	Arrangement	Type		
Poaceae	*Cenchrus ciliaris*	R	Rt	L	M	Gr	Ro	G	U	Ex	Bs	Cc	
	Echinochloa colona	R	Rc	L	G	D	O	M	U	Im	Bs	Cc, Cs y As	
	Eragrostis pectinacea	R	Rc^1 Re^2	L	M	D	Ro	M	U	Im		Cs y Cc	Fc
	Eriochloa acuminata	R	Rt	L	M	D	Red	M	U	Im	Us	Cr, Ta y Cc	
	Panicum hirticaule	R	O	L	G	D	O	G	U	Ex	Us	Cs y Cc	
Rhamnaceae	*Colubrina viridis*	I	Pt	Gra	G	D	O	M	A	Ani y Tet		Ra	
Sapindaceae	*Cardiospermum corindum*	I	Ip	L	M	D	O	P	A	Tet	Us y Gl	Ta	
Simmondsiaceae	*Simmondsia chinensis*	I	Po	Gra	P	Gr	Red	P	A	Ci	Ps	Dr y Ta	
Solanaceae	*Datura discolor*	I	Pt^1 Ic^2	L	M	D	O	P y M	A	Ani y Tet	Ps	Dr y Ta	Fc
	Lycium berlandieri	I	O	L	G^1 y P^2	Gr	O	P y M	A	Ani y Pen		Pa	
	Solanum hindsianum	I	N	N	N	N	N	N	N	N	Pe		
Verbenaceae	*Lippia palmeri*	I	Po	L	M	Gr	O	M	A	Par y Ani	Us y V		Te
Zygophyllaceae	*Fagonia laevis*	I	Ic	L	M	D	Oa	M	A	Pen y He		Pa	
	Kallstroemia parviflora	I	It	L	P	D	Oa	M	A	Tet y Pen	Us	Pa	
	Larrea tridentata	I	Po	L	P	Gr	O	P	A	Ac	Us	Pa	
	Tribulus terrestris	I	Pt	Es	G	Gr	O y Red	P	A	Pen	Us	Pa y Ta	

Abbreviations and symbols:
Epidermal cells
- Arrangement: I, irregular; R, regular; and N, not observed.
- Shape: Po, polygonal; Ip, irregular with deep undulations; It, irregular with faint undulations; Ic, irregular with short undulations; Pt, polygonal with faint undulations; Rc, rectangular with short undulations; Rp, rectangular with deep undulations; Rt, rectangular with faint undulations; Re, rectangular; O, oval; N, not observed; 1, beam; 2, underside.
- Cell texture: L, smooth; Es, striated; Gra, granular; N, not observed.
- Size: P, small; M, medium; G, large; N, not observed.
- Cell wall: D, thin, Gr, thick; N, not observed.
Stomata
- Shape: O, oval; Oa, elongated oval; Red, round; Ro, rhombic.
- Size: P, small; M: medium; G, large; N, not observed.
- Orientation: A: random; U, unidirectional; N, not observed.
- Arrangement: Di, diacytic; Ani, anisocytic; Ac, actinocytic; Ano, anomocytic; Tet, tetracytic; He, hexacytic; Pen, pentacytic; Ci, cyclocytic; Par, paracytic; Im, implanted; Ex, exposed; N, not observed.
Trichomes:
- Type: Bs, simple bicellular; Us, simple unicellular; Ps, simple multicellular; V, vesicular; Ud, unicellular with two branches; Pe, multicellular stellate; Ug, unicellular glandular; Gl, glands; Pg, multicellular glandular; Ub: unicellular with bulbous base.
Special structures: Dr, druses; Ra, raphidia; Gl, glands; Pa, papillae; Ta, tannins; Cr, crystals; Cc, cork cells; As, asperidia; Sc, silica cells.
Difference between beam and underside: Ee, stomata only on underside; Fc, cell shape; Tc, cell size; Te, trichomes more abundant on the underside; Th, trichomes more abundant on the beam; To, trichomes only on the underside.

Although various modifications have been proposed for the development of the reference catalog (Catán *et al.*, 2003; Castellaro *et al.*, 2007; Arellano *et al.*, 2019), scraping has proven to be a simple and efficient method for the observation of epidermal structures. The application of this technique in the present study obtained a high percentage of observation of epidermal structures (95.95%) with a simple methodology, implying an economic saving in the purchase of inputs compared to the modifications proposed by other authors. In cases where some epidermal structures could not be clearly observed, especially because of the high density of stellate trichomes (*e.g.*, family Malvaceae), particular modifications should be made for certain plant groups (Catán *et al.*, 2007).

The combination of epidermal structures enabled the identification of the most common characteristics of certain families (Cactaceae, Fabaceae, Malvaceae, Poaceae and Zygophyllaceae), which can serve as a starting point for the development of identification guidelines for the plants present in the diet of herbivores (Desbiez and Santos, 2014). In fact, the collection of references and microhistological images from this catalog has already been used to characterize the diet of bighorn sheep, mule deer, white-tailed deer, and cattle at UMA Rancho Noche Buena (Peralta, 2020). Differences between beam and underside were found in 23% of the plant species analyzed, which is considered an important percentage. Consequently, given its absence from previous studies, future microhistological characterization works should consider both sides of the leaf.

CONCLUSIONS

Scraping, which is a modification of the microhistological technique, provided a good description of the structures of the epidermis of the vegetation of UMA Rancho Noche Buena. Differences were found between the tissues of the beam and those of the underside of the same species; therefore, in some cases, they would appear to belong to different species. This reduces the estimation error regarding the composition of the diet of domestic and wild herbivores. In this way, the reference catalog developed for the vegetation of UMA Rancho Noche Buena can be used to determine with greater accuracy the diet of herbivores distributed in other parts of the Sonoran Desert.

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ANNEX 1

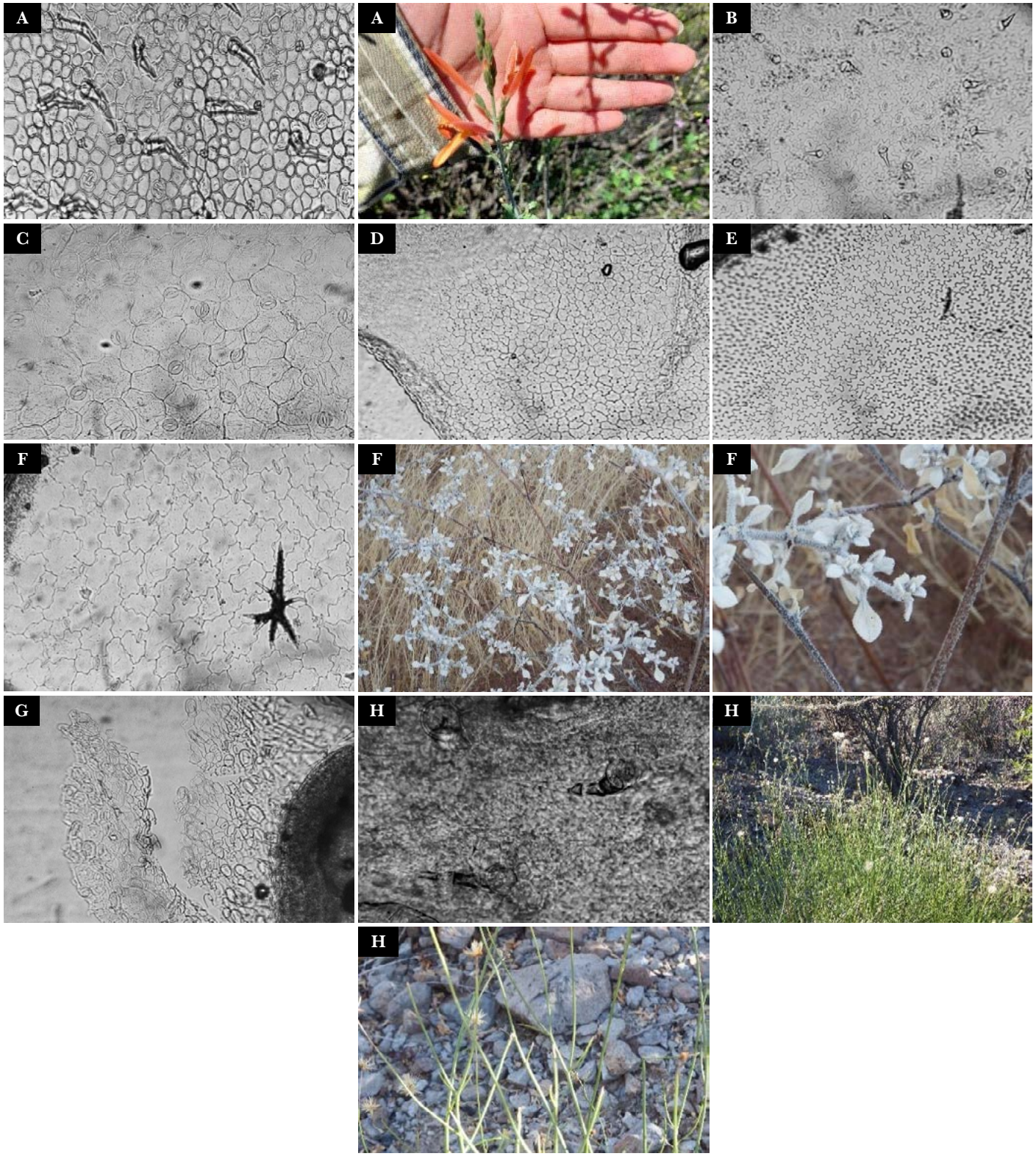

Figure 1. A. *Justicia californica*; B. *Ruellia californica*; C. *Trianthema portulacastrum*; D. and E. *Amaranthus palmeri* beam and underside; F. *Tidestromia lanuginosa*; G. *Ambrosia dumosa*; H. *Bebbia juncea*.

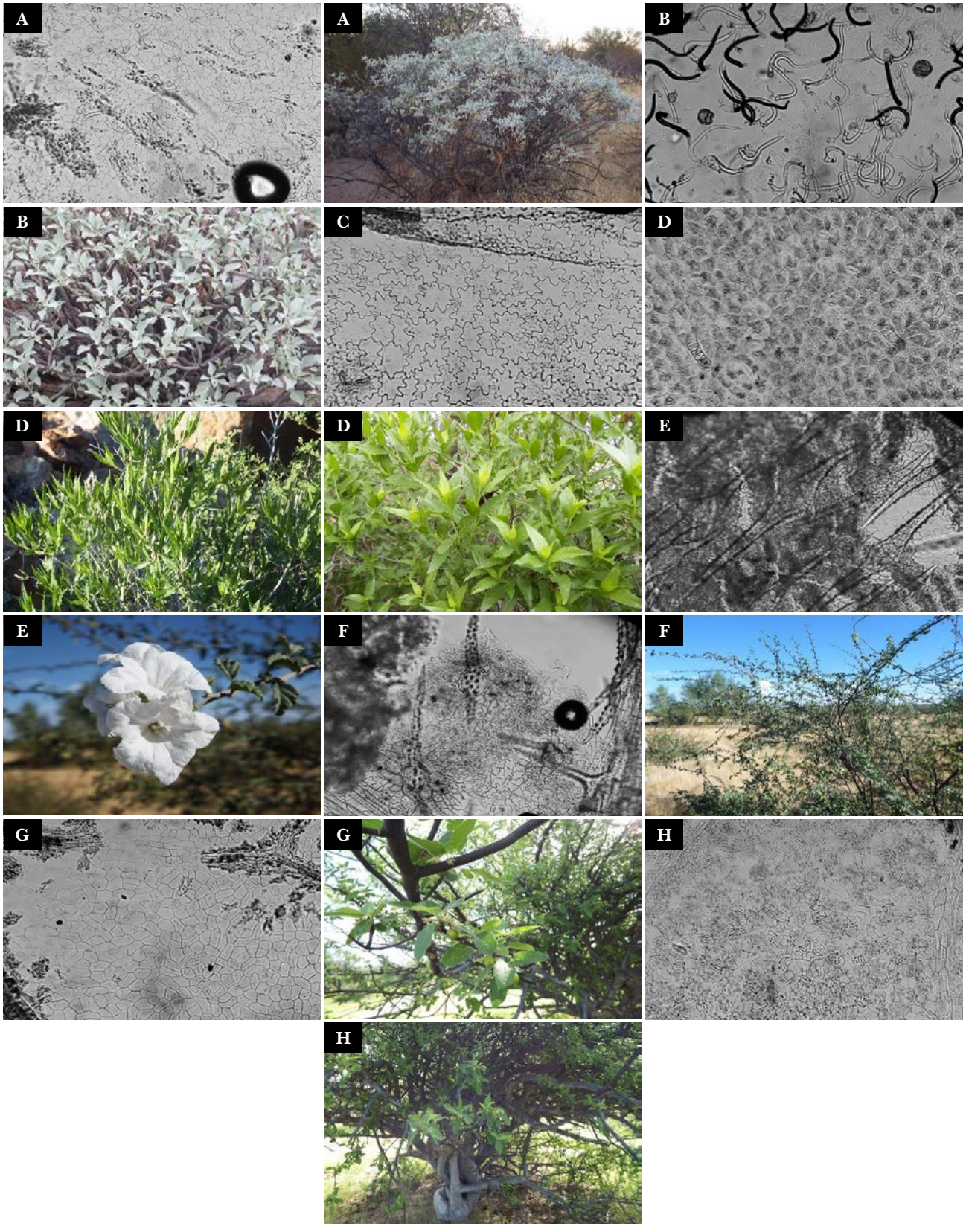

Figure 2. A. *Encelia farinosa*; B. underside; C. *Pectis rusbyi*; D. *Trixis californica*; E. and F. *Cordia parvifolia* beam and underside; G. and H. *Bursera laxiflora* beam and underside.

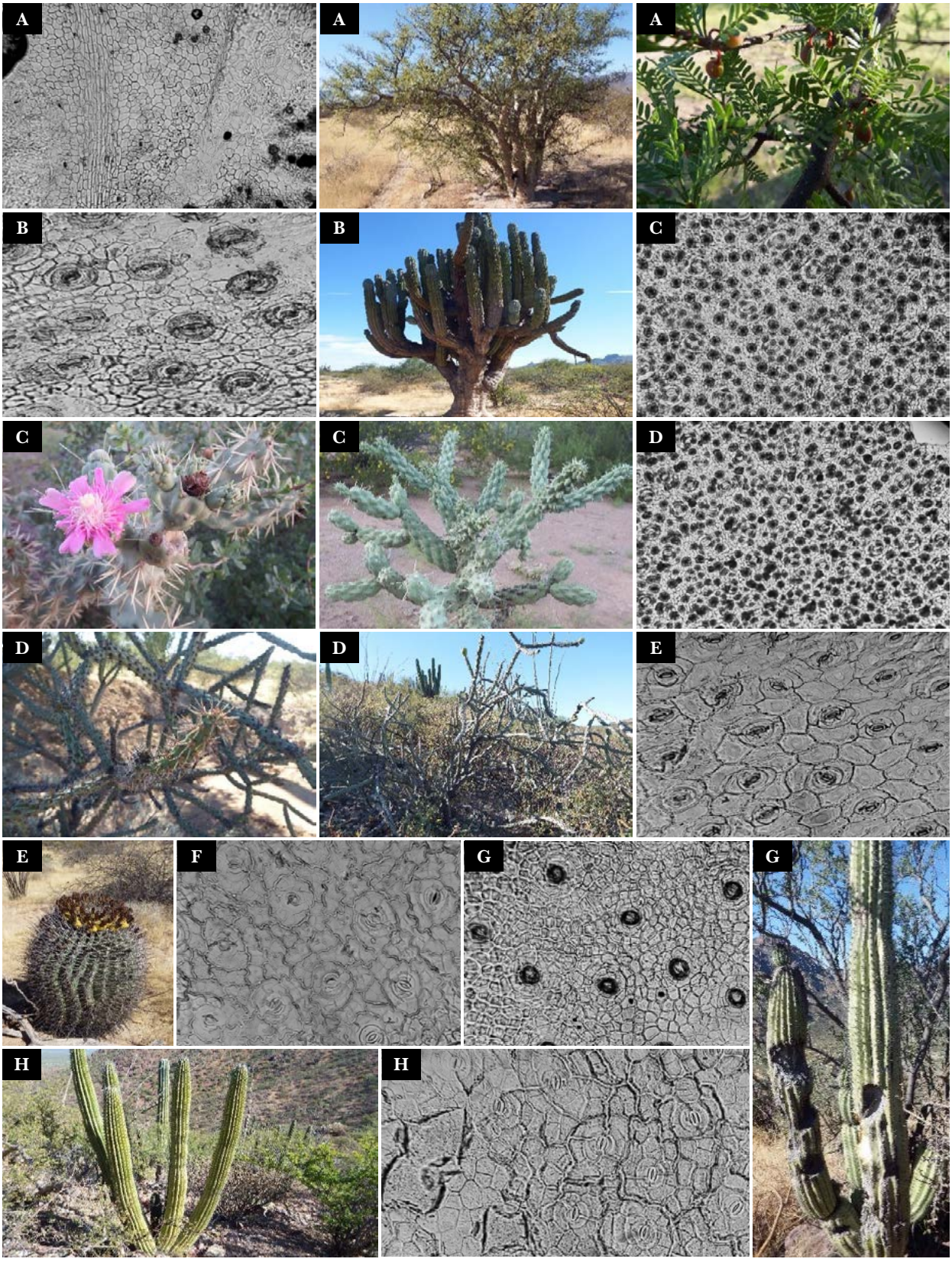

Figure 3. A. *Bursera microphylla*; B. *Carnegiea gigantea*; C. *Cylindropuntia fulgida*; D. *Cylindropuntia thurberi*; E. *Ferocactus wislizenii*; F. *Lophocereus schottii*; G. *Pachycereus pringlei*; and H. *Stenocereus thurberi*.

Colegio de Postgraduados

Determining the economic threshold for the sugarcane stalk borer (*Diatraea* spp.) in the Córdoba-Golfo region, Veracruz, Mexico

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ABSTRACT

Objective: To determine the economic threshold for *Diatraea* spp. in the Córdoba-Golfo sugarcane growing region in Veracruz, Mexico.

Design/Methodology/Approach: During the 2020-2021 production cycle, we established 21 sampling plots to measure damage percentage due to borer larvae in sugarcane stalks. Based on these measurements, we calculated the economic damage level (EDL) and the economic threshold (ET) by regions and subregions.

Results: The most affected subregion was Yanga, with an average annual damage of more than 5 % and a real economic threshold of 1.36. The average ET in the Córdoba-Golfo region was 2.76, which indicates that applying control strategies for *Diatraea* spp. enables the regulation of insect populations.

Study limitations/Implications: Strategies to obtain reality-driven diagnoses are still necessary to design and apply assertive management procedures to control stalk borer populations in the field.

Findings/Conclusions: We posit a suitably calculated ET for each studied subregion, considering updated parameters that include real crop losses per zone (field performance). This can provide the basis for a course of action with an effective management that will, in turn, increase field performance and sugarcane juice quality.

Keywords: Sugarcane stalk borer, Sugarcane, Spatial-temporal data analysis, Economic damage level.

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INTRODUCTION

Sugarcane (*Saccharum* spp., hybrid, Poales: Poaceae) holds the sixth place in crop relevance in Mexico (CONADESUCA, 2021a). The most damaging insect pests for this crop are the species comprised in the genus *Diatraea* spp., a group known as sugarcane stalk borers. When their population is abundant, they cause significant economic losses in the sugarcane sector (Wilson *et al.*, 2021).

Forty-one species of the *Diatraea* genus have been described that have a natural

distribution in the American continent. Some of these are considered insect pests in sugarcane, corn, sorghum, and rice crops, and affect cultivated fields in various territories from the United States to Argentina (Joyce *et al.*, 2014; Solís *et al.*, 2015; Francischini *et al.*, 2019).

Due to their vagility and natural colonizing capacity, the pest species of the *Diatraea* genus have affected more than 192,662.52 ha of sugarcane fields, which supply raw materials for 18 sugar mills in Mexico. Considering this impact, a decrease of 2 to 10 tons of cane/ha was estimated for the 2020-2021 harvest season (Rodríguez-del-Bosque *et al.*, 2014; Francischini *et al.*, 2019; CONADESUCA, 2021b).

During their larval stage, *Diatraea* spp. pierce the stem and consume the meristematic tissue, causing the "heart" of the sugarcane plant to die. The action of larvae reduces the yield and juice quality and increases susceptibility to pathogens, which makes strategies for their management and control essential (Rodríguez-del-Bosque *et al.*, 2014; Joyce *et al.*, 2014; Wilson, 2021).

However, the intensity of the damage caused by *Diatraea* spp. in sugarcane calls for procedures that require a high economic investment from producers. Calculating the economic damage level (EDL) and the economic threshold (ET) based on regional dispersion will allow the implementation of management strategies in the correct stage and location, thus reducing costs (Serra and Trumper, 2020).

The Córdoba-Golfo region is the site of the largest sugarcane growing area in the country. There, the ET for *Diatraea* spp. shows regional variations and differences. Moreover, its interpretation is unclear because its calculation uses the standard ET value of 10% and does not consider the particularities of each sugarcane growing municipality (Rodríguez-del-Bosque *et al.*, 2012).

Therefore, as a means of social restitution to support the sugarcane sector of the Córdoba-Golfo region, the objective of this work was to determine the EDL by region to calculate an ET based on the percentage of damage caused by larvae of the *Diatraea* spp. group in commercial sugarcane crops during the 2020-2021 production cycle.

MATERIALS AND METHODS

Study area. We studied seven commercial sugarcane crop subregions distributed among three sugar mills in the Córdoba-Golfo region (Table 1). We established a 59.73 linear km transect corresponding to an area of influence of 53,073 ha.

Damage percentage caused by *Diatraea* spp. larvae. We established 21 sampling sites where one hectare is an experimental unit. We counted healthy cane stems and stems perforated by borer larvae (with an entrance hole or feeding tunnels with or without frass) in a 10 linear meters transect that included the four corners and the center of each experimental unit (Flores, 2007).

We quantified the stems that showed perforations by *Diatraea* spp., those with central tunnels starting at the apex between the internodes and with accumulated residues (frass) at the entrance hole (Figure 1) (Rodríguez-del-Bosque *et al.*, 2014).

To determine the percentage of damage per hectare, we analyzed the data obtained in field counts following the equation proposed by Flores (2007).

Table 1. Location and main characteristics of the studied sites

Subregión	Coordenadas		Ingenio	Precipitación (mm^3) promedio anual	Temperatura promedio anual (°C)
	Norte	Oeste			
Potrero Nuevo 1	18.90321	96.78188	Central El Potrero	126.23	22.31
Palmillas 1	18.81905	96.77774	San José de Abajo	128.05	22.48
Paso del Macho 1	18.9467	96.75098	Central Progreso	127.08	23.36
Paso del Macho 2	19.03341	96.63239			
Paso del Macho 3	18.98595	96.70435			
Zentla	19.05551	96.72147			
La Flor	19.05536	96.71426			

CONADESUCA (2021b).

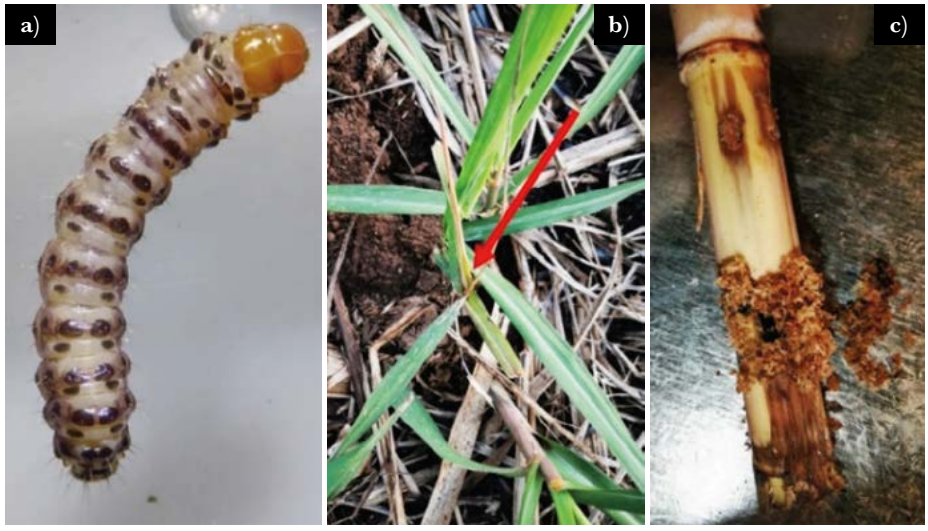

Figure 1. Damage caused by the sugarcane borer. a) *Diatraea* spp. larva; b) "death of the heart" symptom (red arrow); c) stem perforated by *Diatraea* spp., with frass. Laboratorio de Biotecnología Microbiana Aplicada, Colegio de Postgraduados, Córdoba, Veracruz, Mexico.

Economic damage level and threshold. We conducted the theoretical calculation of the economic damage level following Pedigo *et al.* (1986) (Equation 1), considering the application of chemical insecticide (Rynaxypyr®: anthranilic diamide: IRAC Group 28) as well as statistics for production costs and yields (García-Montalvo and Muñoz-Flores, 2017; Serra and Trumper, 2020; CONADESUCA, 2021b).

Equation 1:

$$EDL = C/P*D*K$$

Where: *EDL*=Economic damage level due to *Diatraea* spp., per stem; *C*=Cost of the control procedure (MXN/ha^{-1}), 1,746.75 Mexican pesos; *P*=Price per production unit (MXN/ton^{-1}), 20,537.92 Mexican pesos; *D*=Damage percentage due to *Diatraea* spp. larvae; *K*=Efficiency of the control procedure established at 16.70%.

To compare, establish, and/or modify existing economic damage thresholds, we followed the equation proposed by Trumper (2006).

Equation 2:

$$ET = \frac{EDL}{TD * \frac{(100 - M)}{100}}$$

Where: *ET*=Economic threshold; *EDL*=Economic damage level; *TD*=Number of eggs per individual (Rodríguez-del-Bosque *et al.*, 2012); *M*=Mortality exerted by control established at 16.70% (García-Montalvo and Muñoz-Flores, 2017).

RESULTS AND DISCUSSION

Damage percentage due to *Diatraea* spp. larvae. The most affected subregion was Yanga, with an average annual damage percentage of more than 5% with monthly seasonal peaks.

Damage percentage is indicative of pest incidence. However, it is not sufficient to determine the economic threshold of *Diatraea* spp. Factors such as price per unit of production and investment in control must be considered to determine the ET (Trumper, 2006).

The age of the plant, the intensity of the damage, the damaged part of the plant, the type of damage, and the environmental effects are also factors that can intensify yield losses in the field (Atencio *et al.*, 2017).

Economic damage level and threshold. The annual average ET for the Córdoba-Golfo sugarcane region is 2.76, well below the general ET of 10% (Table 2).

