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Contacto principal
Jorge Cadena Iñiguez
Guerrero 9, esquina avenida Hidalgo, C.P. 56220, San Luis Huexotla, Texcoco, Estado de México.
agroproductividadeditor@gmail.com

Contacto de soporte
Soporte
5959284703
agroproductividadsoporte@gmail.com

Directrices para Autores/as

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Comparative analysis of four corn (*Zea mays* L.) varieties, transformed from grain corn into tortilla

Maimone-Celorio, José A.[1]; **Regalado-López, José**[1*]; **Gallego-Moreno, Francisco J.**[2]; **Pérez-Ramírez, Nicolás**[1]; **Méndez-Espinoza, José A.**[1]

[1] Colegio de Postgraduados, Campus Puebla, Programa en Gestión del Desarrollo Social., Puebla, México.
[2] Universidad de Castilla-La Mancha, Facultad de Trabajo Social, Cuenca, Castilla-La Mancha, España.
* Correspondence: josere@colpos.mx

ABSTRACT

Objective To identify the corn variety with the best yield, nutrients, flavor, and profitability to use as main input for a future *