These results could be related to the low efficacy of the current control since management is conducted at the wrong time —when the population of *Diatraea* spp. has exceeded the ET (Solís *et al.*, 2015; Francischini *et al.*, 2019). The Yanga region showed a difference of 4.38% in regard to the estimated ET, followed by Potrero Nuevo-Paso del Macho 2, with 3.35% and 3.75% respectively. Therefore, considering that the ET for applying control strategies equals 5% and is based only on the damage percentage, this parameter is inefficient (Vázquez and Valdez, 2012; Rodríguez-del-Bosque *et al.*, 2014).

Table 2. Estimation of EDL and ET by subregions.

Región	%Daño	NDE	UE	Sobrestimación del daño
Potrero Nuevo	4.39±0.52	6.23	1.04	3.35
Yanga	5.74±0.49	8.16	1.36	4.38
Paso del Macho 1	1.82±0.61	2.58	0.43	1.39
Paso del Macho 2	4.91±0.55	6.98	1.16	3.75
Paso del Macho 3	3.18±0.69	4.51	0.75	2.43
Zentla	2.59±0.42	3.68	0.61	1.98
La Flor	2.70±0.00	3.84	0.64	2.06

The variations in ET lead to untimely management, which in turn leads to an increase in the borer population. This affects the crop yield and/or the quality of sugarcane juice and can even give rise to incidents such as epizootics in the points of origin (Molnár *et al.*, 2016). The impact of borer damage is often incorrectly estimated due to a lack of information about the pest. Consequently, the information generated in this study is an innovative proposal that focuses on the EDL by subregions and allows a precise estimation of ET (Campos *et al.*, 2016).

The damage percentage can be practically expressed in yield losses based on this assumption: "cane stalks can reach an average weight of 1.0 kg in a plot that contains approximately 70,000 stalks/ha, which totals 70 tons/ha". Based on this, if the economic threshold (ET) is 2% due to damage by sugarcane borer larvae, the loss will total 1.4 tons/ha. Considering an EDL of 5%, up to 3.5 tons/ha are lost due to the presence of borers. Therefore, in the 2020-2021 harvest, the economic loss could go from 1,400.00 to 3,500.00 pesos per hectare, bearing in mind that the price per ton of cane was 1,000.00 (one thousand pesos 00/100 M.N.).

CONCLUSIONS

Our study concluded that the EDL has been underestimated. The current ET parameters of 5% for *Diatraea* spp. are inefficient since they do not offer a realistic view of the phenomenon observed in the field, and the economic losses can surpass the range of 1,400.00 to 3,500.00 pesos per ton of sugarcane.

Our calculations allowed us to posit a theoretical ET by subregions and to identify the sites most affected by *Diatraea* spp. larvae feeding on sugarcane. These results will help to establish the bases for a targeted and successful management of *Diatraea* spp. populations.

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Colegio de Postgraduados

Evaluation of orange peel (*Citrus sinensis*) bioplastic through morphological and thermo-mechanical characteristics

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ABSTRACT

Objective: To evaluate the morphological and thermo-mechanical properties of a bioplastc film obtained from orange peel.

Design/methodology/approach: Pectin, a polysaccharide obtained from orange peel, has the potential to be used as a raw material in the bioplastics industry. The samples obtained were characterized by the Scanning Electron Microscopy (SEM) technique, mechanical tension and by thermogravimetric analysis (TGA).

Results: The elastic modulus was in the range of 7.7 to 29.9 MPa, depending on the plasticizer content. The thermogravimetric analysis showed a thermal decomposition between 134.42 to 153.98 °C depending on the plasticizer content and up to five events were identified.

Limitations of the study/implications: During the process, a pectin yield of 75% of orange peel was obtained.

Findings/conclusions: In developing countries such as Mexico, waste from agricultural and agro-industrial activities represents an important source of natural carbohydrate polymers that can be used to produce bioplastics, intended to replace petroleum-derived materials. In the case of orange peel, it can become a potential raw material to obtain value-added products in sectors of the food industry. These results indicated that our pectin has suitable properties to be used as raw material for the manufacture of bioplastics.

Keywords: bioplastic, mechanical properties, pectin film, thermal properties.

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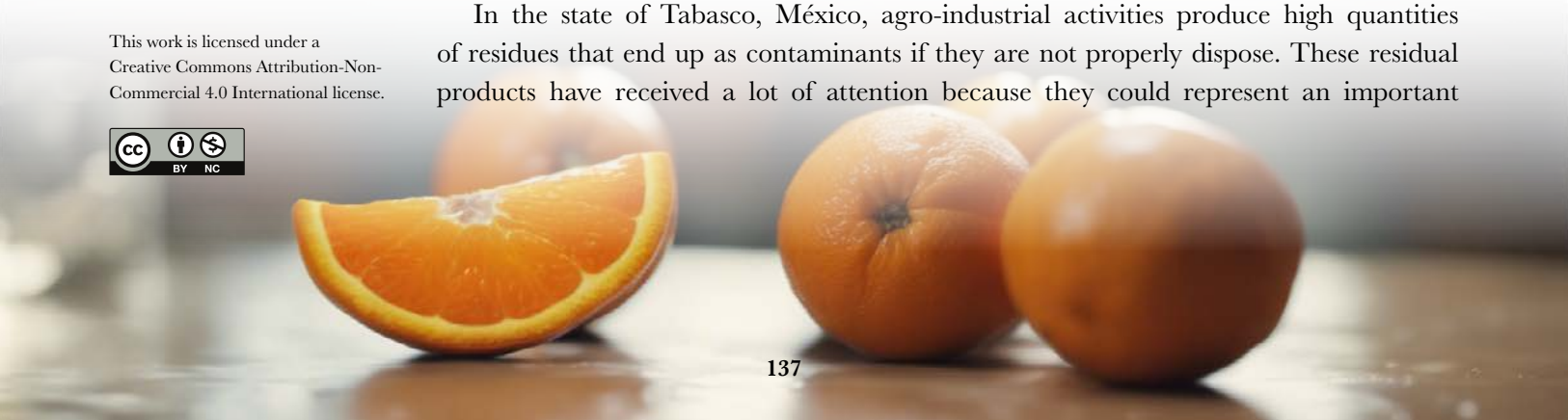
INTRODUCTION

In the state of Tabasco, México, agro-industrial activities produce high quantities of residues that end up as contaminants if they are not properly dispose. These residual products have received a lot of attention because they could represent an important



source of highly valuable materials such as bioplastics used in food packaging, biomedical applications, and drug delivery (Lara-Espinoza *et al.*, 2018). Banana, orange, cocoa, pineapple, coffee, sugar cane and mango are some agricultural products that generate organic waste which can provide mainly fibrous materials as cellulose and nanocellulose, and others like lignin and pectin. The orange is one of the main citrus fruits with the largest number of hectares planted in our country, mainly in the states of Veracruz and Tamaulipas. The production forecast for the 2020/22 campaign was 4.85 million metric tons (SAGARPA, 2022). Within the waste generated from within the juice industry is the orange peel, obtaining up to 60%, which, due to its characteristics, cause various environmental problems such as soil contamination, since it has a degradation time of approximately 6 months. To reduce this problem, various investigations have been carried out to give added value to this agro-industrial residue. Pectin is found in the primary wall of mesenchymal and in the parenchymal tissue of fruits and vegetables, and pectin acts as an intercellular adhesive (Nwanekezi, Alawuba and Mkpolulu, 1994; Tandon, Kaira and Neelima, 1996). It has different properties according to its esterification degree and can be classified as high methoxylated pectin (HMP) for high esterification degree, and low methoxylated pectin (LMP) for a low content of ester groups. Commercial HMP can be obtained from citric peels and apple pulps. Orange peel has been reported to contain pectin up to 25% calculated on dry weight basis (Müller-Maatsch *et al.*, 2016). HMP is a potential raw material to produce bioplastic. This bioplastic has physical-mechanical characteristics that can be transformed in dishes, bags, or other containers for packing biodegradable goods (Mellinas *et al.*, 2020). In this work, morphologic, mechanical, and thermal characteristics of a bioplastic film obtained from pectin extracted from orange peel are reported.

MATERIALS AND METHODS

Orange peel waste was collected in city of Cárdenas, Tabasco, Mexico, citric acid anhydrous and glycerol were purchased from Meyer.

Preparation of Bioplastic Film

The used procedure was previously described by Ramos-Alvarado (Ramos-Alvarado *et al.*, 2020). In brief, orange peel was washed with abundant water to remove impurity and then rinsed with distilled water. Orange peel is cut into pieces and placed in 0.1% citric acid at 90 °C for 90 min. Subsequently, a homogeneous mass was obtained using a blender, and it was filtered with a 250 μm sieve to obtain pectin. Glycerol was added at 3% (PG3) and 5% (PG5) in two different containers mixing vigorously in order to evaluate its plasticizer effect Next, the mixtures were placed on aluminum foil and spread as thin films. Finally, the films were dried in an oven at 45 °C for 24 h (Figure 1).

Scanning Electron Microscopy (SEM)

A morphological analysis was performed using a JEOL JSM-7500P scanning electron microscope. The samples PG3 and PG5 were previously dried in a desiccator and then covered with a thin layer of gold. Images were collected using 5,000x magnification.

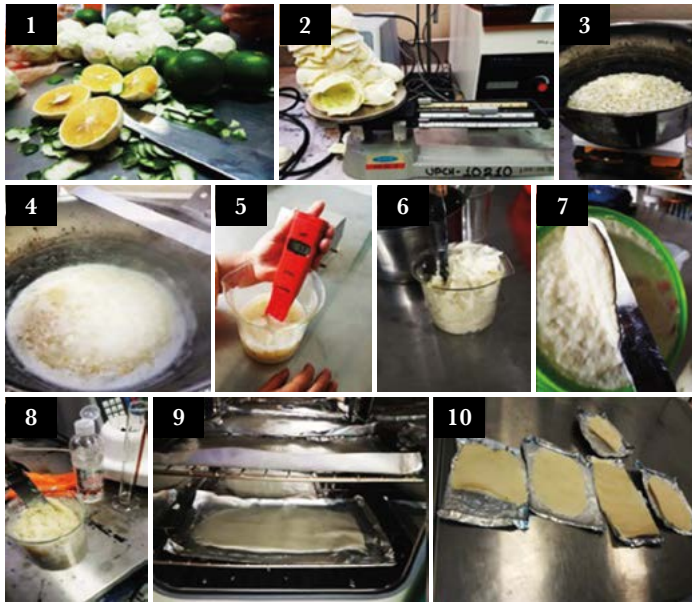


Figure 1. Extraction of Bioplastic from orange peel waste (*C. sinensis*). 1) Orange peels; 2) Weighing of shells (mesocarp); 3-4) Hydrolysis; 5) pH measurement; 6) Pectin mass obtained; 7) Pectin sieving; 8) Mixture of pectin with glycerol: 9) Drying of biofilms in a conventional oven; 10) Orange biofilms obtained.

Tension Mechanical Test

A mechanical test was conducted in an Instron model 1120 universal machine in accordance with the ISO 527-3 standard. Six samples were prepared from each film with a thickness of ~0.3 mm by cutting with a die in a hydraulic press. A strain rate of 10 mm/min was used, at atmosphere temperature, with a relative humidity of 50%.

Thermogravimetric Analysis

A thermic analysis was carried out in a TA Instruments model TGA Q5000 equipment. Samples from 4.8 to 10.87 mg were used. The heating range was from 34 to 600 °C with a ramp of 10 °C/min. Nitrogen was used as an inert atmosphere.

Statistical Analysis

The data from the mechanical properties of the bioplastic film were evaluated using Student's t-test, with a $p \leq 0.05$ indicating statistical significance.

RESULTS AND DISCUSSION

Bioplastic and its Morphological Characteristics

The yield of pectin extracted was 75% with respect to the dry mass. The films were flexible, with a smooth texture, a pleasant smell, and an opaque yellow color. The color tone visibly decreases with increasing glycerol content, as previously reported (Ramos-Alvarado *et al.*, 2020). The obtained thickness was ~0.3 mm. The films did not present cracks and were homogeneous in their conformation, which indicates that the drying temperature was optimal. The mechanical integrity of the films allowed to easily detach

them from the aluminum foil. The surfaces of the bioplastic films (Figure 2) in samples PG3 and PG5 have a heterogeneous surface, with agglomerates and striations that may be caused by fibrous material. It is evident that the PG3 sample has a greater number of striations, and it presents agglomerates above 2 μm. On the contrary, the PG5 sample is seen to be smoother and more uniform. It is possible that the proportion of 3% of plasticizer in the PG3 sample was not enough to completely disintegrate the pectin domains, creating agglomerates that could be caused by its interaction with the residual fibrous content generated during the extraction process. It is known that pectin films are characterized by the absence of a homogeneous structure, which is apparently due to the formation of packed pectin agglomerates (Giancone *et al.*, 2011).

Bioplastic films based on pectin with a high content of methoxy groups have a high degree of esterification, which gives them the ability to form networks with a high degree of gelation at room temperature. This type of film had high values of tensile strength ~21 MPa, which made it rigid and with little deformation capacity (~1-3.6%), making it feasible to produce films for food packaging (Giancone *et al.*, 2011; Bátori *et al.*, 2019). To improve the performance of these films, the use of a plasticizer is required. Glycerol is one of the most widely used plasticizers in the food and pharmaceutical industries. Due to its low molecular weight (92.09 g/mol), glycerol can permeate the intermolecular spaces of the pectin main chains, hindering the formation of hydrogen bonds and reducing polymer-polymer interactions, promoting an increase in the mobility of the polysaccharide chains.

Mechanical Analysis

The mechanical behavior of the bioplastic films was evaluated by the stress-strain curve. Elastic modulus, tensile strength, and strain at break were obtained. The curve of the tensile test of both PG3 and PG5 samples (Figure 3) showed that they possess a characteristic behavior of a plastic material, since no change in the slope of the curve of each sample is observed.

The proportion of plasticizer modified the mechanical properties of the bioplastic film (Figure 4). The elastic modulus was reduced by 67.86% when going from 23.976±3.993 MPa, to 7.705±0.470 MPa, for PG3 and PG5, respectively. Regarding the tensile strength, the PG5 sample presented a reduction of 57.41%, when changing from 4.560±2.588

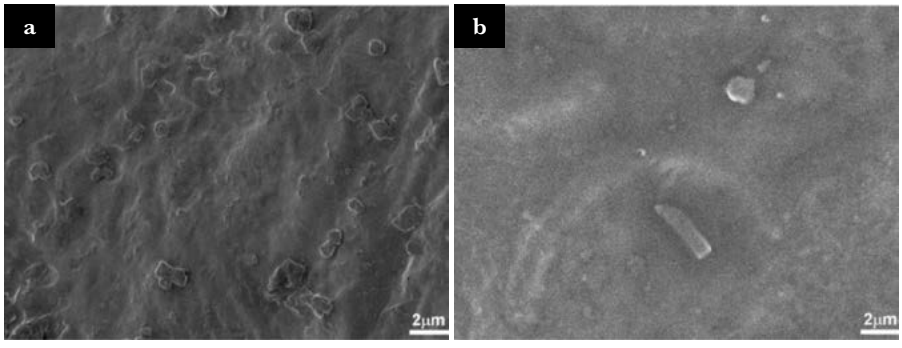


Figure 2. Scanning electron microscopy, PG3 (a), PG5 (b); 5000x resolution.

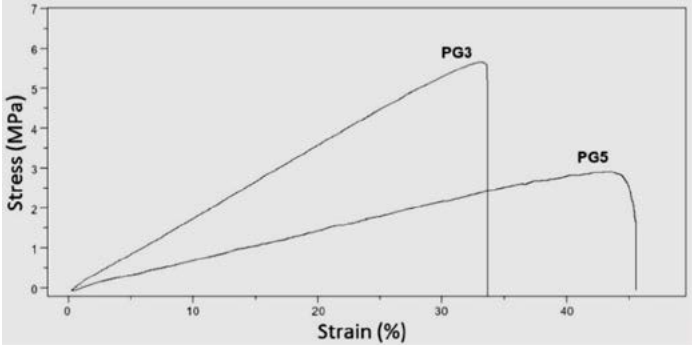


Figure 3. Stress-strain curve of bioplastic films.

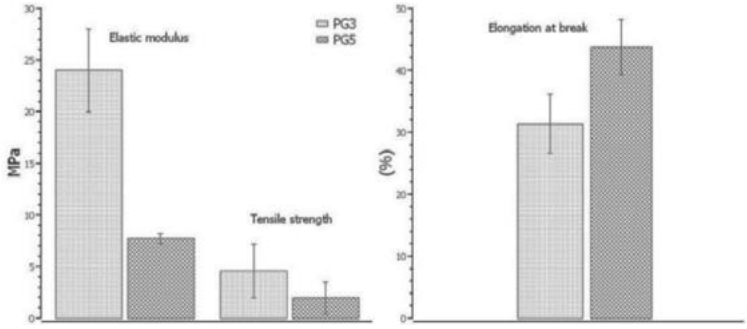


Figure 4. Mechanical properties of bioplastic film. The bars indicate the standard deviation. In all parameters, the proportion of glycerol produced changes with statistical significance $p<0.05$.

MPa, to 1.942±1.550 MPa. Finally, the strain at break was improved with an increase in plasticizer, since the PG5 sample presented a value of 43.716±4.435%, against 31.370±4.765% of PG3.

Thermogravimetric Analysis (TGA)

Thermal decomposition appears in 134.42 °C and 153.98 °C for PG5 and PG3, respectively. Five events of thermal decomposition were observed in the TGA curve of the bioplastic films (Figure 5). This behavior depended on the proportion of glycerol

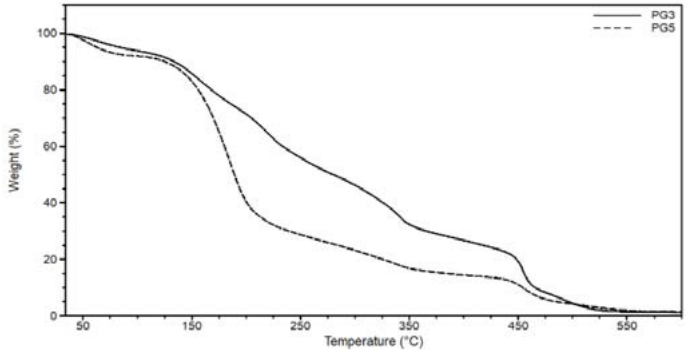


Figure 5. TGA curve of orange peel bioplastic films.

in the film. The first two events corresponded to the evaporation of water and thermal degradation of pectin, respectively. There was a clear difference in PG3 and PG5, which corresponds to the plasticizing effect of glycerol. The greater proportion of water in PG5 originated from the fact that a greater number of glycerol molecules which favored the formation of more intermolecular spaces to admit water.

The DTG curve (Figure 6) represents the kinetics of thermal degradation. Pectin in PG3 decomposed in two events, the first one with a peak at 156.8 °C and the second one at 220.1 °C. The first presented a shift to the left, while the second was within the common interval of decomposition. This degradation behavior may be due to structural differences within the polymeric matrix, caused by the heterogeneous distribution of the hydrogen bonds of the pectin-pectin interactions, which may benefit from the heterogeneous dispersion of the glycerol molecules, possibly caused by the high fibrous content of the sample (Darni *et al.*, 2017; Costanza *et al.*, 2019). This fiber content may also be related to the better thermal stability of PG3. The insoluble fiber content in orange peel is between 42.7 and 48.3%, mainly composed of cellulose and lignin (Rincón *et al.*, 2005; Garcia-amezquita *et al.*, 2019). Finally, the last event corresponds to the gasification of carbonaceous residues. The results of the quantitative analysis of the thermal decomposition are shown in Table 1.

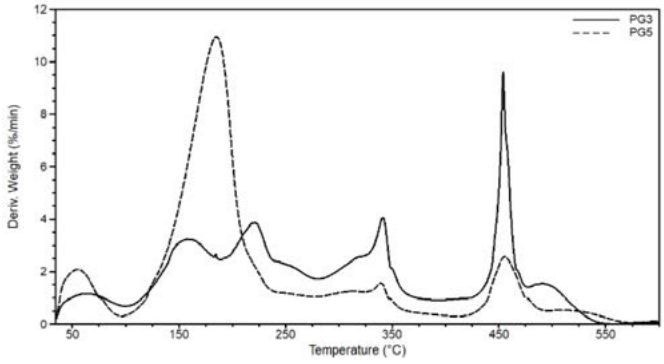


Figure 6. TGA curve of orange peel bioplastic films.

Table 1. Thermal events of the orange peel bioplastic in PG3 and PG5 samples.

PG3				PG5				Events
T_{On} (°C)	T_P (°C)	T_{Off} (°C)	Δm (%)	T_{On} (°C)	T_P (°C)	T_{Off} (°C)	Δm (%)	
33	63.9	98.5	7.55	33	55.3	96.1	8.13	Water evaporation
117.4	-	280.2	53.03	101.9	184.6	277.5	72.33	Pectin decomposition
328.1	340.6	392.0	15.25	329.2	338.8	409.2	5.68	Glycerol decomposition
425.8	454.9	475.5	15.96	418.6	455.7	489.5	9.09	Cellulose-lignin breakdown
476.0	-	559.3	6.71	490	-	565	3.1	Carbonaceous gasification
1.25 %				1.43 %				Ashes

T_{On} Onset Temperature, T_{Off} Offset Temperature, T_P Peak Temperature, Δm mass loss during TGA.

In our bioplastic films, the proportion of evaporated water from the sample corresponds to the proportion of glycerol (Figure 7), since a higher content of plasticizer molecules increases the admission of water.

The difference in free water content (Table 2) is an indicator of the type of pectin structural arrangements in the film matrix and could also be an indicator that at a greater amount of free water, a greater amount of energy is required to convert the water molecules to the gaseous state.

The plasticizing effect of glycerol can be explained in two ways; the first is that the hydroxyl groups of glycerol can interact with the OH and COOH groups of pectin, to form covalent ester bonds of the hydroxyl-hydroxyl or hydroxyl-carbonyl type, through condensation reactions. The second way of glycerol-pectin interaction is through the solvation of the polar sites in polysaccharide main chain, which causes a masking of the hydrophilic sites. This produces a reduction in pectin-pectin interactions, increasing the mobility of the chains to produce films with a lower elastic modulus and tensile strength, but with greater deformation capacity (Darni *et al.*, 2017; Costanza *et al.*, 2019). The thermogravimetric analysis showed that the water content in the bioplastic films increased with the glycerol content. It is possible that this mechanism explains the difference observed in the surface of the films, in which a higher proportion of plasticizer in PG5 served to promote a better distribution of the pectin domains, obtaining a smoother surface, since in the dehydrated state and without glycerol, the hydrophilic regions of the pectin can form aggregates causing an increment of hydrogen bonds and reducing the amount of water admitted. One way to infer the level of pectin-

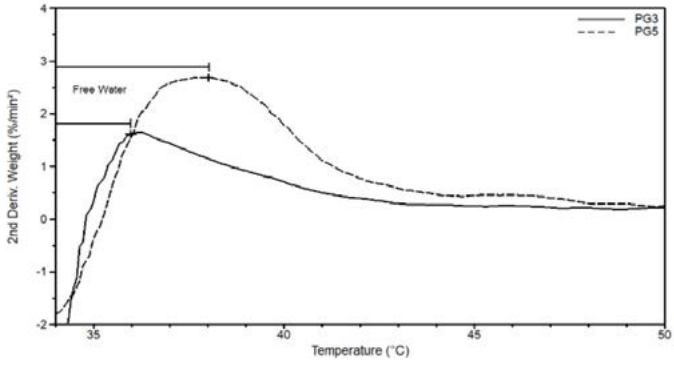


Figure 7. 2ndDTG curve (second derivative of thermal degradation) corresponding to water loss in PG3 AND PG5 samples.

Table 2. Quantification of the free water contained in the PG3 AND PG5 bioplastic film samples.

Parameter	PG3	PG5
T_P (°C)	35.98	38.15
Mass loss (%)	0.18	0.40
Free water ratio (%)	2.38	4.92

TP Peak temperature indicates the change in kinetics.

glycerol interaction in the film is by monitoring the peaks at 925 cm^{-1} and 850 cm^{-1} of the FTIR spectrum, corresponding to the vibration of the C-C bonds. On this orange peel bioplastic, this behavior is observable since these peaks reduce their intensity by changing the proportion of glycerol from 3 to 5%, as reported in a previous FTIR analysis (Ramos-Alvarado *et al.*, 2020). Pectin films can thermally decompose in an interval from 150 to 580 °C, with a maximum decomposition peak between 201 and 260 °C. The thermal degradation of pectin begins with the depolymerization and degradation of the galacturonic acid chains, followed by secondary decompositions related to the breaking of bonds and functional groups, which gives rise to a gas phase. Subsequently, chemical reactions of the gaseous phase and oxidation of volatile organic compounds take place to form CO, CO_2 and H_2O, even under inert atmosphere conditions (Giancone *et al.*, 2011; Espitia *et al.*, 2014; Aburto *et al.*, 2015; Al-Amoudi *et al.*, 2019).

CONCLUSIONS

The water in the polymeric matrix of pectin exists as free water and as bound water. The bound water consists of all the water molecules that are joined by hydrogen bonds to the different components of the polymeric matrix, while the free water is admitted within the free volume caused by the plasticizer, without forming hydrogen bonds. This phenomenon can be observed in the curve of the second derivative of the mass loss (2ndDTG). During the water evaporation process, a peak appears in the 2ndDTG indicating the change in the kinetics of mass loss, which means that the free water finishes its evaporation process to allow the evaporation of bound water. The matching of maximum of that peak with the TGA curve indicates the mass of evaporated free water. The occurrence of this peak depends on factors such as the rate of heating and the velocity of the gas flow during the TGA. It has been observed that the peak of this event appears shifted to the left with the increase in the heating rate (Aburto *et al.*, 2015; Wang *et al.*, 2018; Costanza *et al.*, 2019). The pectin obtained has properties of potential use for the food product packaging industry. By surface analysis, the films have good integrity. Mechanical tests showed a direct effect of plasticizer content, obtaining a reduction of elastic modulus about 68% but an increasing of deformation at break around 28 % when changing from 3 to 5% the plasticizer content. Thermogravimetric analysis indicate that the bioplastic obtained from orange peel waste has fiber content. Both results indicate that our film provide suitable properties to make it a potential material for production of packaging for food products.

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Colegio de Postgraduados

Characteristics of the white-tailed deer hunting exploitation (*Odocoileus virginianus*) in Chihuahua, Mexico

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ABSTRACT

Objective: To describe the characteristics of the number of hectares (located in the UMAs registered in the state of Chihuahua) used for the white-tailed deer free-range production, the level of exploitation of the species, and its economic value.

Design/Methodology/Approach: This study determined the number of Units for the Conservation, Management, and Sustainable Use of Wildlife (UMAs) registered in the state of Chihuahua, where white tailed deer had been exploited since 2015. Forty-three municipalities in the state of Chihuahua, with a total of 159 UMAs, were analyzed. Twenty-three randomly selected UMAs were characterized, taking into account the hectares and the presence of white-tailed deer per municipality. Finally, the exploitation value of the species use per community was established in order to determine its exploitation and economic value.

Results: The total area used for the exploitation of the white-tailed deer reaches 1,067,380 hectares. Thirty-two municipalities had potential for the exploitation of white-tailed deer. Thirty-three deer were hunted per season in the 23 UMAs under study, which accounts for a $990,000 Mexican pesos gross income for the state of Chihuahua per season; this exploitation generates a total of 115 temporary jobs for the communities surrounding the 23 UMAs studied. Chihuahua's UMAs welcome a total of 33 white-tailed deer hunters per season. Hunters pay $30,000 to $34,000 Mexican pesos for each white-tailed deer specimen.

Study Limitations/Implications: The study provides an overview of the current state of the UMAs in the state of Chihuahua that have a permit for the white-tailed deer hunting exploitation. Each of the UMAs under study has specific characteristics, including: the services offered, the associated hunting species, and the exploitation populations under an integrated sustainability arrangement. This study does not include the benefits of exploiting associated species, such as the collared peccary (*Dicotyles tajacu*) and the wild turkey (*Meleagris gallopavo*).

Findings/Conclusions: Based on the number of registered UMAs, 32 out of 40 municipalities use 100% of their registered area for the exploitation of white-tailed deer. The white-tailed deer hunting exploitation increases the profitability and productivity of livestock ranches.

Keywords: Deer, hunting, Chihuahua, UMA, sustainable.

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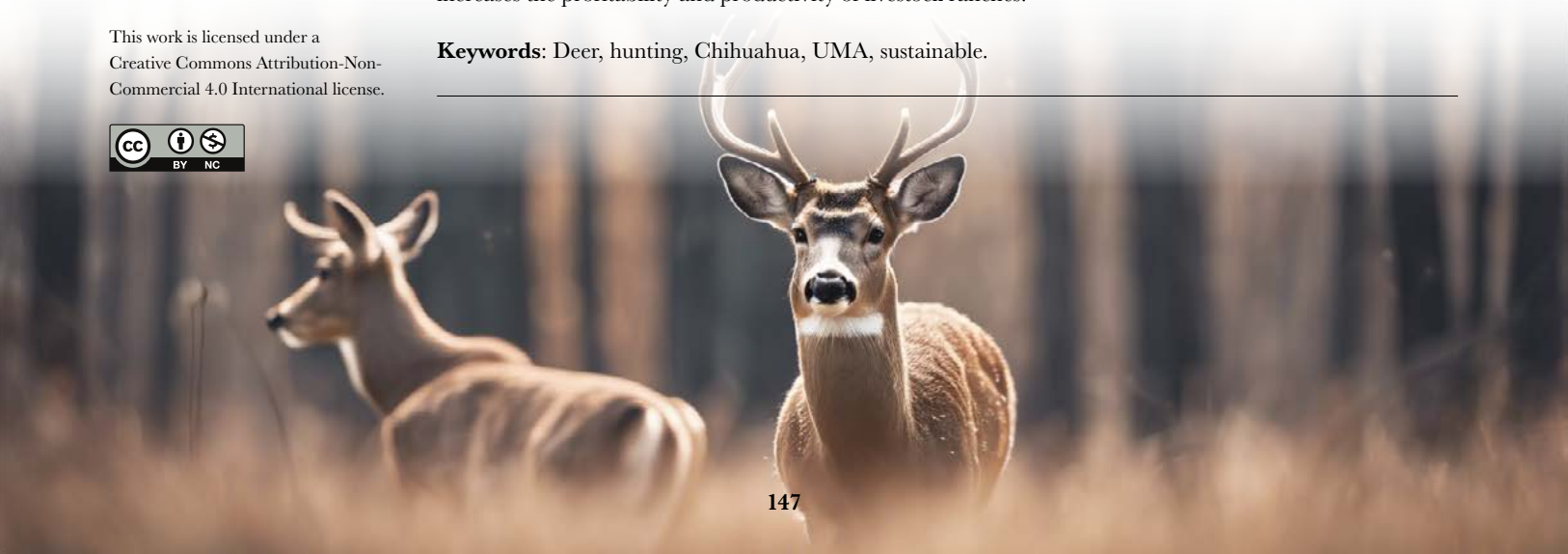

INTRODUCTION

The white-tailed deer exploitation guideline is linked to the historical characteristics of the communal exploitation and management of natural resources, as part of which livestock is the main economic activity, while hunting is a casual and opportunistic practice. This pattern has been relatively stable; however, during the last five years, a new trend has emerged: hunting exploitation has become important under the UMA system. In Mexico, white-tailed deer has played a fundamental cultural, aesthetic, hunting, and economic role (CONABIO 2012).

The Cervidae family is widely distributed in the Americas. Four species can be found in Mexico: *Mazama temama*, *M. pandora*, *Odocoileus hemionus*, and *O. virginianus* (González *et al.*, 2005). *O. virginianus* (commonly known as white-tailed deer) includes 38 species, 14 out of which are distributed throughout the Mexican territory. Currently, 70% of the Mexican surface has some degree of habitat degradation. Fifty percent of the vegetation cover has been lost as a consequence of livestock, agriculture, deforestation, and uncontrolled hunting activities, as well as human population expansion, and air, water, and soil pollution. This situation has severely damaged species diversity and abundance, pushing them to the brink of extinction and endangering a vast number of them. Consequently, the objective of this study was to gather information about the number of hectares used for the white-tailed deer exploitation in the state of Chihuahua, in order to establish an exploitation trend pattern for this species.

MATERIALS AND METHODS

Twenty-three out of 159 registered UMAs in the 43 municipalities of the state of Chihuahua were analyzed. The number of hectares where white-tailed deer were reported were taken into account in the characterization of the municipalities. The number of deer hunted per season, the price of the deer as trophy, the hunting species within the ranch, and the number of employments generated per season were also included in the analysis. This information was gathered through visits and direct surveys with the owners of the 23 registered UMA ranches where the white-tailed deer exploitation is carried out. The presence of white-tailed deer was confirmed in each of the UMAs through transect tours, during which hints that proved the presence of the deer were recorded.

RESULTS AND DISCUSSION

Sixty-four percent of the surface of Chihuahua has the UMA hunting exploitation registration. In total, 1,067,380 hectares are used for the white-tailed deer exploitation, which accounts for 72.6% of the registered UMA area (INEGI 2009). This area has different types of vegetation, which has an impact on the number of deer (Del Angel and Mandujano, 2017). The municipality of Madera recorded the highest number of hectares (344,732) used for hunting exploitation and the same number of hectares for white-tailed deer exploitation. Meanwhile, the municipality of Delicias recorded only 75 hectares with an UMA register for white-tailed deer hunting exploitation. Thirty-two municipalities have potential for the white-tailed deer hunting exploitation. Thirty-three

deer were hunted per season in the 23 UMAs under study, which accounts for a $990,000 Mexican pesos gross income per season for Chihuahua. The average income per UMA per season reached $43,043 Mexican pesos, which results in a sustainable exploitation that generates an income for the UMAs and a total of 115 temporal employments for the surrounding communities. Chihuahua's UMAs welcome a total of 33 white-tailed deer hunters per season. Hunters must pay $30,000 to $ 34,000 Mexican pesos for each white-tailed deer.

The successful inclusion of the white-tailed deer in the populations of the state of Chihuahua is the result of the actions that the owners of the UMAs constantly carry out. These practices include the improvement of the habitat and the application of the management strategies described in the Plan de Manejo Tipo for the preservation and sustainable exploitation of the white-tailed deer (SEMARNAT, 2014; Villerreal, 1999; Villarreal-Espino, 2006).

Some of the owners have started to use an assisted reproduction technique and reproductive handling, in order to increase the trophy quality and the number of births (Mellado *et al.*, 2013; González-Maldonado *et al.*, 2021; Asher, 2011; DelGiudice, 2007). The UMAs located in Mexico take into account the analyses about their management and administration carried out by the CONABIO (2012).

CONCLUSIONS

The white-tailed deer hunting exploitation UMAs in the state of Chihuahua carry out a sustainable exploitation, generate temporal employments in the nearby communities, and offer hunting services.

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Colegio de Postgraduados

Yield and nutritive value of *Urochloa* hybrids at different regrowth ages

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ABSTRACT

Objective: To evaluate the productive behavior of *Urochloa* hybrids, depending on the regrowth age.

Design/Methodology/Approach: The study was carried out under rainfed conditions during 2018. The Cayman, Mulato II, Convert 330, Cobra, Camello I, and Camello II hybrids were evaluated based on the regrowth age (2, 4, 6, 8, and 10 weeks). The following variables were evaluated: plant height (PH), total dry matter (TDM) yield, dry matter per leaf (DMl) yield, dry matter per stem (DMs) yield, crude protein content (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF). The data obtained were evaluated by means of a randomized complete block design with three repetitions, divided into plots: a large plot for the cultivars and small plot for the regrowth ages.

Results: The Camello II cultivar obtained the highest TDM yields during the sixth and eighth weeks (4.15 and 6.35 t DM ha^{-1}, respectively); however, during the tenth week, the yield was equal to the yield obtained with the Mulato II and Cayman cultivars ($p<0.05$). The highest DMl yield was obtained by the Mulato II cultivar during the sixth, eighth, and tenth weeks (3.37, 4.56, and 3.86 t DM ha^{-1}, respectively). The Mulato II cultivar recorded the highest CP values during the second and fourth weeks (158 and 126 g kg^{-1}, respectively); however, the Camello II cultivar obtained the highest CP values during the sixth, eighth, and tenth weeks (99, 95, and 87 g kg^{-1}, respectively). The NDF and ADF values increased as the regrowth age increased: in the tenth week, the Camello II and Cobra cultivars obtained the highest NDF values, while the Camello II cultivar recorded the highest ADF value during the same period.

Study Limitations/Implications: *Urochloa* cultivars were developed for their establishment in humid tropical conditions, where their productive performance is greater. However, in dry tropical conditions, the Cayman, Mulato II, and Cobra cultivars have had a better performance than other grasses —such as buffel grass (*Pennisetum ciliare*), which is used to feed ruminants. In this sense, other *Urochloa* cultivars (*e.g.*, Camello I and Camello II), which have greater tolerance to droughts, show desirable forage characteristics, such as yield and forage quality.

Findings/Conclusions: The cultivars with the best productive performance were Camello II, Mulato II, and Cayman.

Keywords: Forage production, forage quality, regrowth age, *Urochloa* hybrids.

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INTRODUCTION

Grass cultivars (hybrids) have been developed to increase the productivity of ruminant production systems. Some of them were generated by the Centro Internacional de

Agricultura Tropical (CIAT) through a genetic improvement program. The combination of the desirable characteristics of *Urochloa brizantha* (syn. *Brachiaria brizantha*), *Urochloa decumbens* (syn. *Brachiaria decumbens*), and *Urochloa ruziziensis* (syn. *Brachiaria ruziziensis*) led to the release of three hybrids: Mulato II (CIAT 36087), Cayman (CIAT BR02/1752), and Cobra (CIAT BR02/1794) (Pizarro *et al.*, 2013). These hybrids have been evaluated in Mexico under semi-arid conditions, during the rainy and drought seasons, and have shown better forage characteristics than *Pennisetum ciliare* (syn. *Cenchrus ciliaris*), the most frequently used forage grass by livestock farmers in semi-arid areas (Garay-Martínez *et al.*, 2017). In this sense, Garay-Martínez *et al.* (2018) reported that hybrid grasses of the genus *Urochloa* have a higher forage yield than *Pennisetum ciliare* during the rainy (9.05 *vs.* 8.34 t ha^{-1}) and drought (1.06 *vs.* 0.79 t ha^{-1}) seasons. Furthermore, the highest protein content (9.2-10.2 *vs.* 7.4%) and digestibility (66.3-67.3 *vs.* 56.3%) were recorded by the hybrids at 8 weeks of regrowth (Garay *et al.*, 2020). The development and release of cultivars is a dynamic process and, in recent years, new *Urochloa* cultivars have been released to increase forage yield, its nutritional value, and the animal production in production systems. However, in order to determine the productive potential of forage grasses, before their integration into a production system, the forage behavior of the new materials must be evaluated (Njarui *et al.*, 2014). In this sense, the biomass accumulation of forage species can be evaluated through a growth analysis, responding to different climatic and management conditions (Rojas-García *et al.*, 2018). Therefore, the objective of the present study was to evaluate the yield and nutritional value of forage from *Urochloa* hybrids at different regrowth ages, in semi-arid rainfed conditions.

MATERIALS AND METHODS

Location of the experimental site

The research was carried out at the Posta Zootécnica Ingeniero "Herminio García González," Facultad de Ingeniería y Ciencias, Universidad Autónoma de Tamaulipas. The experimental site is located in Güémez, Tamaulipas, Mexico (23° 56' 26.5" N and 99° 05' 59.9" W), at 193 meters above sea level (INEGI, 2015).

Climatic and edaphic characteristics of the experimental site

The site has a type BS1 (h') hw (BShw) climate (Vargas *et al.*, 2007). The average annual temperature is 23.9 °C and the average annual precipitation is 719 mm (SMN, 2010). During the evaluation period, the temperature and precipitation were recorded at the evaluation site (Figure 1).

Prior to the evaluation, a soil sampling was carried out, in order to determine the physical and chemical characteristics of the soil (Table 1).

Plant material, treatments, and agronomic management

The materials evaluated were six *Urochloa* hybrids: Cayman, Mulato II, Cobra, Camello I (GP3025), Camello II (GP3207), and Convert 330. The botanical seeds were sown in April 2018, with a manual seeder; the distance between plants and rows was 0.1 and 0.3 m, respectively. Eighteen 3×3 m experimental plots (9 m^2) were used; each experimental

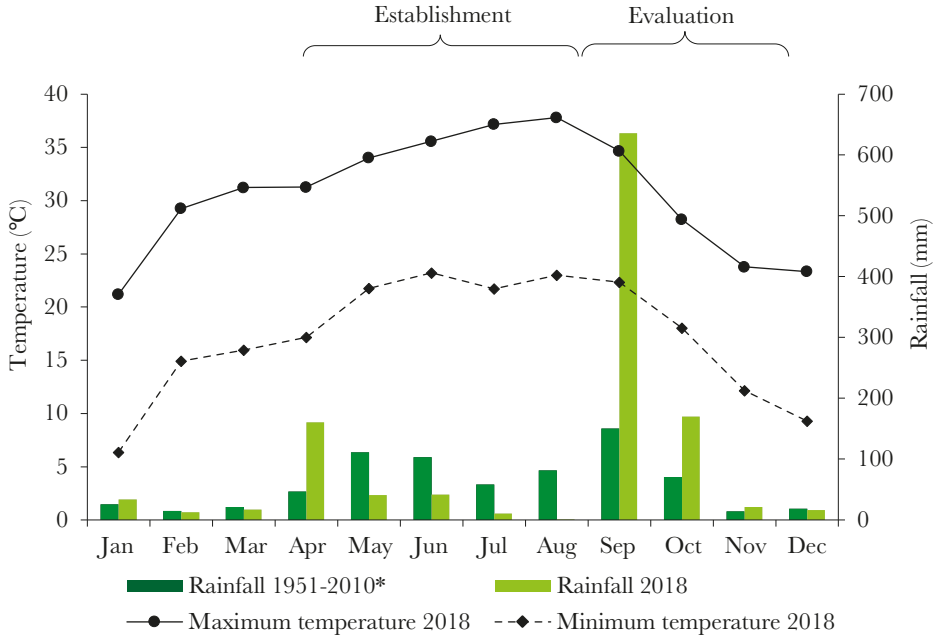

Figure 1. Accumulated monthly precipitation and average maximum and minimum monthly temperature recorded in Güémez, Tamaulipas (2018).
*Accumulated monthly precipitation, 59-year average (1951-2010; SMN, 2020).

Table 1. Physical and chemical characteristics of the soil of the Posta Zootécnica "Herminio García González" experimental site in Tamaulipas, México

pH	TN	OM	TCa	P	K	Fe	Zn	Sand	slime	clay	SAR
	%			mg kg^{-1}				%			
8.3	0.25	4.27	38.2	7.46	288.6	1.43	0.46	11.3	23.3	65.4	0.19

TN: total nitrogen; OM: organic matter; TCa: total carbonates; P: phosphorus; K: potassium; Fe: iron; Zn: zinc; SAR: sodium adsorption ratio.

plot consisted of ten furrows. One linear meter was delimited in each of the five central furrows to form the useful plot (experimental unit) for each regrowth age. Each treatment consisted of three repetitions. No fertilization was applied to the cultivars during the 5-month establishment period. Prior to the evaluation, a uniformization cutting was made at 15 cm and, subsequently, another cutting was made at the same height in each sampling (regrowth age: 2, 4, 6, 8, and 10 weeks).

Variables evaluated

Plant height

Prior to each sampling, the plant height (cm) was measured with a wooden ruler from the ground to the ligule of the last fully expanded leaf.

Forage yield as dry matter

The forage was harvested in each useful plot and weighed on a CQT 2601 analytical balance (ADAM®, USA). A 200 g subsample was then taken and separated into its

morphological components: leaf (leaf blade+pod) and stem. The subsamples were placed in a Heratherm™ OMS60 forced air oven (Thermo Scientific®, USA) at 60 °C, until constant weight was obtained. At the end of the drying period, the dry weight of each subsample was recorded, and the dry matter yield was estimated: total (TDM) and per morphological component [leaf (DMl) and stem (DMs)]. For each regrowth age, the yield obtained in 1 linear m was extrapolated to 1 ha and reported in t ha^{-1}.

Bromatological analysis

The crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) content (g kg^{-1}) was determined. The protein content was determined following the method described by AOAC (2000), while the neutral detergent fiber (NDF) and acid detergent fiber (ADF) content was established using the method of Van Soest *et al.* (1991).

Statistic analysis

The data obtained were analyzed with PROC GLM (general linear models) in the Statistical Analysis System software (SAS, 2002), by means of a randomized complete block design with three repetitions, divided into plots: a large plot for the cultivars and a small plot for the regrowth ages. Tukey's mean comparison test was performed ($\alpha=0.05$).

RESULTS AND DISCUSSION

Until the eighth week, the average plant height increased as the regrowth age increased ($p<0.05$); subsequently, it decreased due to the lodging of the plants caused by the wind (Table 2). The differences in plant height between the hybrids were recorded after 8 weeks of regrowth ($p<0.05$), because their growth habit is generally modified by environmental and management conditions (González *et al.*, 2020).

In this sense, Hare *et al.* (2015) reported that the Cobra hybrid has an erect growth habit, while Enríquez *et al.* (2015) determined that the Cayman hybrid grows in a semi-recumbent manner —a similar behavior to that observed in this research. Meanwhile, the Camello II hybrid showed a more erect growth than Camello I; therefore, wind incidence had a greater effect on this cultivar, lodging the plant after 10 weeks of regrowth. Consequently, in the tenth week, the Camello I cultivar surpassed Camello II in plant height.

In general terms, total dry matter (TDM) production in all cultivars increased as regrowth age increased. The highest TDM yields were recorded in the tenth week ($p<0.05$). Total dry matter increased by 52, 49, 32, and 17%, when the regrowth age increased from 2 to 4, 4 to 6, 6 to 8, and 8 to 10 weeks, respectively.

In the second regrowth week (Table 2), the Cayman and Mulato II cultivars obtained the highest TDM yields (0.95 and 0.88 t ha^{-1}, respectively); meanwhile, in the fourth regrowth week, Cayman obtained 15% more TDM than Mulato II. In general, the greater accumulation of TDM observed during the second and fourth weeks (52 and 49%, respectively) was caused by the favourable temperature (22-34 °C) and precipitation (635 mm) that led to a greater grass growth (Maia *et al.*, 2014). The yields in this research are higher than those reported by Garay-Martínez *et al.* (2018) for Cayman (1.3 t DM ha^{-1}),

Table 2. Plant height (PH), total dry matter (TDM) yield, leaf dry matter (DMl) yield, and stem dry matter (DMs) yield of *Urochloa* cultivars at different regrowth ages evaluated in Güémez, Tamaulipas.

Cultivar	Regrowth ages (weeks)									
	2	4	6	8	10	2	4	6	8	10
	PH (cm)					DMT (t ha^{-1})				
Cayman	39 a	47 a	75 a	78 a	65 b	0.95 a	2.17 a	3.48 b	4.67 c	6.32 a
Mulato II	35 a	47 a	66 b	81 a	84 a	0.88 ab	1.86 b	3.49 b	5.54 b	6.26 a
Convert*	32 a	43 a	61 c	69 b	77 a	0.85 b	1.78 c	2.44 e	3.73 e	5.86 b
Cobra	32 a	45 a	56 c	61 c	61 b	0.83 b	1.27 f	2.53 d	2.99 f	3.56 d
Camello I	31 a	44 a	66 b	72 b	62 b	0.66 c	1.63 d	2.80 c	4.44 d	4.61 c
Camello II	32 a	48 a	76 a	71 b	49 c	0.63 c	1.47 e	4.15 a	6.35 a	6.47 a
Mean	36 D	46 C	70 AB	75 A	70 B	0.80 E	1.70 D	3.15 C	4.62 B	5.51 A
	DMs (t ha^{-1})					DMl (t ha^{-1})				
Cayman	-	0.06 b	1.12 a	1.21 b	2.11 a	0.95 a	2.06 a	2.42 c	2.58 e	3.42 c
Mulato II	-	-	0.07 e	0.68 e	1.62 d	0.88 ab	1.84 b	3.37 a	4.56 a	3.86 a
Convert*	-	-	0.14 d	0.54 f	2.01 b	0.85 b	1.76 c	2.27 d	3.10 c	2.91 d
Cobra	-	0.09 a	0.48 b	0.76 d	0.76 f	0.83 b	1.02 f	1.68 f	1.79 f	2.18 f
Camello I	-	0.06 b	0.44 c	1.09 c	1.33 e	0.66 c	1.46 d	2.18 e	3.00 d	2.82 e
Camello II	-	0.06 b	0.63 a	1.71 a	1.97 c	0.63 c	1.35 e	3.24 b	4.14 b	3.59 b
Mean	-	0.04 D	0.40C	1.00 B	1.63 A	0.80 E	1.60 D	2.50 C	3.20 A	3.10 B

(-): absence of the component at the time of sampling; Convert*: Convert 330. Different literals between cultivars (a, b, c, d, e, f) and regrowth ages (A, B, C, D, E) indicate a significant statistical difference (Tukey; α=0.05).

Cobra (2.2 t DM ha^{-1}), and Mulato II (3.2 t DM ha^{-1}) at 4, 6, and 8 weeks of regrowth, respectively. The said yields are mainly attributed to the management and distribution of precipitation during that year (Garay-Martínez *et al.*, 2018). In this evaluation, the Camello II cultivar surpassed Cayman and Mulato II in dry matter yield, during the sixth and eighth weeks; however, the yield was similar in the tenth week.

From week 2 to week 8, the increase of the average DMl production depended on the regrowth age; subsequently, it recorded a 2% decrease ($p<0.05$). From week 2 onwards, leaf production differed in all cultivars (Table 2). The highest leaf yield in weeks 2 and 4 was obtained by the Cayman cultivar, while, in weeks 6, 8, and 10, it was obtained by the Mulato II cultivar (Table 2). The decrease in the average DMl yield from week 8 (Table 2) is attributed to the increase in senescent leaves, since prolonging the cutting or grazing periods leads to an increase in forage losses, as a result of leaf senescence (Cruz -Sánchez *et al.*, 2018). Consequently, Garay-Martínez *et al.* (2018) have suggested that, during the rainy season, forage from the Cayman, Mulato II, and Cobra cultivars should be used between 4 and 6 weeks of regrowth. In this regard, the Camello II cultivar obtained higher leaf yields than the Cayman cultivar; however, these yields were lower than with the Mulato II cultivar, which matches the findings of Bernal *et al.* (2016), who mention that the Cayman and Mulato II hybrids produce a greater number of leaves. Therefore, it can be assumed that the Camello II hybrid also has this forage quality.

The presence of stems was recorded from the fourth week, except in the Mulato II and Convert 330 cultivars, where the stems appeared from the sixth week. The highest stem yields were obtained in the tenth week, when the Cayman cultivar recorded the greatest ($p<0.05$) stem accumulation (Table 2). The stem accumulation was greater in Cayman than in Camello II. In this regard, Rojas *et al.* (2017) have mentioned that the increase in the accumulation of stems is caused by the elongation and increase in weight and greater population density of the stems, resulting from longer exploitation periods. In this sense, Lucio-Ruíz *et al.* (2021) have reported that the stem density of the Cayman cultivar ranges from 2,227 to 2,553 stems m^2, when they are harvested at 15 cm of residual height, at 4-week cutting intervals. Meanwhile, the Camello II cultivar record stem densities that ranged from 1,802 to 4,099 stems m^2, when they are harvested at 10 cm, at 4-week cutting intervals (Lucio *et al.*, 2023). Therefore, the greatest accumulation of stem in the Cayman cultivar can be attributed to the weight of the stems. For their part, Cruz-Hernández *et al.* (2017) and Silva *et al.* (2016) have documented that using grasses with greater frequency and light cutting intensities reduces the accumulation of stem and dead matter in the forage, which favours obtaining more nutritious forage.

The crude protein content (CP) decreased ($p<0.05$) with an increase in regrowth age from 136 to 73 g kg^{-1}, from the second to the tenth weeks (a 47% reduction). The Mulato II cultivar had the highest ($p<0.05$) protein content in weeks 2 and 4 (158 and 126 g kg^{-1}, respectively); meanwhile Camello II recorded the highest CP in weeks 6, 8, and 10 (99, 95, and 87 g kg^{-1}, respectively). Despite the decrease in protein content as the regrowth age increases, only the Cobra, Camello I, and Camello II cultivars have adequate CP values that actually meet the requirements of ruminants. Animals must be offered a minimum protein content of 70 g kg^{-1} to promote the ruminal activity of the microorganisms responsible for degrading the fiber and obtaining the energy and protein from structural carbohydrates, hemicellulose, and cellulose (Lazzarini *et al.*, 2009; Belachew *et al.*, 2013), consequently ensuring the adequate productivity of ruminants in production systems. Acid detergent fiber (ADF) and neutral detergent fiber (NDF) increased as the regrowth age increased (Table 3). The decrease in protein content and increase in NDF and ADF content in the leaves is the result of the increase in cell walls, as the age of the plant increases, and the degradability of the forage diminishes (Lara *et al.*, 2010). This phenomenon is a consequence of the decrease in the bacterial population in the rumen (Galindo *et al.*, 2011). However, the Camello II hybrid recorded higher protein content during the sixth, eighth, and tenth weeks than the rest of the hybrids, which makes its use a viable option for feeding ruminants.

The NDF values obtained at 4, 6, and 8 weeks in the Cayman and Mulato II cultivars are similar to those reported by Garay *et al.* (2020) in their research about different grasses of the genus *Urochloa* (including Cayman and Mulato II), at different regrowth ages. At 4, 6, and 8 weeks of regrowth, Garay *et al.* (2020) obtained, on the one hand, 567, 587, and 593 g kg^{-1}, and 596, 627, and 648 g kg^{-1} NDF values for Cayman and Mulato II, respectively; on the other hand, they recorded 23.6, 28.4, and 27.8 g kg^{-1}, and 24.7, 26.1, and 27.1 g kg^{-1} ADF values for Cayman and Mulato II, respectively. These values were different from those obtained in the present research.

Table 3. Crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) concentration in *Urochloa* hybrids at different regrowth ages, under semi-arid rainfed conditions, in Tamaulipas, México.

Cultivar	Regrowth ages (weeks)				
	2	4	6	8	10
	CP (g kg^{-1})				
Cayman	149 b	107 e	78 d	79 d	65 d
Mulato II	158 a	126 a	87 e	71 e	66 c
Convert 330	140 c	107 e	76 f	65 f	64 d
Cobra	130 d	112 c	91 b	85 b	78 b
Camello I	114 f	109 d	89 c	81 c	78 b
Camello II	124 e	120 b	99 a	95 a	87 a
Mean	136 A	113 B	85 C	79 D	73 E
	ADF (g kg^{-1})				
Cayman	257 e	358 c	414 a	437 a	436 c
Mulato II	276 d	334 f	387 c	413 d	451 a
Convert 330	274 d	341 e	367 d	421 b	445 b
Cobra	292 c	347 d	406 ab	418 c	424 d
Camello I	321 a	386 a	398 b	402 f	424 d
Camello II	302 b	364 b	383 c	411 e	452 a
Mean	292 E	360 D	402 C	429 B	443 A
	NDF (g kg^{-1})				
Cayman	548 d	572 d	656 a	685 c	694 d
Mulato II	550 d	637 bc	651 a	679 d	714 c
Convert 330	562 c	645 ab	687 a	711 b	734 a
Cobra	538 e	628 c	644 a	664 f	677 e
Camello I	654 a	659 a	667 a	722 a	733 a
Camello II	645 b	647 ab	662 a	677 e	721 b
Mean	590 E	632 D	669 C	695 B	718 A

Different literals between cultivars (a, b, c, d, e, f) and regrowth ages (A, B, C, D, E) indicate significant statistical difference (Tukey; α=0.05).

CONCLUSIONS

Under semi-arid conditions and during the period of greatest precipitation, the Camello II, Mulato II, and Cayman cultivars had the best productive performance, in terms of total dry matter and leaf dry matter. In previous evaluations, the Cayman and Mulato II hybrids had recorded the best agronomic characteristics. In conclusion, the Camello II hybrid could be an alternative for feeding ruminants in semi-arid conditions, due to its TDM performance and nutritional value.

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Colegio de Postgraduados

Opportunities for territorial development in the transisthmic corridor; baseline diagnosis in the region of the Isthmus of Tehuantepec, Oaxaca

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ABSTRACT

Objective: The main objective was to know the current situation of livestock production, problems and potentialities, in the municipalities of Matías Romero, Santa María Petapa and San Juan Guichicovi, Oaxaca, located in the transoceanic corridor of the Isthmus of Tehuantepec.

Design/methodology/approach: The diagnosis was made in eight communities in the municipalities of Matías Romero, Santa María Petapa and San Juan Guichicovi, located north of the Isthmus of Tehuantepec region, Oaxaca. To determine the sample size, the formula suggested by (Snedecor and Cochran, 1967 and Rojas, 1979) was used. It indicates that the elements must be selected through a random draw with replacement, to define the population, the list of production units registered in the Ministry of Agriculture and Rural Development, whose universe is 215, from which, a sample of 41 units was taken.

Results: 36% of the interviewees indicated that the ownership of their land is ejidal, 34% is communal and 30% is small property. The interviewed livestock producers develop their livestock activities on an average of 37 hectares. The production units with the smallest area are 8.5 hectares and those with the largest area are 140 hectares. Of the total number of interviewees, 78% provide themselves with water for cattle in the pasture or corrals, coming from rivers and streams, other sources are springs with 12% and dams with 10%. It is considered that the characteristics described provide adequate conditions for livestock. A problem that afflicts livestock in the tropics in the presence of *Ixodoida* spp, in addition to other types of Mites, the options and alternatives to combat the tick in the PRODETER territory are through the bathroom, regularly it is done by using spray backpack, also the use of Pour on (loin) and tick-killing baths. The misuse of tick control products has generated resistance and problems for farmers (Piña *et al.*, 2017). More than half of the farmers do not participate in animal health campaigns, only 36% do participate. The animal health campaigns in which farmers participate in PRODETER are bovine tuberculosis and paralytic rabies, 24% respectively, tick control 20% and finally brucellosis with 16%. Leos-Rodríguez, (2008) in the work of economic and productive characterization of bovine cattle producers that make up the list of PROGAN beneficiaries in Mexico, observed that the percentage of producers that participated in campaigns against ticks, tuberculosis and brucellosis is above 91%. What is superior to what was found in this diagnosis.

Limitations on study/implications: One of the main limitations was that the PRODETER Program was financed by the State for one year only and with that, in the first instance, it limited the intervention to see the effects and levels of adoption of the technological model in the Family Production Units.

Findings/conclusions: There is ignorance in the use of food supplements, so the development of calves, and the milk production and fertility of the cows, do not express the potential due to the lack of the necessary nutrients in the different productive stages. There is little use of the rangelands because the farmers ignore the practices to give maintenance, make divisions in the paddocks, so they do not rotate. Among the problems detected, the following stand out, among others: the lack of training, the lack of availability of technicians or

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experts to attend them, the cost of artificial insemination technology and the long periods between births, which causes calf production to decrease. Therefore, the lack of training in artificial insemination, stallion evaluation and crossbreeding systems for genetic improvement, limit the development of livestock with better quality standards in the region of the Isthmus of Tehuantepec, Oaxaca. The diagnosis as such provides elements for the territorial development of livestock in the transoceanic corridor, since it offers areas of opportunity throughout the production process and can satisfactorily help livestock in that region.

Keywords: PRODETER, Dual purpose, training, Isthmus of Tehuantepec.

INTRODUCTION

The geographical, environmental, and social characteristics of the Isthmus of Tehuantepec Region create a rich tapestry of culture, ecosystems, natural resources, and diverse productive activities. It is also one of Mexico's regions with conditions of accentuated poverty and a high degree of marginalization. The Government of the Mexican Republic, based on the Sustainable Rural Development Act among others, proposed the Development Program of the Interoceanic Corridor of the Isthmus of Tehuantepec, whose main objective is to contribute to the growth of the regional economy with full respect for history, culture and traditions of the Oaxacan and Veracruz Isthmus. The Interoceanic Corridor plan, in addition to providing first-world infrastructure, aims to interconnect the ports of Coatzacoalcos, Veracruz and Salina Cruz Oaxaca by land. In addition to the comprehensive consolidation of primary activities, the plan encompasses the consolidation of rural economic activities, the development of the Corridor of primary, peripheral and marginalized areas, as well as the development of the primary distribution, collection points and value-added centers. This plan aims to contribute to generating the social, economic, environmental and food security well-being of the rural population, increasing production, productivity and the integration of producers into the value chain, through more inclusive agriculture and livestock, responsible and sustainable, and generating differentiated policies that contribute to the development of the main productive activities of the Region. The Interoceanic Corridor Plan of the Isthmus of Tehuantepec considers four transversal axes of attention: I. Capacity Development, Extension and Rural Consulting; II. Health and Safety Services; III. Water and soil Capture, Conservation and Management; and IV. Access to Financing Services; as well as the Economic Integration component of the Productive Chain…" (SIC), (DOF Gobierno de México, 2020).

The public policy in the Mexican Republic for the 2018-2024 administration was issued and, in the general provisions and operating guidelines of the rural development program of the Ministry of Agriculture and Rural Development, it is stated that the support of the Rural Development Program will be aimed at small producers in areas of high and very high marginalization, applying criteria of social inclusion and gender equity. The Family Production Units (UPFs —in Spanish), are defined as: "…a group of producers who associate to achieve a common objective, without legal formality or constituted as associative entities under the national legal regulations." To achieve this, efforts from three parties were combined: extension services, research, and the productive sector, in order to create synergies and be able to manage innovation. (Avalos *et al.*, 2021; de la O *et al.*, 2021; Cabrera *et al.*, 2022).

The Ministry of Agriculture and Rural Development conceptualized territorial development as an action where two segments converge: investment in infrastructure and investment in knowledge, an aspect widely documented in (Avalos *et al.*, 2021). The aim is for farmers, agricultural workers, producers or livestock farmers (for the purposes of this document, the management of the three concepts will be considered as synonymous with each other and make a differentiation with livestock farmers, due to the activity they undertake, drawing on concepts by Chayanov (1974); Wolf (1975); Galesky (1997) and the pro-peasant concepts of Armando Bartra, cited by Boltvinik (2009), etc. be regarded as subjects and not as beneficiaries and recipients of government programs that contribute to the well-being of them and their households. The Ministry of Agriculture and Rural Development of Mexico conceptualizes three interrelated actors: Producers, Extensionists, and Researchers. Regarding the aforementioned, in the knowledge segment, the National Institute of Forestry, Agriculture, and Livestock Research (INIFAP) has a direct influence where it is committed to having three fundamental actions: Taking the available technologies to the producer, providing technical accompaniment to UPFs already grouped into functional organizations to achieve or manage innovation; conducting a territorial diagnosis through the characterization of UPFs, prioritizing the identified issues, and intervening with a differential working model in the selected territories.

The main objective was to know the current situation of livestock production, problems, and potential in the Oaxacan municipalities of Matías Romero, Santa María Petapa and San Juan Guichicovi, located in the Transoceanic Corridor of the Isthmus of Tehuantepec.

Technical-productive diagnosis of the Family Production Units: which consisted of the following sections or activities:

a. Technological characterization of Family Production Units.
b. Identification of the productive issues.
c. Definition and estimation of productive indicators, baseline diagnosis to contrast the annual advances of technological intervention.
d. Proposal of a technological model based on the technologies available by INIFAP or other higher education/research institutions.

Technology transfer proposal

a. Establishment of demonstrative modules (on producers' lands) and hosting demonstrative events.
b. Implementation of a program for the development of technical skills for extensionists and producers.
c. Sessions for the exchange of experience and knowledge among producers.

Technical Support Strategy

The objective was to provide feedback to producers and extensionists in the application of the technological components, which allowed direct interrelation in the field between

extension agents, producers, and the researcher. Technical support was provided on the plots and/or farms of the agricultural and livestock producers. The researcher designed a program of visits to the territory, considering: the phenological stages of the crop, the physiological stages in the animals, the recommended technological components, and other specific aspects. The present diagnosis on livestock farming is part of the National Territorial Development Project (PRODETER), developed between 2020 and 2021 in the Mexican Republic.

In this framework, field activities were conducted in different regions of the country. One of the undertaken activities was the baseline study, for which a diagnosis of production was conducted in a territory characterized by its vocation and background in livestock production, in the municipalities of Matías Romero, Santa María Petapa and San Juan Guichicovi, located to the north of the Isthmus of Tehuantepec region, Oaxaca. This region has gained special interest for being a trans-isthmus corridor in two development poles: the port of Coatzacoalcos, Veracruz in the Gulf of México, and the port of Salina Cruz, Oaxaca in the Mexican Pacific. The diagnosis was conducted to understand the current situation regarding the technological management of livestock in the aforementioned municipalities, addressing aspects related to nutrition, feeding and product marketing. The information was obtained through the application of a pre-coded questionnaire, field trips, as well as interviews with key stakeholders. A diverse set of issues was identified, of which the following stands out: differentiation of potential across production unit areas, the availability of forage throughout most of the year, but also the limited use of technologies to improve aspects of health, nutrition and added value.

MATERIALS AND METHODS

The diagnosis was carried out in eight communities in the municipalities of Matías Romero, Santa María Petapa and San Juan Guichicovi, located north of the Isthmus of Tehuantepec region, Oaxaca. To determine the sample size, the formula suggested by (Snedecor and Cochran, 1967 and Rojas, 1979) was used. It indicates that the elements must be randomly selected with replacements. The definition of the population was based on the list of production units registered in the Ministry of Agriculture and Rural Development, with a total universe of 215. From this, a sample of 41 units was selected.

$$n = \frac{\frac{Z^2 p_n\ q}{d^2}}{1 + \frac{Z^2 p_n\ q}{N\ d^2}}$$

The mathematical equation is detailed as follows based on a hypothetical universe:

Where: Z=Confidence level; d=Precision level; pn=Proportion of the population that belongs to the interest group; q=$(1-p_n)$; N=Population size; n=Sample size.

The information was obtained by applying a pre-coded questionnaire with sections on social issues, elements for production, and technological characterization, including reproductive and productive parameters, as well as field trips and interviews with six key actors (stakeholders). The information from the questionnaires was captured in the Excel © database, and analyzed in a program for social sciences, from which the results were obtained and are described later.

RESULTS AND DISCUSSION

Socioeconomic aspects. Regarding gender, 80% of the participants are men and 20% women, which clearly demonstrates the predominance of men in this activity. This situation is similar in other branches of countryside activities (León *et al.*, 2002). The average age of participating producers is 46 years; this represents a productive age, with the presence of young individuals, which is attributed to the economic orientation of livestock farming that prevents migration and abandonment of the activity (Chávez *et al.*, 2019).

Concerning education, 95% of those interviewed can read and write, 5% lack this skill. Those who cannot read or write are in the age range of 69-76 years. Among those who have education, 51% completed elementary education, 43% the secondary level and 7% the high school or equivalent. The data from the working area differ from the results of other studies in indigenous areas, where it is common to find higher percentages of people who cannot read or write (León *et al.*, 2002; Bautista 2018).

46% of those interviewed identify themselves as indigenous, belonging to the Zapotec ethnic group, the remaining 54% do not recognize themselves as indigenous.

Regarding membership in organizations, 71% of those interviewed do not belong to any organization, while 29% indicated that they belong to an organization. The above illustrates that the work, in general, has been individual, and the organizational potential has not been taken advantage of for the development of the activities, although it must also be considered that on many occasions the negative experiences in the organizational aspects, limits new efforts due to associativity and willingness to undertake new productive entrepreneurships.

Regarding how they obtain information for production, 49% of the producers stated that they receive advice or information from other producers, 36% receive advice from a technician or researcher, 12% obtain information from the supply store, and 3% mentioned other sources. These data show that producers have greater trust among themselves, based on the experience that is shared, even though a significant amount of them receive information from technical personnel (Amaro-Rosales and Gortari-Rabiela, 2016). Similar research was conducted by Zambada *et al.* (2013) and Cadena *et al.* (2018), in which they found that information flowed from three actors in the region or territory: an Agronomy professional, the manager of a veterinary store, and a government institution and on a smaller scale among peasants. Regarding the source of resources to develop their productive activity, 90% indicated that they use their own resources, while other sources indicated they used loans (10%). The low proportion of producers who prefer loans is attributed to distrust of credit institutions, the risk of high interest, as well as lack of confidence in credit

institutions, and the poor dissemination of financing opportunities to the countryside (Serrano, 2021).

Elements for production

36% of those interviewed indicated that their land ownership is *ejidal*, 34% is communal, and 30% is small property. The livestock producers interviewed develop their livestock activities on an average of 37 hectares. The production units with the smallest area are 8.5 hectares and those with the largest area are 140 hectares. Of the total interviewees, 78% obtain water for livestock in the pasture or corrals, sourced from rivers and streams; other sources include springs with 12%, and dams with 10%. It is considered that the described characteristics provide suitable conditions for livestock farming.

Predominant cattle breed

There is not a single record of pure and Creole breeds in any of the three municipalities. Farmers prefer to crossbreed bovines of European breeds, *Bos taurus*, with zebu, *Bos indicus*, selecting animals for their racial conformation, rather than for their milk or meat production characteristics. Similar results were found by Aguilar (1992), who, in a diagnosis in Venezuela, observed that the phenotypic characteristics of the animals correspond to the hybrid type, a product of continuous crossbreeding of Creole animals with purebred animals, due to the continuous change of sires since every three or four years, those who have greater possibilities are introduced. The phenotypic characteristics of purebred animals have not been fixed, as these crossbreeds have not been conducted. In the cattle population, there is a higher presence of breeding cows, calves, and heifers. This situation denotes a low percentage of annual extraction and a low reproductive efficiency of the wombs. Quiroz *et al.* (2014), found a similar situation in the herd structure in Tabasco. The number of replacement heifers accounts for 15% of the total herd, as an attempt to increase the number of breeding females; the livestock farmers retain all the females (Medina *et al.*, 2009).

The number of calves, although high, represents only 40% of the total, which reflects a low reproductive capacity of the herd. It means that there are wombs with reproductive problems with the usual decrease in the number of offspring. The maintenance of wombs that are not pregnant after two consecutive mating periods and those that give birth late represents an unnecessary expense and are candidates for culling (Rivera and Quintal, 2011). Some livestock farmers who have sufficient resources to meet the nutritional needs for grazing bulls raise the possibility of taking advantage of the potential for meat production at a local level, preventing calves from being sold at low prices. To address the demand for training, technologies for fattening grazing bulls and feeding systems based on protein and energy banks using cut grass have been developed, which can be transferred to producers (Maldonado *et al.*, 2012a; Maldonado *et al.*, 2012b).

Supply of forages and concentrates

The climate and soil conditions are favorable for livestock farming in the Matías Romero PRODETER, the animal load that livestock farmers handle in relation to the

range area means that they do not feel the need to make silos, produce hay or any method of conservation of forage. Only a few that have exceeded the limit or have faced prolonged draught conditions due to climate change have found necessary to construct silos primarily to support breeding stock and calves, which are of utmost importance to them. 62% of producers indicated that they had supplied silage for livestock, mainly for breeding stock and developing calves. Similarly, mineral blocks (48%) were supplied for breeding stock and calves, although it is not a routine practice (Amaro, 2001).

The supply of vitamins and mineral premixes for livestock is common in Matías Romero PRODETER; 64% of the livestock farmers provide such supplements for animals, including both breeding stock and calves. Most of livestock farmers are accustomed, by tradition, to providing salt to their cattle. However, they do so empirically, without having a precise understanding of the nutritional needs of the livestock. In general, they lack criteria regarding the quantity and quality of mineral salts and vitamin premixes they purchase to offer to their animals (Jiménez *et al.*, 2014). It is important to underscore that concentrates, maize grains and protein pastas are not provided. Some limitations that expressed relate to the cost of concentrates and minerals, as well as the lack of knowledge of how to prepare balanced diets for livestock.

Rangeland Management

It is important to mention that livestock farmers in the communities of Matías Romero PRODETER, given the extensive land areas at their disposal, can place all livestock heads in that area while simultaneously dividing it into lots to effectively manage the available pasture. However, often the livestock tends to scatter in a manner that cannot be entirely controlled by the farmers. For this reason, pasture subdivision (62%) is implemented, leading to the practice of rotational grazing. The use of electric fencing was minimal, with only two cases reported throughout the entire territory, similarly to the adjustment of stocking rates. González (2013) in Tuxpan, Veracruz, observed a similar situation where animals graze freely with minimal or no management, receiving little attention from an ecological perspective, resulting in an impact on biodiversity and ecosystem integrity (Maldonado *et al.*, 2015). The lack of knowledge about new forage species to improve the quality of the feed was also mentioned; likewise, reference was made to the dry season period from March to June (48%).

Reproductive practices management

Regarding reproductive management practices carried out by livestock farmers in Matías Romero PRODETER, the only practice identified is free mating (92%). Issues were identified, including the low number of calvings per year (32%), abortions at 16%, and the fact that females take a long time to conceive again after giving birth (36%).

External and Internal Livestock Health Management

A problem affecting livestock in tropical regions is the presence of *Ixodoida* sp., as well as other types of mites. The options and alternatives for tick control in the PRODETER territory include bathing, commonly done using backpack sprayers. Additionally, the use

of Pour-on (on the loin) and tick-dipping baths are employed. The misuse of tick control products has led to resistance issues and challenges for livestock farmers (Piña *et al.*, 2017). More than half of livestock farmers do not participate in animal health campaigns, only 36% do participate. The zoosanitary campaigns where PRODETER farmers participate include bovine tuberculosis and paralytic rabies, 24% respectively, tick control 20%, and finally, brucellosis with 16%. Leos-Rodríguez (2008) in the work of economic and productive characterization of the cattle producers that make up the registry of PROGAN beneficiaries in Mexico, observed that the percentage of producers who participated in campaigns against ticks, tuberculosis and brucellosis is above 91%, which surpasses what was found in this diagnosis. Regarding the vaccination program, 86% of the livestock farmers indicated that they do have a vaccination program.

The vaccination programs established among the farmers of Matías Romero PRODETER are for pneumonia (72%), Leptospirosis (68%), Clostridiosis (60%), derriengue (56%), and finally, the triple vaccine (48%).

Regarding the sample size in this study, it was found that 92% do not perform any hygiene practices during milking. Only 4% engage in udder washing, and the use of teat sealants is also at 4%. This indicates that there are no good management practices in obtaining milk, which could represent a potential public or industrial health risk depending on the destination of the milk. On the other hand, the most frequent health problems in the livestock are mastitis 68%, peripartum issues and diarrhea 48%, foot rot 44%, abortions and rabies with 9 cases 36%, septicemias and respiratory diseases 24%, ocular diseases 16%, and finally, 8% are parasitic conditions associated with ticks. The diagnosis of subclinical mastitis is not carried out in any of the communities or municipalities within Matías Romero PRODETER. Lack of training for disease control (80%) and the absence of information recording (60%) were identified.

Marketing of Livestock Products

Livestock farmers in PRODETER Matías Romero, when it comes to marketing, respond based on the capacity of their pastures to sustain the number of animals they own, as well as their economic needs and the opportunities they have to sell at a better price. Following these criteria, they sell weaned calves first, and then heifers that can be offered at a better price, followed by fattening calves and finished steers, and finally cull cows. The latter are sold last because they have a lower price per kilogram, and they can be sold at any time to meet local demand. The common practice is the sale of live cattle. The method of sale is centered around intermediaries, so it is likely that, in this business relationship, producers do not fully benefit, as they do not have a direct connection with the final link in the marketing chain.

Villate and Martínez (2011), in a diagnosis conducted with producers in a province in Colombia, mention that the data found suggests that the operations belong to small and medium-sized producers who work in isolation. This isolation hinders their access to appropriate technologies for production and specialized markets that could improve the income and social well-being of the community.

Definition and Estimation of Reproductive and Productive Indicators

A critically important fertility indicator is the age at first calving, with an average value of around 36 months of age. This suggests a low growth potential and deficient strategies in replacement management. The average percentage of females calved in Matías Romero PRODETER is 64%. Although the calving percentage is relatively high, the proportion of breeding females to the total is low. The average time between one calving and the next for a female is 443 days (15 months) in PRODETER. After a 12-month calving interval, $1/9^{th}$ of a gestation calf is lost (280 days). If the average is 15 months, $3/9^{th}$ or a third of a calf is lost for each non-pregnant cow. The average age at first birth in PRODETER is 33 months. When records are not available, predicting this data becomes difficult, however, these data reflect a good level of productive efficiency according to the environmental conditions, given the availability of pasture during most of the year. However, a drawback in the system is the lack of productive and reproductive records.

With the characteristics of pasture or rangeland management, as well as the cattle and nutritional values, we can indicate that, due to the climatic conditions and access to natural resources in this territory, livestock farming is potentially an alternative for economic development in the Isthmus of Tehuantepec. Although there are many areas of opportunity in each of the points described, it is essential for farmers to approach government institutions to request constant and/or permanent guidance to improve the described parameters and enhance with good livestock practices. PRODETER, as such, fulfilled its objectives of facilitating access to knowledge through technologies and the presence of the extension technician in the territory. However, it is understandable that any technology, no matter how simple, requires resources, whether human for development, economic, or material, depending on the magnitude of the issues and the proposed technologies within the technical support strategy provided to the producers.

Based on the technical-productive diagnosis, the implementation of a technological model was prepared and proposed to producers based on the technology generated and available by INIFAP. The proposed model was implemented through training courses with the Field Schools method, a concept that academics and researchers in Mexico have extensively developed and described, among others: Morales *et al.* (2006); Morales (2007); Morales *et al.* (2015); Morales *et al.* (2016); Chain (2016); Martinez *et al.* (2019) and Morales *et al.* (2022) aimed at producers in the participating communities.

The main activity, in which a significant amount of time and resources were invested, was the technical-productive diagnosis, which allowed the identification of the problem, which translates into opportunities to improve the production process, of livestock farming in the Isthmus of Tehuantepec. The same diagnosis facilitated the integration of the technological model, which was implemented, along with the technical support, with the particularity that the application period, both of the model and the support, was very short in time. Regarding the possible effects of training and technical support, these may be little or none. Likewise, the usefulness of the diagnostic information transcends the operation of PRODETER, since this territory coincides with the scope of the interoceanic corridor, contemplated in the program for the development of the Isthmus of Tehuantepec, which requires technical-productive information for its operation.

CONCLUSIONS

There is a lack of knowledge in the use of nutritional supplements, so the development of the calves, and the milk production and fertility of the cows, do not express their potential due to the lack of the necessary nutrients in the different productive stages. There is little use of the pastures because livestock farmers ignore the practices to maintain them, and make divisions in the pastures, so they do not rotate them. Of the problems detected, among others, the following stand out: the lack of training, the low availability of technicians or experts to address them, the cost of artificial insemination technology and the long periods between births, leading to a decrease in calf production. Therefore, the lack of training in artificial insemination, evaluation of breeding bulls, and crossbreeding systems for genetic improvement limits the development of livestock with higher quality standards in the region of the Isthmus of Tehuantepec, Oaxaca. The diagnosis as such provides elements for the territorial development of livestock farming in the transoceanic corridor, since it offers areas of opportunity throughout the production process and can satisfactorily help livestock farming in that region.

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Colegio de Postgraduados

Fire effect on the diversity of forest species in a medium superennifolia forest of Mexico

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ABSTRACT

Objective: Evaluate the effect of fire on natural regeneration and forest species diversity in a medium superennifolia forest in southeastern Mexico.

Design/methodology/approach: Natural regeneration was classified into three height categories (0 to 30 cm, 31 cm to 1 m and 1 to 3 m) and trees in three forest sites burned and unburnt by fire.

Results: A total of 1193 individuals belonging to 69 species in 29 taxonomic families were recorded. Regeneration from 0 to 30 cm presented significant differences in species diversity in unburnt forest sites, while in regeneration from 1 to 3 m in burned forest sites.

Limitations on study/implications: These types of studies are a first approximation to natural regeneration after a fire in tropical forests, so it is important to maintain permanent sites to monitor the recovery of ecosystems and thus be able to establish management strategies for the restoration of these ecosystems.

Findings/conclusions: Regeneration after the fire was established with a low but constant number of species, indicating a tendency towards vegetation resilience. This information allows government institutions to make better decisions on the management and prevention of these ecosystems in Mexico.

Keywords: Conservation, Resilience, Richness, Vegetation composition, Forest fires.

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INTRODUCTION

The Yucatan Peninsula has one of the regions with the largest area of tropical rainforests in Mexico (Islebe *et al.*, 2015). They are characterized by a very marked seasonality with a dominant floristic composition (Fabaceae), different structural patterns and a high rate of species turnover (β-diversity) (Hernández-Ramírez and García-Méndez, 2015). Despite their importance, they are considered threatened ecosystems due to the reduction of forest cover and the presence of hurricanes and forest fires (Trejo and Dirzo, 2002). In particular, the presence of forest fires causes alterations that directly affect the diversity and successional

dynamics of tropical forests (Martínez-Garza *et al.*, 2022). That is, after a fire, the natural regeneration process determines which trees will be replaced because many species are shade intolerant in their establishment stage and are therefore favored by the opening of clearings resulting from the impact of fire (Martínez and García, 2008). Although not all species respond in the same way to fire, they are subject to their regenerative strategies (Martínez-Garza *et al.*, 2022).

An adequate understanding of the restoration process requires information on various aspects, such as seed availability and viability, invasive species, plant succession, species phenology, among others (Harris *et al.*, 2006). Understanding these aspects is relevant to support restoration strategies for tropical rainforest ecosystems, for which continuous evaluations should be conducted to determine evidence that the succession dynamics tend to the restoration of these ecosystems (Gómez *et al.*, 2013). In this way, it is possible to define which aspects favor, which hinder and which restoration processes to choose at different stages of development of the plant community to determine whether it tends to resilience (Vargas, 2011). However, little is known about the restoration processes of medium superennifolia forest in the Yucatan Peninsula, which limits the success of the implementation of appropriate strategies for the restoration of ecosystems impacted by forest fires.

In this sense, extreme climatic changes such as forest fires occur with greater frequency and severity in tropical ecosystems, so the generation of knowledge from natural regeneration as the evaluation of changes in species diversity in different areas affected by fire in medium superennifolia forest becomes a priority issue (Hernández-Ramírez and García-Méndez, 2015). Therefore, the objective of this study was to evaluate the effect of fire on natural regeneration and forest species diversity in a medium superennifolia forest in southeastern Mexico. The information generated in this study will allow the promotion of different strategies that promote better decision making by government institutions to promote the prevention, management, and conservation of one of the most important biosphere reserves in Mexico.

MATERIALS AND METHODS

Sampling was conducted in the Muyil Core Zone of the Sian Ka'an Biosphere Reserve in Quintana Roo, Mexico (19° 59' 40.33" N - 87° 38' 18.3" W) (Figure 1). This area was impacted by a forest fire in the months of July and August 2019 affecting a total of 3,203.71 hectares, with the medium superennifolia forest being the most affected with 148.66 hectares according to the Comisión Nacional de Áreas Protegidas (CONANP, 2021).

Experimental design and biological material

In 2022 a paired experimental design was established with three burned and three unburnt forest sites. At each site, different categories of natural regeneration of post-wildfire vegetation were evaluated with 10 replicates respectively (n=60); a) circular sampling unit of 400 m^2 for adult trees (DBH>7.5 cm); b) three circular sub-sites of 5 m^2 for regeneration from 0 to 30 cm in height; c) three square sub-sites of 25 m^2 for medium regeneration from

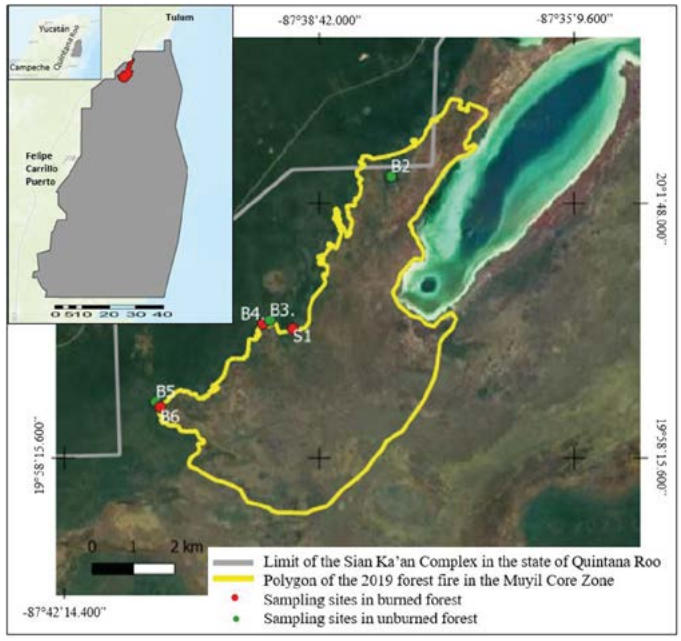

Figure 1. Location of sites for the evaluation of regeneration and forest species diversity in the Muyil Core Zone of the Sian Ka'an Biosphere Reserve.

31 cm to 1 m in height; and d) three square sub-sites of 64 m^2 for large regeneration from 1 to 3 m in height (Flores-Garnica *et al.*, 2018). In addition, the number of species at each site per regeneration level was recorded and botanical samples of the species were collected to identify them taxonomically with specialized keys that were validated in the World Flora Online database (WFO, 2023).

Abundance, richness and diversity species

Range-abundance curves were elaborated (Magurran, 1998), using the number of species and individuals per species recorded in each site (burned and unburnt forest), by regeneration level. The curves were plotted according to the logarithm base 10 of the proportion of each species (Log10 pi+1), and the data were ordered from the most abundant to the least abundant species. A nonparametric Wicolxon rank test was performed between sites by regeneration and trees. Species richness was assessed through rarefaction/extrapolation curve analysis (Chao and Jost, 2015). This analysis was done for each level of regeneration and trees between sites. Thus, curves were constructed from species abundance data considering 999 resamples (bootstrap). Specifically, the rarefaction/extrapolation curves defined a measure of completeness of the population, or community, belonging to the species included in the sample (Chao and Jost, 2015). Analyses were performed in iNEXT software (Hsieh *et al.*, 2016) available at https://chao.shinyapps.io/iNEXTOnline/. Finally, Shannon diversity indices (H'), Simpson dominance ($1/\lambda$) and Pielou's equality (J') were calculated, used to statistically contrast the values recorded between sites by regeneration and trees using the t-test (Zar, 1999). The analyses were conducted with PAST 4.6 software (Hammer *et al.*, 2001).

RESULTS AND DISCUSSION

Species composition and abundance

A total of 1193 individuals belonging to 69 species in 29 taxonomic families were recorded in the six study sites (Table 1). The families with the highest species richness were Fabaceae (15), Euphorbiaceae (6), Rubiaceae (6) and Spindaceae (5), while Arecaeae, Polygonaceae and Salicaeae only recorded 3 each. The first four families include 46%

Table 1. List of species recorded in the medium superennifolia forest of the Sian ka'an Biosphere Reserve in the burned forest (BF) and unburnt forest (UF) sites.

Family/species	0-30 cm		31cm-1 m		1-3 m		Trees	
	BF	UF	BF	UF	BF	UF	BF	UF
Acanthaceae								
Bravaisia berlanderiana (Ness.)	1		1	1	22			
Anacardiaceae								
Metopium brownei (Jacq) Urban.	14	11	31	3	12	1	3	37
Annonaceae								
Malmea depressa (Bailon) R. E. Fries.	2	2	6	6		13		
Mosannona depressa (Baill.) Chatrou		5	2	39	1	70		3
Apocynaceae								
Plumeria rubra L.						1		
Thevetia gaumeri Hemsl.		1	5		12	3	1	3
Araliaceae								
Dendropanax arboreus (L.)							1	
Arecaceae								
Desmoncus orthacanthos Mart.		3		1	2			
Mauritia flexuosa L. f.		2	1	3	6	26		
Thrinax radiata Lodd. ex Schult. & Schult. f.		3				8		
Burseraceae								
Bursera simaruba (L) Sarg.	1	1	20		45		7	38
Capparaceae								
Capparidastrum mollicellum (Standl.)				3	2	1		
Ebenaceae								
Diospyros cuneata Stand.		39	1	20	1	13		17
Ehretiaceae								
Ehretia tinfolia L.			2	2		2		
Euphorbiaceae								
Croton arboreus Millsp.		1	0	6		4	1	
Croton icche Lundell.	3	1	7	1			2	3
Gymnanthes lucida Sw.		1	1					
Jatropha subsect Gaumeri Dehgan.		1			2	2		
Sebastiania adenophora Pax & K. Hoffm.			1					
Fabaceae								
Bauhinia divaricata L.								1

Table 1. Continues...

Family/species	0-30 cm		31cm-1 m		1-3 m		Trees	
	BF	UF	BF	UF	BF	UF	BF	UF
Caesalpinia gaumeri Greenm.		1		1	1	2		2
Caesalpinia pulcherrima (L.) Sw.				1		1		
Dalbergia granadillo Pittier								2
Desmodium incanum (Sw.) DC.			2		1			4
Enterolobium cyclocarpum (Jacq.) Griseb.					2			
Ficus mexicana (Miq.) Miq.			8		6			
Havardia albicans (Kunth) Britton & Rose					2			
Lonchocarpus rugosus Benth.		1	13	1	12			4
Lonchocarpus xuul Lundell			4		6	1		
Lonchocarpus yucatanensis Pittier		1		5		6		2
Lysiloma latisiliquum (L.) Benth			1		10		2	11
Piscidia piscipula (L.) Sarg.			1				1	7
Pithecellobium dulce (Roxb.) Benth.					1			
Senegalia gaumeri (S. F. Blake)					4		1	
Lamiaceae								
Vitex gaumeri Greenm.			4	3	17		3	11
Lauraceae								
Nectandra salicifolia (HBK) Nees.	9	12	33	25	20	12	2	
Malpighiaceae								
Bunchosia swartziana Griseb.				4		5		
Malvaceae								
Ceiba aesculifolia Britten & Baker f.	1							1
Hampea trilobata Standl.			1	2	2	1		
Moraceae								
Brosimum alicastrum Sw.			2				1	
Ficus crassinervia Desf. ex Willd.					2			
Myrtaceae								
Eugenia foetida M. Vahl		19	9	32	2	18		1
Myrcianthes fragrans (Sw.) McVaugh		1						
Phyllanthaceae								
Phyllantus micinianus Baill.					1			
Polygonaceae								
Coccoloba spicata Lundell		8		13		30		2
Neomillspaughia emarginata (H. Gross)				1		3		
Rumex obtusifolius L		2		7	3	7		
Putranjivaceae								
Drypetes laterifolia (Sw.) Krug & Urb.			1					
Rubiaceae								
Guettarda elliptica Sw.					1			1
Hamelia patens Jacq.		1	3		2			

Table 1. Continues...

Family/species	0-30 cm		31cm-1 m		1-3 m		Trees	
	BF	UF	BF	UF	BF	UF	BF	UF
Psychotria pubescens Swartz.	1		1		2		2	
Randia aculeata L.						3		
Randia truncata Greenm. & C.H. Thomps.		1	1	1		2		
Rutaceae								
Esenbeckia pentaphylla Griseb.				1				
Zanthoxylum caribaeum Lam.			2	1	4		1	
Salicaceae								
Laetia thamnia L.			1					
Samyda yucatanensis Standl.				2				
Zuelania guidonia (Sw.) Britton & Millsp.					1		1	
Sapindaceae								
Allophylus cominia (L.) Sw.		1						
Cupania belizensis Standl.					8			
Melicoccus oliviformis (Radlk.) Acev. Rodr.							1	
Sapindus saponaria L.								2
Thouinia paucidentata Radlk.		5				1		3
Sapotaceae								
Chrysophyllum mexicanum Brandegee ex Standl.			1		1	1		
Manilkara zapota (L) Van Royen.				5	1	10	1	2
Simaroubaceae								
Simarouba glauca DC.		1			3	1		11
Solanaceae								
Nicotiana sect. Tabacum G. Don						1		
Solanum erianthum D. Don					5			
Urticaceae								
Cecropia obtusifolia Bertol.					5		2	

of the species recorded in the study, while only 22 families (76%) are represented by one or two species. In the burned forest sites, 461 individuals of 52 species belonging to 28 families were recorded. In contrast, in the unburnt forest sites, 732 individuals of 51 species belonging to 24 families were recorded. The families Urticaceae and Moraceae were recorded in the burned forest sites, while Malpighiaceae was recorded only in the unburnt forest sites.

The abundance of species recorded in the medium subperennial rainforest was different depending on the height category of the regeneration and the impact of fire. In the 0 to 30 cm regeneration the species *Diospyros cuneata* Stand., *Eugenia foetida* M. Vahl, *Nectandra salicifolia* (HBK) Nees and *Metopium brownei* (Jacq) Urban were the most abundant and dominant in unburnt forest sites ($z=-255.0$; $P<0.001$), only *M. brownei* and *N. salicifolia* were recorded in burned forest sites (Figure 2a, b). For the 31 cm to 1 m

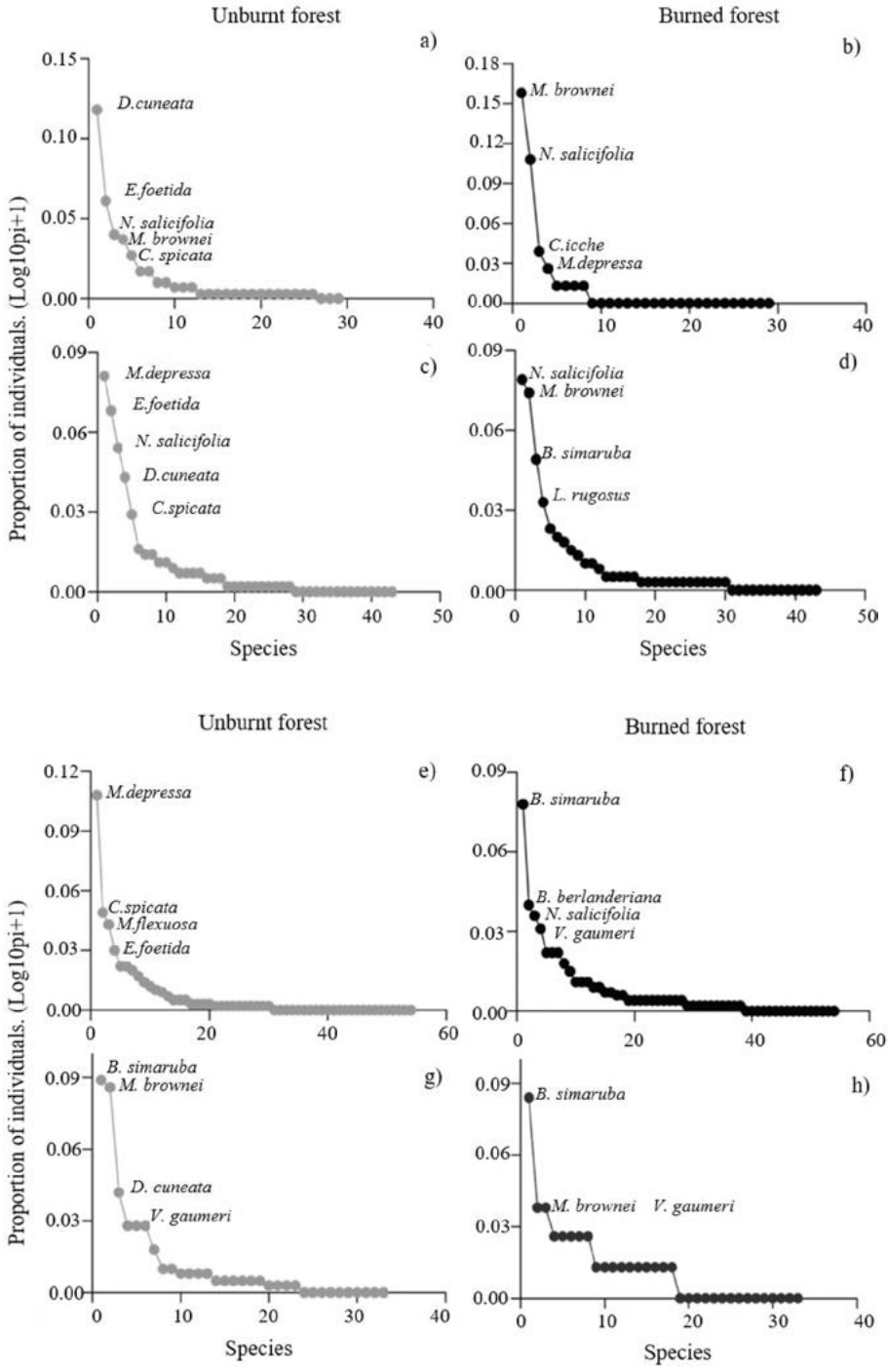

Figure 2. Range-abundance curves at different regeneration levels: a and b=0 to 30 cm, c and d=31 cm at 1 m, e and f=1 to 3 m, g and h=Trees in burned and unburnt forest sites, respectively.

renegeration the dominant species were *Mosannona depressa* (Baill.) Chatrou and *Eugenia foetida* M. Vahl as well as *N. salicifolia* and *M. brownei* for both sites (Figure 2c, d). In the 1 to 3 m regeneration, *Malmea depressa* (Bailon) R. E. Fries stands out with greater dominance in unburnt forest sites while *Bursera simaruba* (L) Sarg in burned forest sites

(Figure 2e, f). Finally, in the trees *B. simaruba* was the most dominant species in both sites (Figure 2g, h).

The Burseraceae, Lauraceae and Anacardiaceae families were found to be the most abundant in the burned forest sites with the presence of *B. simaruba*, *N. salicifolia* and *M. brownei* species, respectively. It has been reported that *M. brownei* is a species that persists after fire disturbance due to its resprouting capacity that makes it a dominant species in post-fire regeneration in tropical rainforests (Wolfe, 2009). Similarly, *B. simaruba* and *N. salicifolia* are species that manage to persist after fire due to their characteristics such as physical seed dormancy, stem thickness and the presence of rhizomes that allow them to potentially adapt to fire, which favors their establishment as early successional species (Juárez and Rodríguez-Trejo, 2003). This coincides with Brokaw's (1984) report that fire generates changes in abiotic factors (humidity, temperature, and soil pH) and biotic factors (herbaceous cover and number of mammals) in tropical rainforests that influence successional dynamics (Rodríguez-Trejo *et al.*, 2019).

Richness species

Regeneration from 0 to 30 cm in unburnt forest sites presented the highest richness as revealed by the rarefaction curve that grew rapidly as a function of individuals in the sample, while burned sites presented the lowest abundance and species richness ($P>0.05$) (Figure 3a). In contrast, regeneration from 31 cm to 1 m and 1 to 3 m presented the highest abundance of individuals with similar species richness in unburned ($S=32$ and $S=29$) and burned ($S=35$, $S=38$) forest sites (Figure 3b, c). The trees presented higher abundance and richness in unburned sites (Figure 3d).

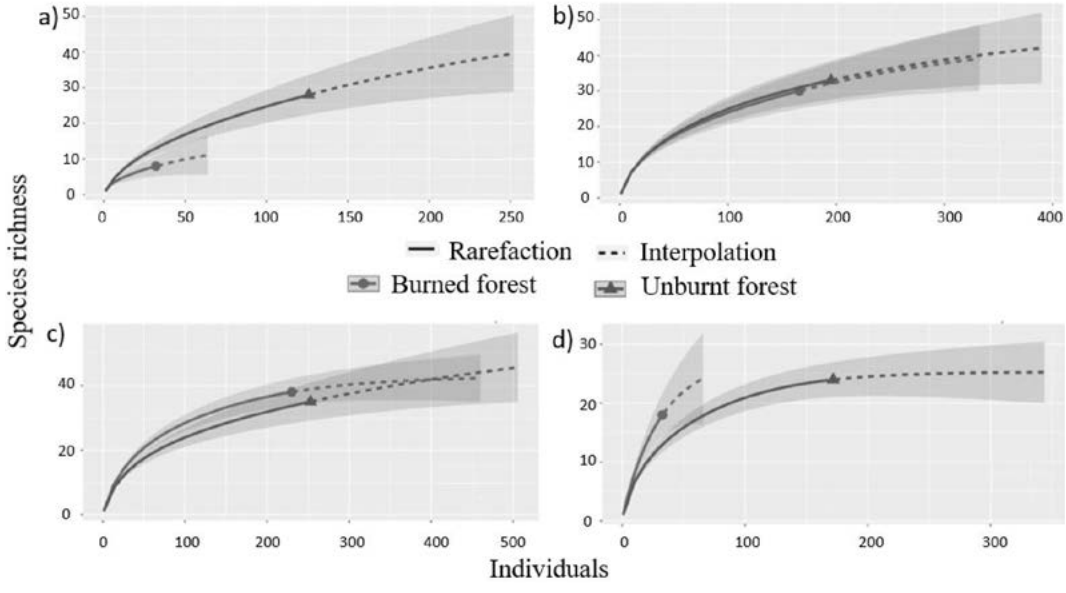

Figure 3. Rarefaction-extrapolation curves in categories a=0 to 30 cm, b=31 cm to 1 m, c=1 to 3 m and d=Trees. Solid line indicates interpolation and dotted line indicates extrapolation and the shadow shows the 95% confidence interval.

The consequences of forest fire on species richness in medium superennifolia forest were evident in burned and unburnt forest sites. However, changes at different levels of regeneration in the abundance and richness of the forest species community were highly variable. That is, species richness in the 0 to 30 cm regeneration was higher in the unburnt forest sites as revealed by the rarefaction curves. On the other hand, the regeneration from 31 cm to 1 m and 1 to 3 m showed similar abundance and species richness between sites, while the trees recorded higher abundance and richness in unburnt forest sites. The above suggests complex responses of forest species to fire related to adaptations to fire, but also to microclimatic conditions and seasonality of subperennial forests that influence the abundance and richness of the post-fire plant community (Ochoa-Franco *et al.*, 2019; Cadena-Zamudio *et al.*, 2022).

Species diversity and dominance

Regeneration from 0 to 30 cm recorded higher species diversity in unburnt forest sites ($t=4.3081$; $P<0.001$) (Figure 4a). Regeneration from 31 cm to 1 m had high diversity values with no significant differences between sites ($P>0.05$). In contrast, regeneration from 1 to 3 m recorded the highest diversity value in burned forest sites ($t=-3.9905$; $P<0.001$) (Figure 4a). Likewise, the trees in burned forest sites registered high diversity values, but without significant differences ($P>0.05$). The dominance of the regeneration from 0 to 30 cm recorded higher values in burned forest sites while the regeneration from 1 to 3 m and the tree stand recorded the lowest dominance values in burned forest sites (Figure 4b). With respect to evenness, values between 0.7 and 0.85 were observed in burned and unburnt forest sites, respectively (Figure 4b).

Changes in species diversity were found in the different regeneration categories, for example, regeneration from 1 to 3 m was more diverse in burned forest sites, contrary to what has been reported by other studies where more regeneration has been found in smaller categories (Rodríguez-Trejo *et al.*, 2019; Flores-Rodríguez *et al.*, 2021). This

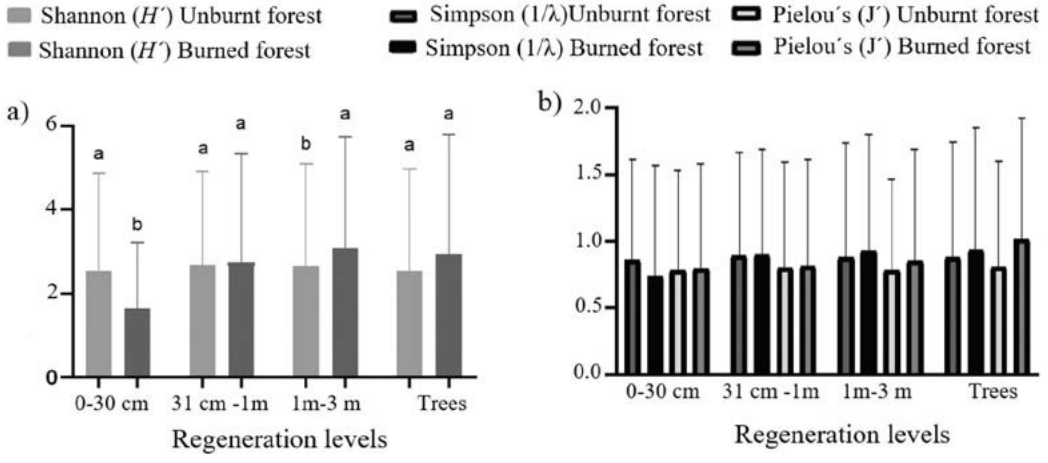

Figure 4. a=Shannon's Diversity Index (H') and b=Simpson's dominance (1/λ) and Pielou's evenness (J') at diverse levels of regeneration in burned and unburnt forest sites. Different letters represent significant differences ($P<0.05$).

could be related to the time elapsed since the beginning of the fire, which influenced the growth and adaptation of species in categories 1 to 3 m (Martínez and Álvarez, 1995). For various forest species of medium superennifolia forest, the opening of the canopy implies better conditions for natural succession, *i.e.*, fire creates suitable beds for the repopulation of species that establish more easily on the mineral soil, eliminating the physical barrier that understory plants represent and temporarily reducing competition for seedlings, which favors certain functional attributes such as rhizomes to act benefiting establishment and growth (Keeley, 2012). On the other hand, Simpson's dominance showed that in unburnt forest sites the species remained very similar in all categories of regeneration and in the trees (Giraldo-Cañas, 2000). In contrast, the smallest regeneration from 0 to 30 cm in burned forest sites was dominated by few species with the highest value, while the regeneration from 1 to 3 m with low dominance values, indicating that there is little probability that two random individuals belong to the same species (Salmerón *et al.*, 2017). With respect to evenness, similar values were observed in all regeneration height categories regardless of whether they were burned or unburnt forest sites (López-Jiménez *et al.*, 2019).

CONCLUSIONS

The results suggest that the vegetation of the medium superennifolia forest presented mechanisms to regenerate showing a capacity to recover from the impacts of fire. However, the environmental conditions after fire disturbance may in turn limit the tendency of ecosystem recovery, restricting new regeneration, so it is important to maintain permanent sites to monitor ecosystem recovery and thus be able to establish restoration management strategies for these ecosystems.

ACKNOWLEDGMENTS

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Colegio de Postgraduados

Isolation and Characterization of fungal pathogens associated with *Carica papaya* L. and their biocontrol with *Trichoderma* sp.

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ABSTRACT

Objective: In this work, we undertook the task of isolating and identifying *Fusarium* obtained from papaya fruits grown in the Veracruz region and carried out antibiotic tests to find a beneficial fungus that could exert biological control.

Methodology: Juvenile fruits with necrosis and rot were collected from papaya plants of the Maradol variety, from here the pathogenic fungi were obtained, which were morphologically and molecularly characterized using the ITS gene. Subsequently, the isolated pathogenic fungi were confronted with the *Trichoderma* sp. fungus.

Results: Ten isolates were obtained, of which four were *Fusarium solani*. From the confrontations, a 66% to 100% percentage of inhibition in these pathogenic fungi was obtained.

Limitations of the study: It is proposed that future evaluations carry out long-term follow-ups to evaluate the persistence and effectiveness of biological control.

Findings/conclusions: Timely identification of pathogens could represent a biological control strategy in disease management programs.

Keywords: Antagonism, *Fusarium solani*, biological control.

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INTRODUCTION

Papaya (*Carica papaya* L.) is a perennial herbaceous plant belonging to the Caricaceae. It is among the most popular fruits in the world as it represents 15% of the total production of tropical fruits worldwide (Fatombi *et al.*, 2019). India is included in the five central papaya-producing countries, followed by Brazil and Mexico, in third place (Sharma *et al.*, 2016, FAOSTAT 2021). In Mexico, the cultivation of the Maradol variety predominates, with a yield of 1,196,300.74 t in 2022. The production of this fruit is led by the states of

Oaxaca, Colima, Chiapas, Veracruz and Michoacán, which together produce more than 80% of this fruit at the national level (Granados *et al.*, 2015; Miranda-Ramírez *et al.*, 2020; SIAP, 2023; Cisneros-Sanguilán *et al.*, 2023).

One of the leading causes that hinder papaya production is biotic stress, which includes attacks by bacteria, fungi, viruses, nematodes and insects. Among the primary diseases that attack papaya is the papaya ring spot virus; some others cause root and stem rot and post-harvest fruit rot, all caused by *Fusarium* spp. (Vega-Gutiérrez *et al.*, 2019; Correia *et al.*, 2013; Ivarez and Nishijima, 1987; Nery-Silva *et al.*, 2007; Nishijima, 1993; Margaret and Egwari, 2015). *Fusarium* control has led to excessive use of chemical pesticides. This has brought environmental damage, such as air pollution, groundwater tables, and decreased soil microbiota. Furthermore, the continuous use of pesticides exerts high selection pressure on pathogens, developing resistance to these chemical inputs (Gómez-Godínez *et al.*, 2019; Bhardwaj *et al.*, 2019; Kumar *et al.*, 2008; Rodríguez *et al.*, 2021). For this reason, it is essential to use alternative biological control strategies that have less impact on the environment and, at the same time, maintain crop yields. These defense and biological control mechanisms can be carried out by interacting with plants and microorganisms, among which we can find *Trichoderma* spp. (Oldroyd, 2013; Vinale *et al.*, 2008).

Fungi of the genus *Trichoderma* spp. with saprophytes and ubiquitous constituents of the soil microbiota are capable of colonizing roots and modulating plant-soil interactions (Vinale *et al.*, 2008; Ghorbanpour *et al.*, 2018; Tyśkiewicz *et al.*, 2022). *Trichoderma* can help plants cope with biotic and abiotic stress conditions, favors the absorption of nutrients by the plant and is known to have the ability to act as an antagonist against phytopathogenic microorganisms so that they do not affect the plant (Mendoza *et al.*, 2015; Stewart & Hill, 2014; Hermosa *et al.*, 2013). The fungi of *Trichoderma* spp. They are capable of exerting antagonism through various mechanisms, for example, the release of enzymes with the capacity to degrade polysaccharides, which can generate a systemic acquired response (SRA) and induced systemic resistance (ISR) in plants (Mathys *et al.*, 2012). Another mechanism is the production of suzukacillin and alamethicin (Ghisalberti & Sivasithamparam, 1991). Furthermore, several enzymes are secreted by *Trichoderma* spp., such as chitinase and protease, which are responsible for degrading the cell wall of some phytopathogenic fungi (Gajera & Vakharia, 2012).

The current work includes the isolation, morphological, and molecular characterization of pathogenic fungi present in papaya fruit and the analysis of the effect that a biological controller, such as *Trichoderma* sp., can exert against these pathogens.

MATERIALS AND METHODS

Isolation of pathogenic fungi from papaya fruit

In different municipalities of Veracruz, Mexico (Table 1), juvenile fruits with necrosis and rot and asymptomatic fruits of papaya plants of the Maradol variety were collected in January and February 2023. The plant material was washed with water, disinfested with sodium hypochlorite at 1.0% for 5 min, washed three times with sterile distilled water, dried with absorbent paper towels, sown in potato-dextrose-agar (PDA) culture medium (BD *et al.*) and incubated for 5 d at 25 °C with white light.

Table 1. Municipalities where infected papaya fruits were extracted were in the center of the state of Veracruz.

Orchard location	Geographical coordinates	Isolation name
1. Santa Teresa, Cotaxtla, Ver.	18° 47' 57" 96° 21' 53"	T14, V2
2. Las Minas, Cotaxtla, Ver.	18° 55' 17" 96° 12' 41"	V4
5. Campo Cotaxtla, Medellín, Ver.	18° 56' 03" 96° 11' 23"	V8
6. Casa Blanca, Tlalixcoyan,Ver.	18° 43' 48" 96° 24' 51"	T7, T19
7. Mata Guitara, Tlalilxoyan, Ver.	18° 43' 07" 96° 21' 00"	T24

Monoconidial cultures purified the fungal colonies formed

The pathogenicity of the fungi isolated from diseased tissues was verified in asymptomatic fruits in February 2023. Each isolation was considered a treatment, and the experimental unit was a fruit. Each fungus was inoculated into 5 asymptomatic juvenile fruits; 5 healthy fruits were used as controls (sprayed with sterile distilled water). The inoculum was prepared by culturing the fungi in PDA at 25 °C with white light for 15 days, and a solution with 1×10^{3} conidia mL^{-1} was prepared from each one. Before inoculation, the experimental units were disinfested with 1.0% sodium hypochlorite for 2 min and rinsed with sterile distilled water. Each was sprayed with 3 mL of the inoculant solution and covered for the first 3 days with a disinfested plastic bag. With alcohol.

Morphological and molecular characterization of pathogenic fungi associated with papaya

The fungi from papaya were isolated and cultured in a PDA medium and incubated in the dark for 3 days at 28±2 °C. The isolated strains were preserved in 30% glycerol and were stored in deep freezing at −80 °C. Colony morphologies such as growth, colony color, texture, and pigmentation were described. The conidiophores' morphology and conidia's characteristics were described using the LEICA compound microscope with magnifications of 10X and 40X. DNA was isolated with the Zymo kit, following the manufacturer's instructions. The DNA obtained was used as template DNA for the polymerase chain reaction (PCR), where the ITS region was amplified using the universal primers ITS1 (5'-GGAAGTAAAAGTCGTAACAAGG-3') and ITS4 (5' TCCTCCGCTTATTGATATGC 3'). (White *et al.*, 1990). Amplifications were carried out in a thermocycler (ThermoFisher), using an initial denaturation of 94 °C for 5 min, followed by 30 cycles of initial denaturation of 94 °C for 1 min to 94 °C, annealing for 1:20 min at 57 °C and extension for 1 min at 72 °C and a final extension of 5 min at 72 °C. The PCR products were verified on 1% agarose gels and sent for macrogen sequencing. The sequences obtained were aligned and compared in the GenBank National Center for Biotechnology Information (NCBI) database using the elemental local alignment search tool BLAST (Johnson *et al.*, 2008).

RESULTS AND DISCUSSION

Isolation of fungi associated with papaya

It is known that fruit rot in papaya is a post-harvest disease that causes significant losses. It is generally caused by improper handling, storage and transportation after harvest.

Fusarium spp. is a phytopathogenic fungus associated with papaya fruit rot (Coates *et al.*, 1997). This phytopathogen infects through cuts or abrasions created during harvesting and handling or through injuries caused by insects. Symptoms caused by *Fusarium* on papaya can be observed as rounded areas that later become small depressions. As these lesions develop, rot and mycelia appear on the surface (Nishijima, 1993; Rahman *et al.*, 2018). Diseased papayas were identified at the sites to isolate the fungi present (Figure 1) subsequently.

A total of ten fungi were isolated from the papaya samples, which were named as follows: T7.2, T14, V8, 7.1, V4, V2, T31, T24, T7.3 and T19.

Morphological identification of pathogenic fungi isolated from papaya

In the Potato Dextrose Agar (PDA) culture media, most pathogenic fungi showed moderate mycelial growth except isolate 7.1. The isolates T7.2, T24, and T7.3 presented purple tones, and the isolates V8, T31, and T19 presented orange tones (Figure 2). Under the microscope, hyaline and septate vegetative hyphae with a smooth wall were identified. Microconidia were observed as abundant, short, non-septate and elliptical structures. They were abundant and elongated, cylindrical, slightly curved, fusiform and with septate structures (Figure 2).

Molecular identification of pathogenic fungi isolated from papaya

The ITS regions were successfully amplified by PCR, obtaining a product of around 650 bp. BLASTn (Nucleotide BLAST)-based sequence identification which confirms the strains as different Fusarium species (Table 2).

The accession IDs of the ten strains fell under different NCBI GenBank numbers (Table 2). Several species of *Fusarium* are associated with diseases in papaya; for example, *F. solani* has been reported in different countries such as Hawaii, India, the Philippines, Malaysia and Brazil, causing diseases such as stem rot (Nishijima *et al.*, 1993; Rahman *et al.*, 2018

Figure 1. Identification of areas with diseased fruits, A) Area/field where isolation was carried out. B) Isolation of the diseased fruit in the laboratory. C) Infection of papaya fruits with fungi isolated from diseased papaya fruits.

Figure 2. Morphological characteristics of pathogenic fungi associated with papaya in PDA medium and microscopic characteristics under a 40X optical microscope.

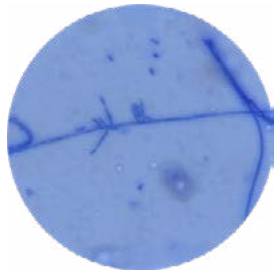
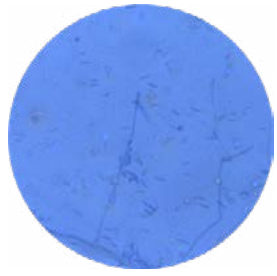
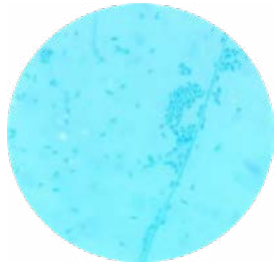
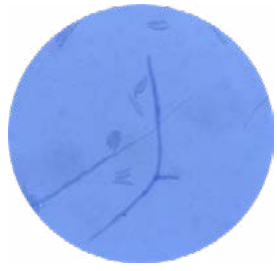
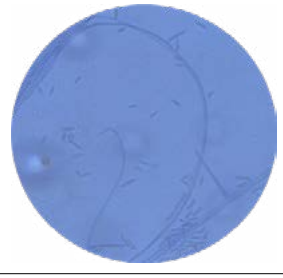
Name isolate	Description	Macroscopic image	Microscopic image
T7.2	White mycelium with purple tones in the center, filamentous aerial mycelium without elevation and regular edge.		
T14	White mycelium, filamentous aerial mycelium without elevation and regular edge.		
V8	White mycelium with orange tones of filamentous type, without elevation and regular edge.		
7.1	White mycelium with a yellow center ring, cottony aerial mycelium without elevation and irregular edge.		
V4	White mycelium, filamentous aerial mycelium without elevation and regular edge.		

Figure 2. Continues...

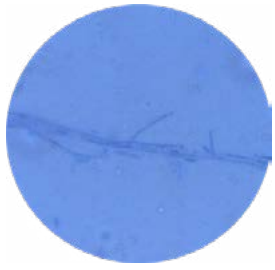
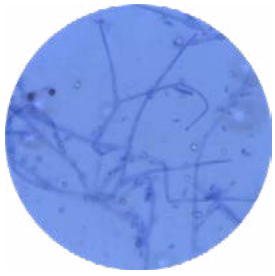
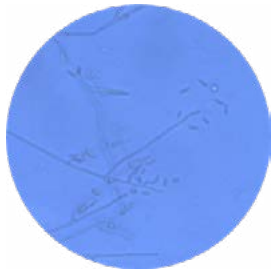
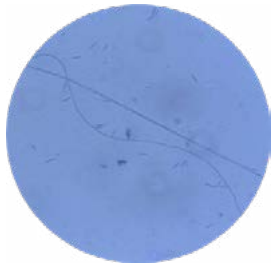
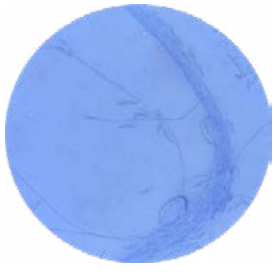
Name isolate	Description	Macroscopic image	Microscopic image
V2	White mycelium with purple tones in the center, cottony aerial mycelium, convex elevation and regular edge.		
T31	Whitish mycelium with orange tones, filamentous aerial mycelium with umbonate elevation and regular edge.		
T24	Whitish mycelium with purple tones, cottony aerial mycelium with ring formation, umbonate elevation and regular edge.		
T7.3	White mycelium with purple tones in the center, cottony aerial mycelium without elevation and regular edge.		
T19	White mycelium with orange tones, filamentous aerial mycelium without elevation and regular edge.		

Table 2. Molecular identification of the ITS marker of pathogenic fungi isolated from papaya.

Isolate ID	Identified species	Identity percentage
T7.2	*Fusarium annulatum*	99.81
T14	*Fusarium solani*	99.81
V8	*Fusarium solani*	99.63
7.1	*Fusarium incarnatum*	100
V4	*Fusarium solani*	99.62
V2	*Fusarium solani*	99.75
T31	*Fusarium solani*	99.82
T24	*Fusarium solani*	99.63
T7.3	*Fusarium oxysporum*	99.70
T19	*Fusarium solani*	99.82

and Correira *et al*., 2019). The dry rot of papaya fruits is also known to be caused by *F. solani* (Alvarez & Nishijima, 1987). This report identified the isolates T14, V8, V4, T31, and T24 as *F. solani*.

Other *Fusarium* species are implicated in cases of papaya fruit rot, including *F. acuminatum*, *F. equiseti*, *F. nivale*, *F. oxysporum*, *F. thapsinum* and *F. chlamydosporum* (Margaret *et al*., 2015); Pathak *et al*., 1976; Gupta *et al*., 1990; Helal *et al*., 2018; Oke *et al*., 1991). In this report, it was also possible to identify *F. annulatum*, which is known to be a species that is also known as *F. proliferatum*, which is known to be pathogenic in up to 200 different plants (Yilmaz *et al*., 2021). This *Fusarium* species has been previously reported to cause decline in the grapevine plant (Úrbez-Torres *et al*., 2017; Bustamante *et al*., 2022).

Antibiosis tests: Inhibition of the growth of pathogenic fungi isolated from papaya

The ten isolates of pathogenic fungi were inhibited by the beneficial fungus *Trichoderma* CC1261, in different percentages, for example, the isolate T14, V4, T24, T7.2, T31, V8 and 7.1 were inhibited by 100%, the isolate T19 and V2 were inhibited by 68% (Figure 3). On the other hand, the *Trichoderma* CC647 strain inhibited isolate 7.1, V8, T7.3, by 100%, isolate V4, was inhibited by 75%, isolates T19, T7.2, were inhibited by 66% (Figure 3).

The two *Trichoderma* tested in this work inhibited papaya pathogenic *Fusarium* in different percentages and exhibited profuse sporulation, which indicates that they are highly competitive for space and nutrients. The application of beneficial antagonists to control pathogens is a sustainable and environmentally friendly strategy. It is known that *Trichoderma* are fungi antagonistic to many pathogens, capable of controlling phytopathogens through multiple mechanisms such as the production of enzymes, antibiotics, volatiles, among others (Tian *et al*., 2020). The selection and characterization of microorganisms highly targeted to a specific pathogen such as Fusarium could be concluded in disease management programs.

Figure 3. Antagonistic effects of *Trichoderma* C647 and C1261 against phytopathogens isolated from papaya.

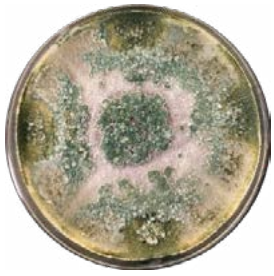
Strain *Trichoderma* sp.	Strain *Fusarium* sp.	*Fusarium* without treatment	Confrontation	PICR
C647	T19			68.82 %
C647	7.1			100 %
C647	T7.2			68.03 %
C647	V2			53.72 %
C647	V8			100 %

Figure 3. Continues...

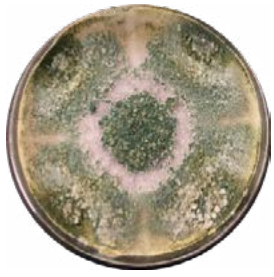
Strain *Trichoderma* sp.	Strain *Fusarium* sp.	*Fusarium* without treatment	Confrontation	PICR
C647	T7.3			100 %
C647	T31			100 %
C647	T24			100 %
C647	T14			100 %
C647	V4			75 %

Figure 3. Continues...

Strain *Trichoderma* sp.	Strain *Fusarium* sp.	*Fusarium* without treatment	Confrontation	PICR
C1261	T7.3			71.37 %
C1261	T14			100 %
C1261	T19			68.82 %
C1261	V4			100 %
C1261	V2			68.43 %

Figure 3. Continues...

Strain *Trichoderma* sp.	Strain *Fusarium* sp.	*Fusarium* without treatment	Confrontation	PICR
C1261	T24			100 %
C1261	T7.2			100 %
C1261	T31			100 %
C1261	V8			100 %
C1261	7.1			100 %

CONCLUSION

Tropical fruit crops can be infected by one or more diseases caused by *Fusarium*. These diseases can represent limitations in the sustainable production of tropical fruit crops since they weaken crop production. Postharvest diseases affect the marketing of fruits since the product is not attractive to consumers. Identifying the fungi that cause postharvest diseases is crucial to search for biological control alternatives, such as *Trichoderma*, which was evaluated in this report, showing inhibition capabilities in the growth of the pathogenic Fusarium characterized in this report.

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Mycorrhizal status of *Guarianthe skinneri* (Orchidaceae) in urban trees in Tapachula, Chiapas, Mexico

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ABSTRACT

Objective: To isolate and classify morphologically and molecularly mycorrhizal fungi associated with adult plants of *Guarianthe skinneri* (Bateman) Dressler & W.E. Higgins (Orchidaceae), distributed in different phorophytes, exotic and native trees, in the City of Tapachula, Chiapas, Mexico.

Design/Methodology/Approach: We sampled roots from adult plants growing in two native phorophytes, *Byrsonima crassifolia* (L.) KUNTH and *Tabebuia rosea* (BERTOL.) BERTERO EX A. DC. and two exotic phorophytes, *Terminalia catappa* L. and *Ficus benjamina* L. located in the city's road. By the isolation of mycorrhizal strains, we had diagnosed them by morpho-physiological attributes, and molecularly (Sanger sequencing of the ITS1-4 region).

Results: Forty-three fungal strains of two anamorphic mycorrhizal genus *Epulorhiza* and *Ceratorhiza* were obtained: 50% of the isolates came from plants growing in the exotic tree *T. catappa* with undigested pelotons and the highest molecular diversity (three contigs of the genus *Tulasnella*). *Ficus benjamina* had one molecular species shared with the native *B. crassifolia*. Roots growing in the native *T. rosea* tree, even though few isolates could be purified.

Study Limitations/Implications: Even if the research was exploratory, it was possible to highlight the diverse mycorrhizal partners that urban phorophytes of *G. skinneri* harbor, showing their potential in the *ex situ* conservation of this species.

Findings/Conclusions: The large number of the anamorph *Epulorhiza* isolates obtained from all phorophytes, reinforces previous observations suggesting that candelaria is preferentially associated with species of the Family Tulasnellaceae.

Keywords: *Ceratobasidium*, *Ceratorhiza*, *Epulorhiza*, *ex situ* conservation phorophyte, *Tulasnella*.

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INTRODUCTION

The epiphytic orchid *Guarianthe skinneri* (Bateman) Dressler & W. E. Higgins is naturally distributed from southeastern Mexico to Panama (Bertolini *et al.*, 2016) and it is listed as threatened in the Mexican Official Legislations (NOM-059-SEMARNAT-2010) (SEMARNAT, 2010), due to illegal trade, land-use change and logging (Coello *et al.*, 2010).

Image by John French at Pixabay

Coutiño-Cortés *et al.* (2018) showed that the genetic diversity of this species may be higher in the urban population of Tapachula, Chiapas, compared to some wild populations of Guatemala. This has been attributed to the diverse provenances of the different established individuals. Backyard and urban cultivation on existing host trees allows this "urban domestication" to occur in transition to colonize new phorophyte species (Cortés-Anzúres *et al.*, 2020). However, the long-term survival, reproduction, and recruitment of these urban populations may be influenced by the tree species that harbor them (phorophyte) and the capability of seed germination on phorophytes (Emeterio-Lara *et al.*, 2021). Part of this adaptive ability depends on their associations with mycorrhizal fungi living in the different phorophyte species (Hossain *et al.*, 2013; Idris and Zaman, 2020; Izuddin *et al.*, 2019). Mycorrhizae that performs symbiosis with orchids belong to the anamorphic artificial polyphyletic group *Rhizoctonia* (López-Chávez *et al.*, 2016), which *Ceratorhiza*, *Moniliopsis*, *Epulorhiza* are recognized as their mainly anamorphic (asexual) genera and whose teleomorphic (sexual) form *Ceratobasidium*, *Thanatephorus*, *Tulasnella* and *Sebacina* are identified through molecular tools by the absence of sexual structures (Nontachaiyapoom *et al.*, 2010; Shimura *et al.*, 2009). The identification of fungi associated in already established orchids is fundamental for the conservation, and ecological restoration of endangered or threatened species (Etanke *et al.*, 2021; Ortega-Larrocea and Rangel-Villafranco, 2015; Suryantini *et al.*, 2015; Zettler *et al.*, 2000). It has been documented that host-mycorrhizal fungus specificity may be determined under natural conditions by forest species (Martins *et al.*, 2020). Therefore, the objective of this research was to know if the native orchid *G. skinneri* develops mycorrhizal associations in their roots in relationship to his phorophytes, exotic or native trees, in the urban context of Tapachula, Chiapas, Mexico. This provides a better understanding about ecological requirements to guarantee mycorrhizal relationships for the conservation and management of this orchid in a strongly anthropic environment.

MATERIALS AND METHODS

Collection of biological material. Root sampling of *G. skinneri* was carried out during January 2021 from two native phorophytes: *Byrsonima crassifolia* (L.) KUNTH and *Tabebuia rosea* (BERTOL.) BERTERO EX A. DC; as well as from two exotic ones: *Terminalia catappa* L. and *Ficus benjamina* L., both from South and Southeast Asia. The exotic phorophytes were located further in the North part of the city of Tapachula de Córdova y Ordoñez Chiapas, Mexico, while native trees were located slightly further South (Figure 1).

To know the micro-climate of sampling sites, we used data from Worldclim (http://www.worldclim.org/). From each plant, three main roots were collected and preserved under refrigeration for immediate analysis of mycorrhizal fungi in the laboratory of Ecology and Sustainable Cultivation of Soconusco Orchids at El Colegio de la Frontera Sur, Tapachula campus (Figure 2).

Isolation and characterization of mycorrhizal fungal isolates. Collected roots were washed with tap water to eliminate organic matter; velamen was removed with a scalpel under a dissecting microscope. To evince pelotons as mycorrhizal structures in the cortex, transversal cuts about 1 mm thick were made every 2 cm along the root and stained with 0.1% acid fuchsin in polyethylene glycol. Segments were analyzed

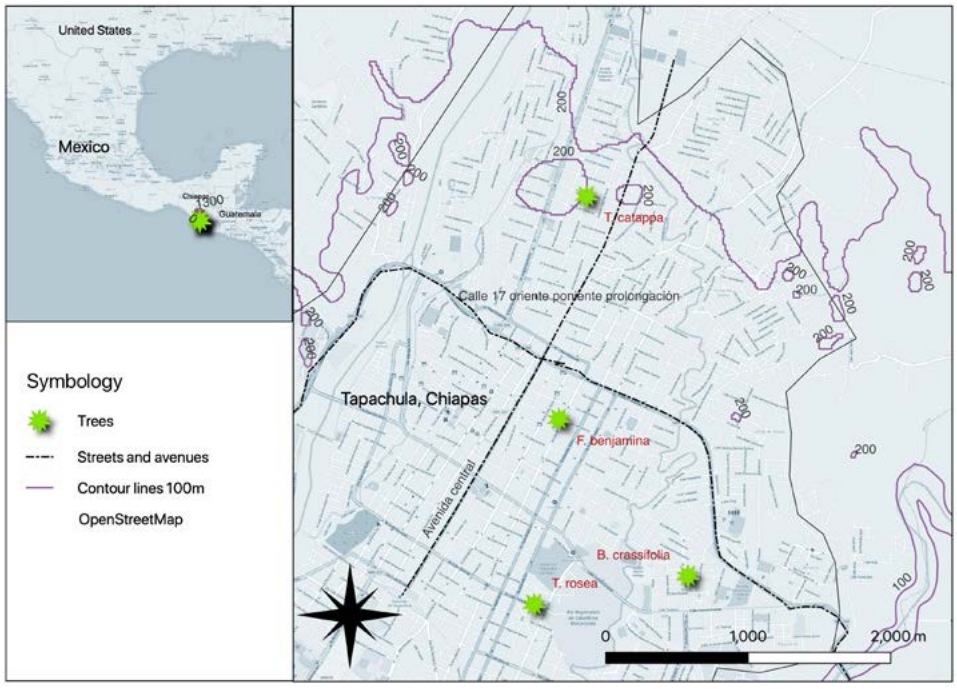

Figure 1. Location of sampled sporophytes were adult *G. skinneri* that were stablished/found in Tapachula, Chiapas, Mexico.

Figure 2. Appearance of the orchid *Guarianthe skinneri* over different host trees in the city of Tapachula, Chiapas, Mexico. a: Phorophyte *Ficus benjamina*; b. Phorophyte *Byrsonima crassifolia*; c. Phorophyte *Tabebuia rosea*; d. Root growth on *F. benjamina* bark (arrow). e. *In situ* recruitment of a near-rooted seedling growing on *Terminalia catappa* bark. f. Cross section of a root growed on *Terminalia catappa* tree, showing undigested mycorrhizal fungal structures (pelotons) stained with acid fuchsin.

under a microscope at 20X and percentage of colonization was calculated according to Rasmussen and Whigham (2002) (Figure 2f). Another 3 mm thin cut was made immediately to the root section where pelotons were observed and sections were placed over MCD LAB® bacteriological agar at 33 g/L in 9 cm Petri dishes (Bertolini *et al.*, 2012). Dishes were incubated at 25±2 °C in the dark. Hyphal tips that emerged within 24 to 36 hours were subcultured twice on the same medium to obtain pure cultures. To observe colony development, they were transferred to BIOXON® potato dextrose agar (PDA) medium at 39 g/L and pH 6.8 under the same incubation conditions. Four-points radial daily growth, colony color and shape at 14 days after culture were recorded. The number of nuclei were observed on hyphae growing in a slide placed on a wet filter inside Petri dishes under axenic conditions incubated under the same conditions for four days. Slides were stained with 200 μL of solution containing 1 μL of 10 000X SYBR®Green I in 10 mM KH_2PO_4 and 18% glycerol for 8 min and washed with 2 mL of sterile water. Observation was done under the Axio Imager2 fluorescence microscope coupled to an AxioVision® image analyzer (CarlZeiss®) at 40 X. Morphometric characters were recorded in light microscopy on hyphae stained with acid fuchsin-stained. The enzymatic polyphenol oxidase test was performed by inoculating each strain in 7.5 g of bacteriological agar and 5 g of malt agar in 425 mL of distilled water with 2 g of tannic acid dissolved in sterile 75 mL distilled water passed through a GELMAN® acrodisc filter with pore size of 0.45 μm. Plates were incubated under the same conditions for five days to record the reaction. A one-way ANOVA was performed to evaluate the differences between the isolates obtained for hyphal width and growth with R Studio® software.

DNA isolation and molecular identification of mycorrhizal fungal isolates. DNA extraction from previously diagnosed strains was carried out with the Promega Wizar Genomic DNA Purification® kit, previously subcultured for one week in potatoe dextrose Broth in sterile 2 mL Eppendorf tubes with apical explants of approximately 3 mm^3. The explant was transferred to microtubes after a rinse with sterile distilled water in a vortex; extraction was performed according to the supplier's instructions. PCR amplification was made with the specific primers ITS1-ITS1F/ITS4. The amplification conditions were PDN 95 °C −2', DN 95 °C −1", AL 55 °C −1", EX 72 °C −1" (22 cycles), EX 72 °C −1" EX final 72 °C −8'. The successfully amplified samples were selected for Sanger sequencing and assembled with Geneious Prime® software (version 2020.0.5), using the Geneious Assembler. Initial regions with weak signals were removed generating a total of six contigs from which consensus sequences were drawn and aligned using MAFFT plugin (Katoh *et al.*, 2002; Katoh and Standley, 2013) to submit to GenBank database using Basic Local Alignment Search Tool (BLAST) (Max E-Value:10, Word size: 11, Gap cost: 5 2) (Altschul *et al.*, 1997). For some of the strains, no sequences were obtained because they could not be assigned to any contig due to low assembly quality and errors (strain 18) or because they were contaminated and not submitted (strains 16 and 34). Phylogenetic reconstruction was done under the Maximum Similarity Procedure (Tamura-Nei substitution model, 1000 node support bootstrap) (Guindon *et al.*, 2010), using MEGA X® (version 10.2.6) and Geneious® program (Version 8.0.4) to

obtain phylogenetic trees. The outgroups selected were *Trementella mesenterica* (AY463475) (Veldre *et al*., 2013) and *Auricularia auricula-judae* (AF291289) (Weiss and Oberwinkler, 2001). Analyses were done for each of the families obtained.

RESULTS

Mycorrhizal colonization, isolation and characterization of strains. All roots were slightly colonized by mycorrhizae. The highest colonization percentage was found in roots growing over the *T. catappa* tree, with 21%, followed by *F. benjamina*, *B. crassifolia* and *T. rosea*, which showed similar rates (13%, 13% and 12%, respectively). The environmental conditions at each site were very similar for all parameters, only the annual rainfall was slightly higher (150-200 mm) at sites where exotic photophytes *T. catappa* and *F. benjamina* species were located.

A total number of 43 fungal strains were purified. From native phorophytes, four isolated from roots on *B. crassifolia* and seven on *T. rosea*. From exotic ones, 21 strains were obtained from roots grown on *T. catappa* and 11 on *F. benjamina*. The morphometric and appearance characteristics of the colonies are shown in Table 1.

All isolates belonging to anamorphic mycorrhizal fungi *Rhizoctonia* (right angles with bifurcation at 90°) (Figure 3b and 3g) and all measured features correspond to the diagnostic characters. The hyphal width was from 2.4 to 5.9 μm, where statistically, isolates 46-48 were significantly different presenting wider hyphae than the rest. The formation of monilioid cells was present in most fungal strains where in isolates smaller than 4 μm were spherical cells with clear septa typical of *Epulorhiza anamorphs*. Instead, *Ceratorhiza monilioids* were slightly discernible digitiforms without evident septal separation (Figure 3c and 3f, respectively). The number of nuclei of all isolates was two per cell (Figure 3d and 3h).

The strains developed two growth rates; slowly ones growing from 1.2 to 6.0 mm per day and fast growing developed 17.0 to 18.2 mm per day, the latter corresponding to three isolates obtained from the anamorph *Ceratorhiza*. Also, two types of growth appearance were evident: smooth creamy with submerged hyphae, sometimes cottony, which corresponded to the strains with lower growth rates, and cottony with rings, which occurred in the strains with higher growth rates (Figure 3a and 3e). Colony color evaluated after 14 days of development; was white to creamy in the low growth strains and white in the faster growth strains. The polyphenol oxidase test was negative for all strains except for strain 19 corresponding to one fungus isolated from the *T. catappa* phorophyte, which had a weak reaction compared to the three isolates of strains 46-48 obtained from the *T. rosea* phorophyte.

The molecular identity of the 40 sequences corroborated the morpho-physiological diagnosis corresponding to the two teleomorphic families Tulasnellaceae and Ceratobasidiaceae (Figure 4). Within the family Tulasnellaceae, four consensus sequences or contigs were grouped: 17 sequences belonged to contig 1 which was phylogenetically separated from all others in a group apart and represented those isolates with wider hyphae, mostly coming from the native tree *T. rosea* and the exotic one *T. catappa*. In another clade formed by two contigs, 2 and 4 which had slight differences in growth rates, 13 sequences

Table 1. Morphometric features of mycorrhizal fungal strains isolated from the orchid *Guarianthe skinneri* in Tapachula, Chiapas, Mexico growing on the phorophytes *Terminalia catappa* (strains no. 1-25); *Ficus benjamina* (26-37); *Byrsonima crassifolia* (38-41) and *Tabebuia rosea* (42-49). PFO=polyphenol oxidase reaction; CM=monilioid cells, CSB=basal septum constriction. Mean ± standard error, different letters mean significant differences at $p<0.05$.

Strain	Colour	Appearance	PFO	Growth	Hypal width	CM	CSB	Mycelium rings
1C1	creamy white	creamy smooth	–	5.8±0.8ac	3.39±0.11a	–	–	+
2C1	creamy white	creamy	–	5.4±0.8ac	2.95±0.09b	+	–	–
3C1	white	cottony	–	6.0±0.5c	3.81±0.12c	–	–	+
4C1	creamy white	creamy smooth	–	4.0±0.4b	4.22±0.10d	+	+	+
5C1	creamy white	creamy smooth	–	4.9±0.4a	3.84±0.14c	+	+	–
6C1	white	creamy smooth	–	4.6±0.2a	4.36±0.16d	+	–	+
8C1	creamy white	cottony	–	4.9±0.3a	3.39±0.10a	+	+	+
9C1	creamy white	cottony	–	4.0±0.2b	4.30±0.13d	+	+	+
10C1	creamy white	creamy smooth	–	4.9±0.3a	4.97±0.17e	+	+	+
12C1	creamy white	creamy smooth	–	6.2±0.6c	3.83±0.14c	+	+	+
14C4	creamy white	creamy smooth	–	4.4±0.6ab	3.07±0.10b	+	+	–
16NA	creamy white	cottony	–	3.5±0.1d	4.51±0.18d	+	+	–
17C2	creamy white	cottony	–	1.5±0.4e	3. 01±0.11b	+	+	–
18NA	creamy white	cottony	–	1.8±0.3e	2.80±0.08f	+	+	–
19C2	creamy white	cottony	+	2.3±0.1f	3.05±0.07b	+	+	–
20C4	creamy white	cottony	–	1.6±0.2e	2.76±0.2bf	+	+	–
21C4	creamy	creamy smooth	–	2.0±0.2ef	3.36±0.08a	+	+	+
22C1	creamy white	cottony	–	5.9±0.3c	3.40±0.12a	+	+	–
23C1	white	creamy smooth	–	4.8±0.4[a]	2.89±0.18bf	+	+	+
24C1	white	Algodonoso	–	4.6±0.3ab	2.98±0.09b	+	+	+
25C2	creamy white	creamy smooth	–	1.5±0.2g	2.56±0.08g	+	+	+
26C2	creamy white	creamy smooth	–	2.2±0.2ef	2.57±0.11g	+	+	+
27C2	creamy white	creamy smooth	–	1.7±0.4eg	2.72±0.08gf	+	+	–
28C2	creamy white	creamy smooth	–	2.6±0.5e	2.33±0.08h	+	+	–
29C2	creamy white	creamy smooth	–	1.2±0.1h	2.58±0.07g	+	+	+
30C2	creamy white	creamy smooth	–	2.5±0.3ef	2.81±0.18bfg	–	+	–
31C2	creamy white	creamy smooth	–	2.4±0.1f	2.76±0.03f	–	+	+
32C2	creamy white	creamy smooth	–	1.9±0.2e	2.71±0.10fg	–	+	–
33C2	creamy white	creamy smooth	–	2.5±0.4ef	2.60±0.06g	+	+	+
34NA	creamy white	creamy smooth	–	s.d.	2.48±0.07g	+	+	–
36C2	creamy white	creamy smooth	–	2.1±0.1e	2.97±0.18b	–	+	–
37C2	creamy white	creamy smooth	–	1.8±0.0g	2.34±0.09h	–	+	–
38C3	creamy white	creamy smooth	–	3.1±0.0e	2.64±0.07g	–	+	–
39C3	white	creamy smooth	–	2.4±0.2ef	2.44±0.10hg	–	+	+
40C3	white	cottony	–	3.2±0.2e	2.76±0.03bf	+	+	–
41C3	white	creamy smooth	–	4.0±0.3b	3.79±0.15c	–	+	–

Table 1. Continues...

Strain	Colour	Appearance	PFO	Growth	Hypal width	CM	CSB	Mycelium rings
42C1	white	creamy smooth	–	4.8±0.6ab	2.86±0.10bf	+	+	+
43C1	white	creamy smooth	–	4.8±0.4a	3.26±0.23ba	–	+	+
44C1	creamy white	creamy smooth	–	3.7±0.4bd	3.16±0.14b	+	+	+
46C5*	white	cottony	++	17.0±0.8i	5.88±0.24i	–	+	–
47C5*	white	cottony	++	17.7±0.4i	5.23±0.17je	–	+	–
48C5*	white	cottony ringed	++	18.2±1.2i	5.62±0.30ij	–	+	–
49C1	creamy white	cottony	–	5.6±0.3ac	3.71±0.16c	+	+	+

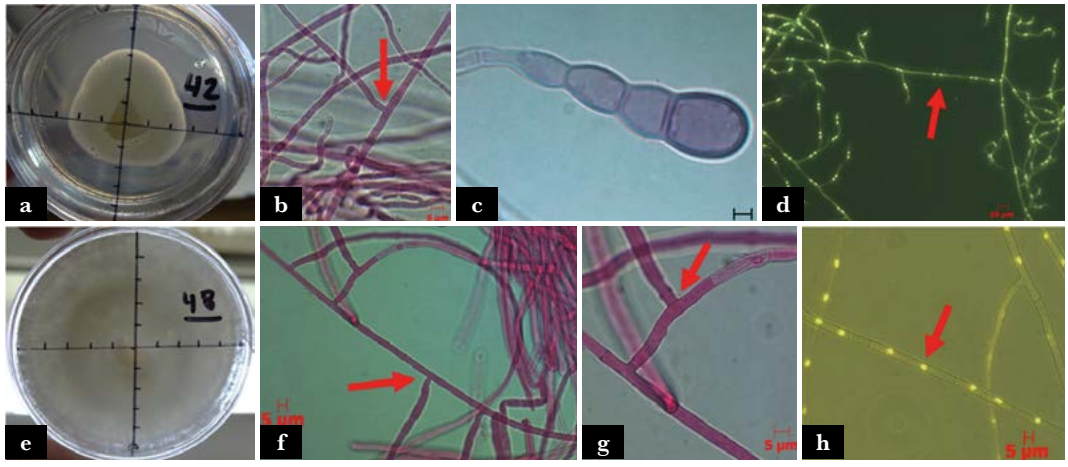

Figure 3. Anamorphs of the mycorrhizal fungi *Epulorhiza* (a-d) and *Ceratorhiza* (e-h) isolated a. Radial growth of strain 42. b. Mycelial growth of strain 9 stained with acid fuchsin. c. Monilioid cells stained with acid fuchsin from strain 20. d. Binucleate cells of hyphae strain 37 under fluorescence. e. Sterile mycelial of strain 48. f. Monilioid hyphae of strain 48 stained with acid fuchsin. g. Hyphal right-angle bifurcation and basal septum of strain 48. h. Binucleate cells of strain 47 seen by fluorescence.

were grouped in contig 2, isolated from the introduced trees *T. catappa* and *F. benjamina* and three to contig 4 isolated from the exotic tree *T. catappa*. A third clade was formed with contig 3 with sequences isolated from native *B. crassifolia*. In the Family Ceratobasidiaceae, only one clade, contig 5, was formed by three isolates obtained from the native phorophyte *T. rosea* (Figure 4).

G. skinneri roots from exotic phorophyte *T. catappa* showed the highest number of isolates (48.8% of total) with characteristics of the anamorph *Rhizoctonia*, or the highest percentage of mycorrhizal colonization and the highest annual precipitation in their location. Roots from *F. benjamina*, located near *T. catappa*, showed 25.5% of the anamorph *Rhizoctonia* strains purified. Concerning native phorophytes, *B. crassifolia* and *T. rosea*, fewer isolates were achieved from them (9.3 % and 16 % respectively), as they were found in a slightly less humid and warmer location with less lush canopy due to pruning. While all phorophytes developed under the same climate, microenvironmental conditions are known to influence the degree of mycorrhizal colonization and species richness on air exposed epiphytic roots

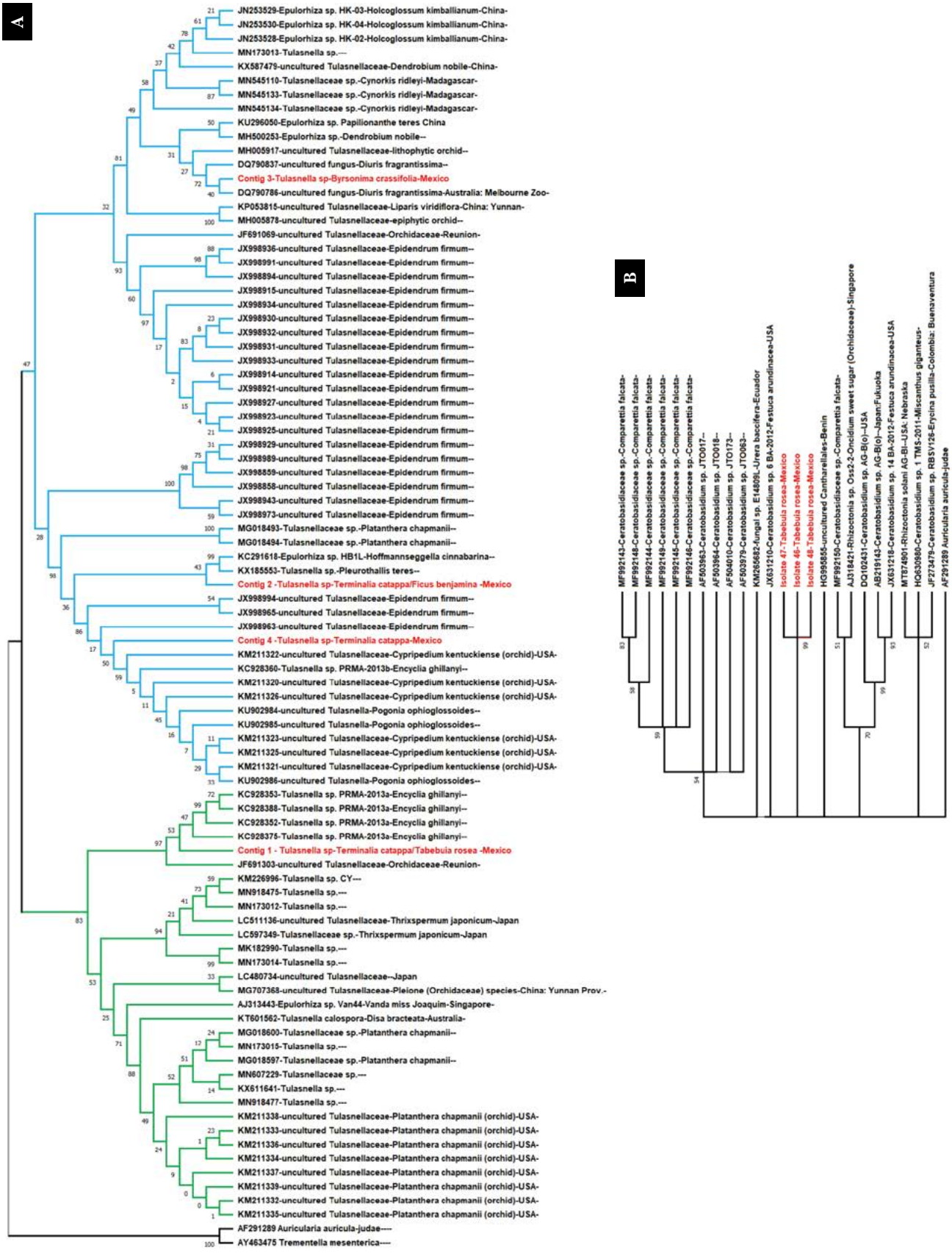

Figure 4. A) Phylogenetic tree of mycorrhizal fungal isolates (contigs 1-4) associated with the Family Tulasnellaceae in the epiphytic orchid *G. skinneri*. The tree was constructed under Maximum Similarity (Tamura-Nei substitution model, 1000 node support bootstrap). B) Phylogenetic tree of contig 5 associated with the Family Ceratobasidiaceae.

very sensitive to dryness (Izunddin *et al.*, 2019). In this urban microclimate at Tapachula City, tree position favored exotic phorophytes by their location, especially in *T. catappa*, exposed to a microenvironment with lower average temperature and receiving a little more precipitation in a year. This had been previously recorded for this species by Ovando *et al.* (2005) who found mycorrhizal colonization favored by the growing conditions and a lower incidence of mycorrhiza under water stress in cultivated plants (Rivas *et al.*, 1998).

Morphological features of strains are quite useful to separate them into the two most common anamorphic mycorrhizal genera: *Epulorhiza* and *Ceratorhiza*. The three isolates belonging to the latter genus were distinguished by forming concentric rings and cottony mycelium, having the highest growth rate, the greatest hyphal width and a positive reaction to polyphenol oxidase. Among the isolates of the anamorph *Epulorhiza*, that were mostly, several of the characters allowed segregating the strains into those with hyphal width less than 3 μm and those around 4 μm and which generally coincided with a lower and higher 3 mm growth rate per day, respectively. The morphology of the monilioid cells also coincided with that previously described for both anamorphs (Freitas *et al.*, 2020; Pereira *et al.*, 2005). Ovando *et al.* (2005) found a high incidence of fungi of the *Epulorhiza* and *Moniliopsis* genera of the Family Tulasnellaceae isolated from different substrates and times of the year on plants cultivated in the Botanical Garden of Tuzantán in Soconusco, Chiapas. Research made by Freitas *et al.* (2020) on two species of the genus *Cattleya* in Brazil showed that this orchid genus in its natural habitat has clear preferences to associate with *Tulasnella* calospora species, the same fungus that was recognized as effective in the symbiotic propagation of *C. purpurata* (Bazzicalupo *et al.*, 2021). The specificity of epiphytic orchids with fungal species of the Families Tulasnellaceae and Ceratobasidiaceae has been previously explored by Otero *et al.* (2002) and Dearnaley (2007). The phylogenetic relatedness of the sequences in GenBank, joint some of these strains (contigs 2, 3 and 4) in a 96-99% identity with terrestrial and epiphytic orchids from the Americas: Costa Rica (*Epidendrum firmum*), Brazil (*Pleurothallis teres*) and the United States (*Diuris fragantisima* and *Cypripedium kentuki*). Contig 1 has 98% similarity to an isolate of *Encyclia ghillani* from Brazil (Kartzinel *et al.*, 2013). In contrast, contig 5 of the Family Ceratobasidiaceae is similar to saprophytic or endophytic fungi colonizing grasses (98% of identity with *Ceratobasidium* sp. isolated from *Festuca arundinacea* from the United States) and closely to other fungi of epiphytic orchids, mainly of the species *Comparettia falcata*. Less than 10% of all characterized strains belonged to the genus *Ceratobasidium* found in only one native phorophyte (*T. rosea*), which reinforces the evidence that this orchid has a greater affinity to associate in the adult stage mostly with species of the genus *Tulasnella*.

CONCLUSIONS

This study shows that *G. skinneri* plants, already established in urban sites, are able to form mycorrhizal relationships with a certain diversity, both on a native or exotic phorophytes. Extending the sampling to more urban phorophytes will allow us to confirm this specificity for a large species of mycorrhizal fungi of the Tulasnellaceae family in adult plants, as well as to test the specificity through symbiotic propagation to implement propagation technologies. Together with previous studies conducted on *G. skinneri* (Aguilar

Diaz *et al.*, 2018; Coello *et al.*, 2010; Coutiño-Cortés *et al.*, 2017;), we propose to employ these species in urban environments as a sustainable strategy in order to conserve the remaining wild populations in nature.

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Volatile organic compounds in the habitat of the escamolera ant (*Liometopum apiculatum* Mayr) in Zacatecas, Mexico

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ABSTRACT
Volatile organic compounds (VOCs) take part in the biological processes of insects; however, these compounds have not been determined for genus *Liometopum*. The objective of this study was to identify the variability of the VOCs found in the *Liometopum apiculatum* habitat during the exploitation season. During the 2017 preseason and season, 35 air samples were collected from the nests of five *L. apiculatum* colonies established in crassicaule scrub vegetation; additionally, another 35 samples were taken from their foraging sites. Using a gas chromatograph with an electronic nose detector, the VOCs were identified with the Kovats index. In addition, a principal component analysis (PCA) was carried out to evaluate the intensity variability per season. Fourty-eight VOCs were identified in the *L. apiculatum* habitat. The most significant VOCs included: saturated hydrocarbon (17%), aldehydes (17%), alcohols (15%), and esters (10%). PCA accounted for 79.5% (PC1=53.8 and PC2=25.7) of the intensity variability of the VOCs in the habitat between seasons. The *escamol* season was characterized by the 3-methyl-3-sulfonyl butan-1-ol, 2-Methylbutanoic acid, and trimethylamine. This profile of the VOCs in the *L. apiculatum* habitat is a pioneer work and has future implications for the conservation and sustainable exploitation of the *escamolera* ant.

Keywords: Formicidae, hydrocarbon, edible insect, semiochemical.

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INTRODUCTION

Ants (Himenoptera: Formicidae) are eusocial organisms characterized by their work hierarchy, cooperation, and an advanced caste system (López-Riquelme and Ramón, 2010). Their specific functions are determined by a highly sophisticated communication system (Peeters, 2019; Slavković and Bendahmane, 2023), divided into radial (light perception), mechanical (tactile or auditory), or chemical (smell and taste). Ants rely mainly on chemical communications, depending on the nature of the habitat, the ecological characteristics, the space, and the social groups of each species (Batey *et al.*, 2020; Paterson and Adams, 2022). The chemical communication system of the ants detects semiochemical compounds,

Image by Cyril at Pixabay

which are responsable for transmiting information among organisms. These compounds include pheromones (intra-specific communication) and allelochemicals (inter-specific communication). Allelochemicals are divided into kairomones (which benefit the receptor), allomones (which benefit the emitter), sinomonas (mutually benefitial), and apneumonas (which are produced by the environment) (López-Riquelme y Ramón, 2010; Alavez-Rosas *et al.*, 2023). They are mainly composed of Volatile Organic Compounds (VOCs) (Batey *et al.*, 2020), expressed as smells or flavours (Welzel *et al.*, 2018).

Combined with stimulus provided by environmental elements (such as temperature), VOCs promote warning, defence, dispersion, recognition, attraction, reproduction, development, and foraging mechanisms (Cruz-Labana *et al.*, 2023; Dupont *et al.*, 2023). VOCs in ants can be recognized through chromatographic analyses, because they can be reproduced in a determined species or population (Acevedo, 2020; Alagappan *et al.*, 2021; Gordon, 2021). However, the behavioral response and function of VOCs depend on the volatility and the released amount (Fujiwara-Tsujii *et al.*, 2006; Cruz-Labana *et al.*, 2023).

All over the world, ants are used for medicinal and cultural purposes, as weather predictors or food. Six ant species are consumed in Mexico (Guzmán-Mendoza *et al.*, 2016): chicatana or de San Juan (*Atta mexicana* S. and *A. cephalotes* L.), mielera (*Myrmecosistus melliger* W. and *M. mexicanus* W.) and escamolera (*Liometopum occidentale* var. *luctuosum* and *L. apiculatum* Mayr) (Lara-Juarez *et al.*, 2015; García-Sandoval, 2022; Ángeles-Tovar, 2022). The escamolera ant (*Liometopum apiculatum* Mayr) has a high nutritional content and economic value (Reyes-Hernández *et al.*, 2021). The larvae or pupae of the reproductive caste are commonly known as escamoles (Lara-Juárez *et al.*, 2015). Escamoles are harvested every year in the wild and it changes depending on the geographical region (Ángeles-Tovar *et al.*, 2022). The sales of escamoles are an economic alternative in arid and semiarid regions of Mexico (García-Sandoval *et al.*, 2022). Consequently, the presence and survival of the escamolera ant in the wild is endangered, as a result of the overexploitation of their nests and the contamination of their habitats (Figueroa-Sandoval *et al.*, 2018). Although *L. apiculatum* is a species of economic interest and biocultural value, there is a lack of information about the VOCs involved in the reproductive stage of the ants and the role they play in the production of escamoles. This information is fundamental for the sustainable handling of *L. apiculatum* (Cruz-Labana *et al.*, 2023).

Identifying the VOCs in the *L. apiculatum* habitat would generate information about the networks of chemical signs used by this species in its physiological processes. In addition, it would enable the evaluation of the feasibility of breeding these edible insects under controlled systems. Therefore, the objective of this study was to identify the VOCs in the *L. apiculatum* habitat established in crassicaule scrub vegetation, as well as their variability during the 2017 escamol production preseason and season, in the Unidad de Manejo para la Conservación de la Vida Silvestre (UMA) El Milagro, Villa González Ortega, Zacatecas.

MATERIALS AND METHODS

The study was carried out in the Unidad para la Conservación, Manejo y Aprovechamiento Sustentable de la Vida Silvestre (UMA) El Milagro (22° 37' 46.41" N, 101° 56' 25.36" W, 2208 m.a.s.l.), It occupies an area of 302.9 ha in the Villa González

Ortega municipality, Zacatecas, Mexico. The dominant vegetation of the area is crassicaule scrub (Rzedowski, 2006) and the climate is semi-temperate arid temperate (BSkw'), with 12-18 °C mean annual temperatures (García, 2004).

Five *L. apiculatum* colonies were located and monitored in the UMA, where they are exploited to extract the escamoles. The foraging sites of the colonies were determined based on the number of paths and the average distance reported by Rafael-Valdez *et al.* (2017). The ant nests were differentiated according to the recommendations made by Hernández-Roldán *et al.* (2017). Air samplings from the nests and the foraging sites were taken from each colony. The sampling ports were buried into the nests with a 45° gradient; the screw cap of the ½-inch wide and 80-cm long PVC TuboPlus® sampling ports was located at ground level. The air samplings of the foraging sites were carried out at ground level in the pricklypear (*Opuntia* spp.), maguey (*Agave* spp.), or palm (*Yucca* spp.) substrates, taking into account the higher impact and activity of the worker ants (Kaspari, 2003).

From January to June 2017, air samplings were taken on a monthly basis, between 7:00 and 10:00 am, while in April —when escamoles can be found in the nests—, the sampling was taken every 15 days. A total of 70 samplings were collected: n=35 nest sampling and n=35 foraging sites sampling. In order to describe the VOCs of each period, this study determined that the preseason was the period when no escamoles were found in the nests (January-March 2017), while the season was the escamol production period of the colonies (April-June 2017).

A 0211-V45R-68cx Marathon® electric vacuum pump was used to extract the air from the nests. On one end, the pump was connected to the sampling ports. On the other end, it was connected to a 1L Tedlar® (EPA 1990) bag, with a Thermogreen® LB-2 septum (Supelco®). The bags were previously purged with ultrapure nitrogen (99.9999%) to reduce background contamination. The collected samples were kept in iceboxes. They were transported to the Laboratorio Nacional de la Coordinación para la Innovación y Aplicación de la Ciencia y la Tecnología of the Universidad Autónoma de San Luis Potosí, where they were stored at −20 °C for less than 24 h prior to their analysis.

Analysis of the volatile organic compounds

The air samplings were analyzed using an ultrafast gas chromatograph with a HERACLES II (Alpha MOS, France) electronic nose detector, with two short columns of different polarities, two flame ionization detectors (DB-5-FID 1 and DB-1701-FID 2) and a preconcentration trap that increases sensibility and the chances to obtain a global chemical fingerprint. A vial was used to take a 40-ml air sample from each bag. Subsequently, it was incubated in an autosampler for 900 s, at 40 °C, and with a 500-rpm agitation. One ml of the sample was taken per headspace and was injected to the GC E-nose. The temperature of the injector remained constant at 200 °C. The compounds were separated with a 50 °C temperature program for 30 s, constantly increasing the speed by 10 °C/s, until it reached a maximum of 280 °C, with a constant 1-mL/min hydrogen flux. The separated compounds were detected using the Alpha MOS software of the electronic nose; the VOCs were identified based on the Kovat index, using the C6-C16 standard (Śliwińska *et al.*, 2016).

Statistical analysis

The Alphasoft V.12 software (Alpha MOS, Toulouse, France) was used to analyze the compounds. The identified VOCs were classified per collecting site (nest and foraging site) and production season (preseason or season). The VOCs with high responses and similar chromatographic profiles were considered significative when their representation models had a >20% similarity ratio. A hierarchical cluster analysis was conducted in the Euclidean distance matrices; afterwards, a head map was obtained with the VOCs response of the individual nest samples (Wu *et al.*, 2016). The principal component analysis (PCA) of the InfoStat® V2020 software (Di Rienzo *et al.*, 2020) was used to establish the chromatographic response of the area under the curve (A∩C) of each VOC identified. Synthetic compounds were excluded from the analysis.

Chemical role of the volatile organic compounds

A literature review of the identified VOCs was carried out, in order to understand the semiochemical role recorded for the Himenoptera: Formicidae insects. The metabolites were determined using the MetaboAnalyst v 3.0 software, linked to the following databases: the Human Metabolome Database (HDMB), the PUBCHEM of the information retrival system of the National Center for Biotechnology Information (NCBI), and the Kyoto Encyclopedia of Genes and Genomes (KEGG) (Xia *et al.*, 2015).

RESULTS AND DISCUSSION

In the *L. apiculatum* habitat (nests and foraging sites), 48 VOCs were identified (Table I; Figure 1); they were mainly classified as saturated hydrocarbons (17%), aldehydes (17%), alcohols (15%), esters (10%) and, in lower proportions, ethers (6%), ketones (6%), terpenes

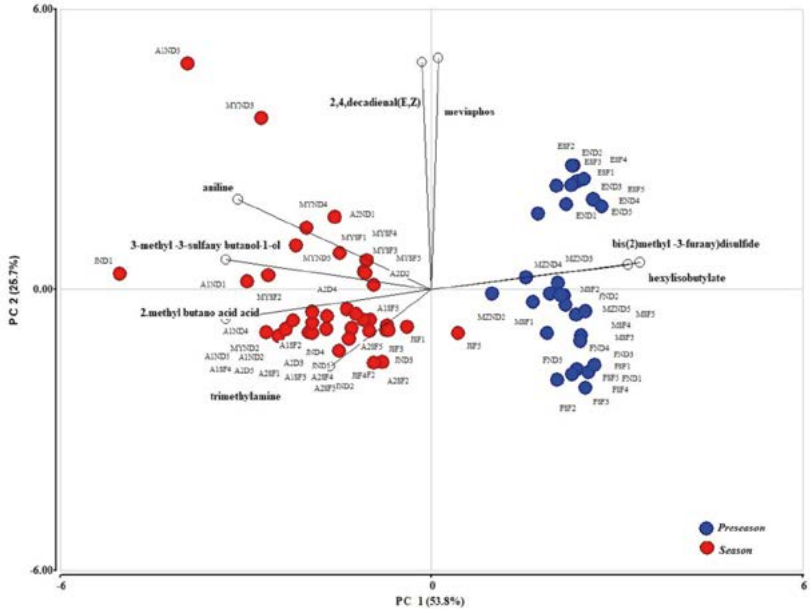

Figure 1. Intensity of the VOCs in *L. apiculatum* habitats (nests and foraging sites), showing the highest variation between escamol seasons (2017).

Table 1. VOCs recorded in the habitat of *L. apiculatum* from January to June 2017, in the UMA El Milagro, Villa González Ortega, Zacatecas. *Indicates agrochemical VOCs.

Retention time	VOCs	Retention time	VOCs
Aldehydes		**Esters**	
15.19-1	Acetaldehyde	54.99-1	Triacetin
24.23-1	2 methyl propanal	58.19-1	methyl undecanoate
26.13-1	Butanal	47.45-1	Hexyl isobutyrate
51.58-1	(E)cinnamaldehyde	34.43-2	methyl hexanoate
42.80-1	Benzeneacetaldehydo	40.48-2	(Z)-octanol
46.76-2	(E, E)2, 4 Nonadienal	**Ethers**	
48.72-2	(Z)-3-Phenyl-2-propanal	20.08-1	disopropyl ether
50.16-2	2,4, decadienal (E, Z)	22.50-1	diethyl ether
Alcohols		45.44-1	2-(2-ethoxiethoxy) ethanol
20.99-1	Propanol	**Amines**	
35.27-1	(E)-2-penten-1-ol	14.70-2	Trimethylamine
37.67-1	3-methyl -2-butane-1-ol	43.60-1	Aniline
39.79-1	(z)-2-hexano-1-ol	**Phenols**	
20.44-2	2-methyl-2-propanol	54.00-1	1,2-benzene dio
39.23-2	3-methyl -3-sulfani butanol-1-ol	38.08-2	1,8-cineole
41.29-2	E-2-None-ol	**Heteromatic compounds**	
Hydrocarbons		25.24-2	2-ethyl furan
18.78-1	Butane	54.35-2	Bis (2) methyl -3-furany) disulfide
31.24-1	2 methyl propane acid acid	**Terpenes**	
15.71-2	2-methyl butane	37.54-2	p-cimene
40.71-1	dimethyl benzene*	43.33-2	Citronellal
52.83-1	1-p-menthen-8-thiol	**Organophosphate esters***	
24.28-2	Heptane	57.44-1	Mevinphos
35.52-2	Decano	62.15-1	Molinate
36.31-2	2-methyl butano acid acid	68.40-1	dicrotophos
Ketones		70.70-2	Monocrotophos
41.55-1	2-methyl-2 cyclopenten 1 one	**Triazine***	
56.21-1	beta-damascenone	70.25-1	Prometon
30.29-2	3-hexanone	60.55-2	Atrazine

(4%), aromatic compounds (4%), amines (4%), phenols (4%), organophosphate esters (8%), and triazines (4%). Out of the total of VOCs identified in the escamolera ant habitat, 36 are semiochemical compounds recorded in insects of the family Formicidae found in plants of the study area. Four of the found compounds (E,E)-2-4-nonadienal, propanol, 2 methyl-2, beta-damascenone) influence the aroma volatility; two compounds are odorants (bis(2-methyl-3-furyl) disulfide; (E,E)-2,4-nonadienal), and six have traces of agrochemicals.

The VOCs in the escamolera ant habitat showed a 79.5% seasonal variability (PC1=53.8%, PC2=25.7%) with a 0.95 cophenetic correlation (Figure 1). The hexyl

isobutyrate and the bis(2-methyl-3-furyl) disulfide were the VOCs with the highest intensity variability during the preseason (March). This intensity considerably diminished during the escamol season. During the escamol production season the increase and correlation of the intensity between 2-Methylbutanoic acid, 3-methyl-3-sulfanylbutan-1-ol, aniline, and trimethylamine stood out. A negative correlation between the escamol season and the presence of synthetic VOCs (mevinphos) was recorded.

The VOCs variability in the foraging sites was 89.8% (PC1=61.2%, PC2=28.6%) and was influenced by six VOCs (Table 2; Figure 2), with a 0.99 correlation index. During the exploitation of escamol, a negative correlation was observed between the intensity of hexyl isobutyrate and the bis(2-methyl-3-furyl) disulfide regarding the presence of escamoles, while the intensity of 2-Methylbutanoic acid and 3-methyl-3-sulfanylbutan-1-ol were essential VOCs in the foraging substrates.

The VOCs variability of the nests —determined by the hierarchical cluster analysis with Euclidean distance matrices— resulted in a head map of the VOCs response of the nests with a 68.71 discrimination index (Figure 3). The PCA of the VOCs variability in nests accounts for up to 73% (PC1=45.6%; PC2=28.2%) of the seasonal variability; it included 12 VOCs (Table 3; Figure 4). The escamol season is specially correlated to the intensity increase of 2-methyl propane acid and trimethylamine. Nevertheless, a relevant factor for this analysis is the negative correlation between the escamol production season and the meviphos synthetic compound.

Table 2. Average variability of VOCs from *L. apiculatum* foraging sites during the 2017 January-July preseason and season, in UMA El Milagro, Villa González Ortega, Zacatecas.

VOC	Preseason A∩C	Season A∩C
Acetaldehyde	43.9	5.5
2-methyl propanoacid	243.9	522
(E)cinnamaldehyde	482	25
E-2-None-ol	495	292
(E,E)2, 4 Nonadienal	1 711	1 066
methyl salicylate	2 232	527
Hexyl isobutyrate	22 539.4	6 064.5
Bis (2) methyl -3-furany disulfide	29 912	9 827.6
1,2-benzene diol	0	48
3-methyl -2-butane-1-ol	41.2	91.1
2-methyl butane acid acid	104	436
2-methyl-2 butand acid	161.2	272.4
(Z)-octanol	226	346.9
methyl hexanoate	329.8	375.1
3-methyl -3-sulfany butanol-1-ol	339	1 142.8
Aniline	3 87.6	831.9
1-p-menthen-8-thiol	1044	1075
Beta-damascenonel	2 857	3 165

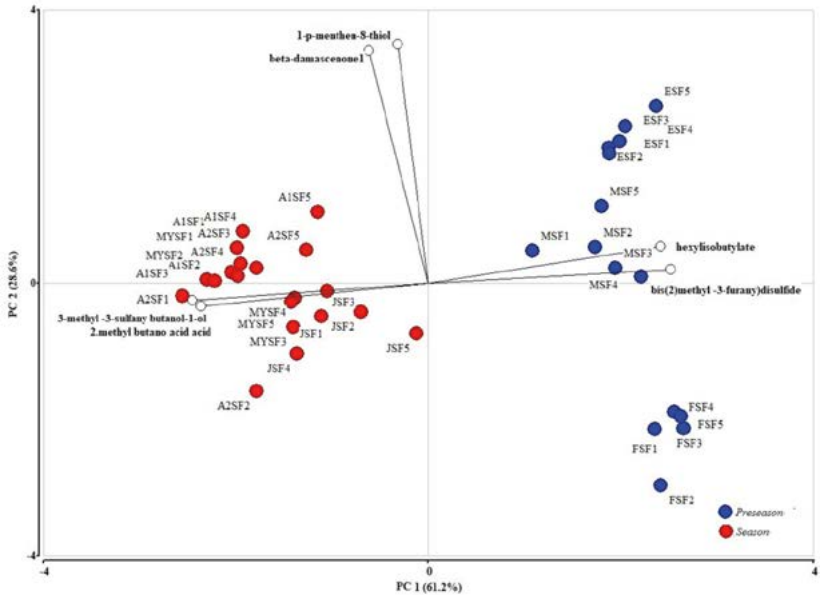

Figure 2. VOCs variation in *L. apiculatum* foraging sites per production season.

Table 3. Response intensity of the VOCs with higher variability in *L. apiculatum* nests per season.

Chemical compound	Preseason A∩C	Season A∩C
(E, E)2,4 Nonadienal	2255.25	864.71
(E) cinnamaldehyde	921.293	890.263
2,4, decadienal (E,Z)	1 285	933.302797
Hexyl isobutyrate	15 469.291	3 373. 998
Bis (2) methyl -3-furany disulfide	31 234.229	7 461.019
Trimetilamina	0	100
1,2-benzene diol	35	778.81
2-methyl butane acid	131.909	751
(Z)-octanol	206.553	1 316. 563
3-methyl -3-sulfany butanol-1-ol	470.829	1 166.088
Aniline	586.63	945.96
meviphos	1 181	922

The 48 VOCs detected in the escamolera ant habitat had an important variation in their intensity response during the escamol production preseason and season. Although some compounds had a low intensity response, their semiochemical role can influence the level of response of the organism (Acevedo, 2020).

In this study, the following compounds were identified in the habitat: mainly saturated hydrocarbons, aldehydes, and alcohols, and, in a lower proportion, esters, ethers, ketones, terpenes, aromatic compounds, amines, and phenols. Gordon (2021), Jaffé (2004), Kaspari (2003), and other authors have previously established that the following pheromones

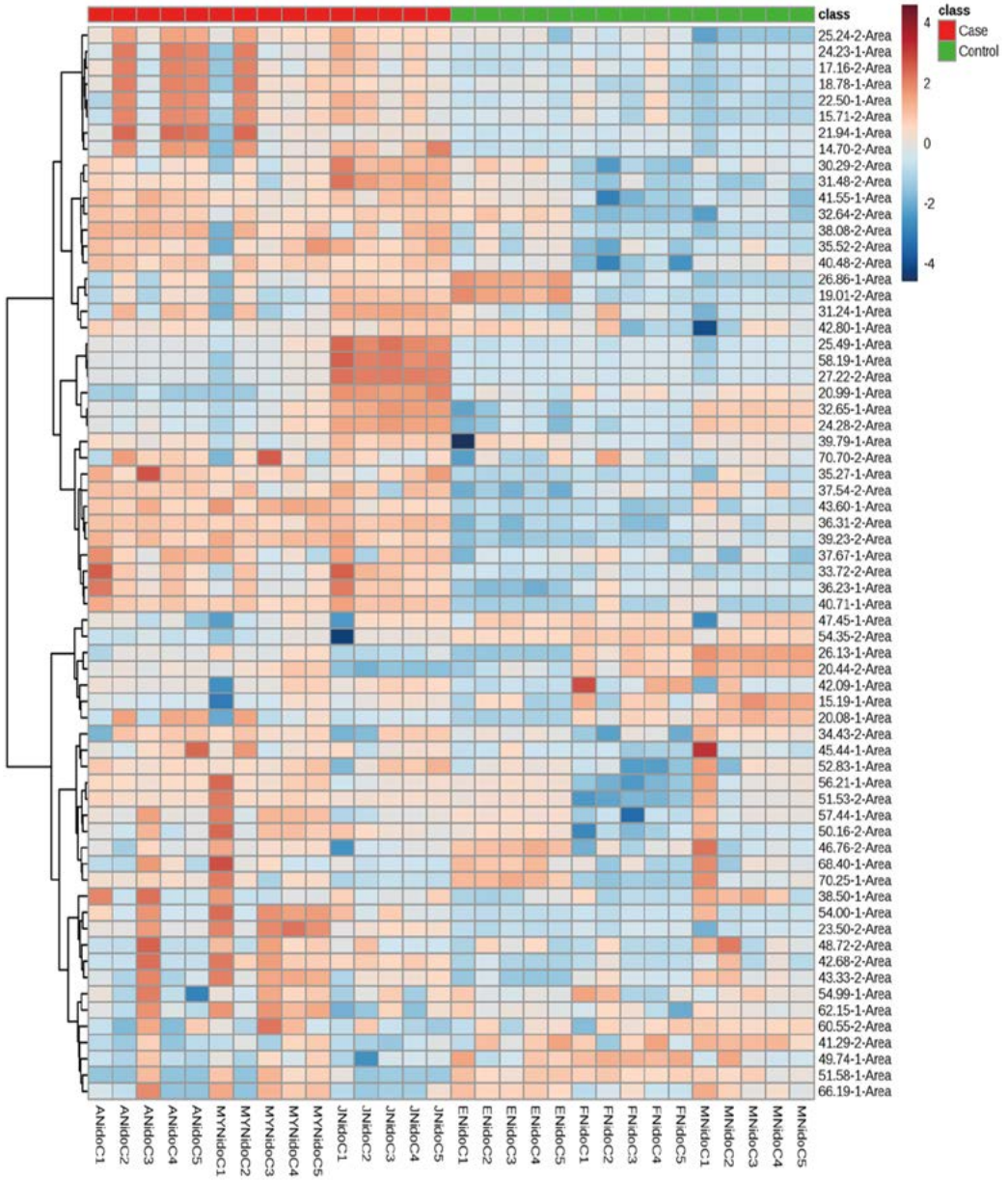

Figure 3. VOCS head maps in the air samplings obtained from the *L. apiculatum* nests during the production season (green: preseason; red: escamol season). The intensity of each VOC is represented in the horizontal axis. Each square shows the individual response of each compound of the samples.

regulate most of the life of ants: acetates, aldehydes, alcohols, alkanes, and ketones (Cantúa-Ayala *et al.*, 2019; Cruz-Labana *et al.*, 2023). Paterson and Adams (2022) have determined that alkanes are the main components of the tracking, warning, and sexual pheromones of family Formicidae. In addition, they play a fundamental role in the antimicrobial activity, creating toxins that repel predators. Alagappan *et al.* (2021) found that alkanes account for 50%, of the VOCs in the body of ants, followed by alcohols and, in lower proportions, aldehydes (0.8%) and the amides in the carboxylic acid (0.2%). In this study, the VOCs with

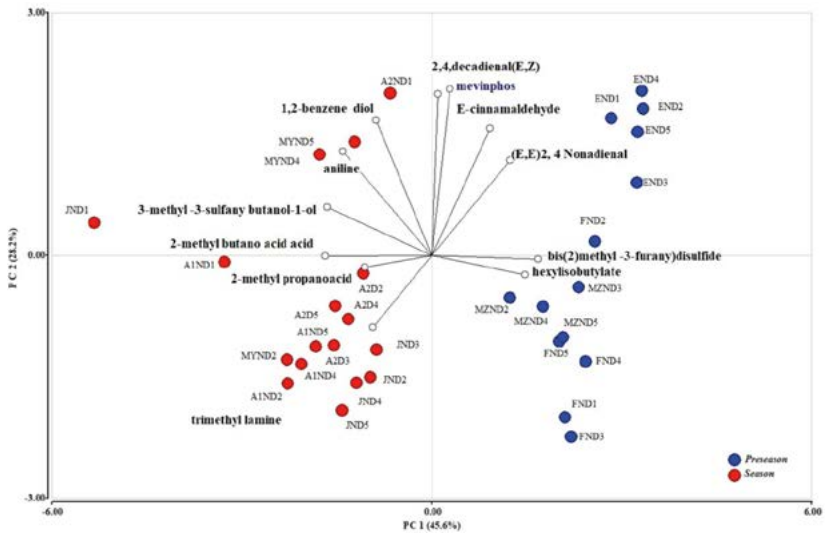

Figure 4. Variation of the response intensity of the VOCs found in *L. apiculatum* nests per escamol production season, from January to June 2017.

the highest presence in the habitat were saturated hydrocarbons and aldehydes, which helps to recognize a VOCs profile for this ant species.

Traces of VOCs used in agrochemicals were also detected in the *L. apiculatum* habitat (Carrera-Sánchez *et al.*, 2019). The source of these VOCs can be found in the agricultural areas inside or nearby the study area. Particularly, the intensity of the meviphos in the nests has a negative correlation (0.95) with escamol production. This compound is widely used in pesticides, as an acetylcholinesterase inhibitor (NCBI, 2023). Consequently, further studies should be carried out regarding the effect of agrochemicals in the reproductive biology of edible insects such as the escamolera ant and their impact on the escamol production in semiarid regions, given the lack of records about their influence in scientific literature.

On the one hand, in the foraging sites the intensisty of hexyl isobutyrate and the bis(2-methyl-3-furyl) disulfide diminished during the escamol production season. On the other hand, 1-p-Menthen-8-thiol, beta-damascedone, 3-methyl-2-butene-1-ol, and 2-methyl-2 butene acid reached high peaks of intensity noticeable in the environment.

Meanwhile, the intensity of bis(2-methyl-3-furyl) disulfide and hexyl isobutilate in the nests recorded higher peaks than the foraging sites. The intensity considerably diminished in the nests during the escamol season. Trimethylamine was an exclusive compound in the nests during the escamol season. Another characteristic was the increase of the intensity of 2-Methylbutanoic acid, 3-methyl-3-sulfanylbutan-1-ol, aniline, and 1,2-benzene diol. These compounds had the highest variation in the nest during the escamol production season. These compounds should be evaluated to determine their role in the reproductive biology of *L. apiculatum* and its influence in the escamol production.

Other VOCs have been reported in the inter-specific communication of ants. Their presence and intensity in the air of the nests and foraging sites can be related to the specific flora of their habitat, nesting substrates, and extrafloral nectaries. A wide variety of

plants depend on ants to spread their seeds and to pollinate them. However, other type of plants produces various types of compounds to protect themselves (Delnevo *et al.*, 2020). For instance, (E)-2-none-ol volatil compound, a characteristic element of pricklypears (*Opuntia* sp.) (HMDB41498) can be associated to the inclusion of pricklypears in the diet of the escamolera ant and its presence in the nesting substrate (Lara-Juárez *et al.*, 2015). Meanwhile, (E) cinnamaldehyde attracts ants to pollinize plants (*Cytinus* spp.) (Vega *et al.* 2014). For its part, the 2-methylbutanoic acid compound is produced by plants of the family Salicaceae to reduce its palatability in the *Spodoptera eridania* larvae (NCBI: Manuwoto *et al.*, 1985).

Meanwhile, the intensity of acetaldehyde in the habitat is interesting, because this compound has been related to the foraging activity of ants. The *escamol* season includes part of the winter, where the sources of food are scarce and the temperatures are low (Kaspari, 2003). Consequently, *L. apiculatum* must adapt to weather variations when they forage seeking sources of food. The intensity and concentration of foraging pheromones depend on the source of food (Cruz-Labana *et al.*, 2023). Therefore, the semiochemical role of the VOCs found in the external environment (*i.e.*, the foraging sites of *L. apiculatum*) are determinant in the *escamol* production.

The VOCs identified in this study also have been recorded in the intra-specific communication of the physiological processes of the insects. For instance, decano is the main element of the warning pheromone of *Camponotus obscuripes*, *Lasius fuliginosus, L. latreille*, and *Fomica rufa* ants (Hölldobler and Wilson, 1990; Mizunami *et al.*, 2010), while 3-methyl-3-sulfanylbutan-1-ol is an element of the volatile warning pheromone of the northern giant hornet (*Vespa mandarinia*) (Ono *et al.*, 2003). The VOCs related to defensive chemical secretions prevent the theft of eggs, larvae, or food, as well as other threats to the nests (Hölldobler and Wilson, 1990; Lara-Juárez *et al.*, 2015). For instance, hexyl isobutirate is a compound produced by the males and females of two species of bedbugs (*Lygus lineolaris* and *L. elisus*), as a defense mechanism against predators; however, it is also used as sexual pheromones (Byers *et al.*, 2013).

Escamoles are harvested only once per year and requires specific conditions in the wild habitats. It also requires a previous mating that, in the Altiplano Potosino, takes place from March to April (Lara-Juarez *et al.*, 2015). However, the semiochemicals involved in the reproduction of the escamolera ant are unkown.

In this study, a variation in the intensity of the 2-methylbutanoic acid was recorded; this compound can be found in the mandibular gland of the *Cephalotes alfaroi* and *C. cristatus* ants (Wood *et al.*, 2011). The importance of this gland lies in the initiation pheromones, which, in some insect species, produces the queen substance that inhibits the reproduction of worker ants. However, Fujiwara-Tsujii *et al.* (2006) and Alagappan *et al.* (2021) have reported the lack of information about VOCs in the reproduction pheromones.

Compounds such as bis(2-methyl-3-furyl) disulfide considerably diminished their intensity during the escamol season (Buttery *et al.*, 1984). This compound has been associated with the smell of roasted beef, which has a 1.0% odor detection threshold. Meanwhile, its taste has been described as sulfuruous and meaty, with traces of onion and roastbeef and a taste detection threshold with soupy and tasty characteristics, an a slightly metallic

flavor. It does not have known allergenes. In high concentrations, it can be associated with a rancid or rotten meat smell (Wang *et al.*, 2020). In its synthetic form, it is an aromatic compound used to improve the natural, fresh, and rich sensation of milk. In this study, the decrease of the intensity of this compound in the habitat was determinant for *escamol* production. Further research would determine its effects on the aromatic characteristics and taste of escamoles. (E,E)-2,4-nonadienal is another compound related to the smell of food; it has been reported as an aromatic substance that can be found in butter and in the taste and fragance of caviar (HMDB: 31685). Its intensity increases during the escamol production season. These VOCs are probably related to the characteristic smell and flavor of the escamol, which Holldöbler and Wilson (1990) have compared to the smell and flavor of rancid butter. As a result of its distinctive flavor, escamoles are popularly known as the Mexican caviar.

Finally, thrimethylamine was only found in the nests during the *escamol* season; however, it was not detected in the foraging sites. This compound is involved in the growth of the eggs of *Daphnia magna* (Lass *et al.*, 2001). Meanwhile, the size of the eggs of the escamolera ant caste may be influenced by the presence of trimethylamine.

CONCLUSIONS

This study identified 48 VOCs in the *L. apiculatum* habitat, during the preseason-season. The variability in the intensity of the VOCs found in the nests and foraging sites enabled their charactyerization during the escamol production season. This study recorded, for the first time, the semiochemical profiles related to the reproductive behavior of the escamolera ant. This species has the potential to contribute to food security. However, further research is required to evaluate the role of VOCs and the variability of their concentrations in the physiological behavior of ants. VOCs can influence the preservation and exploitation of this edible insect. Finally, the agrochemical impact of VOCs on the production of escamoles should be acknowledged.

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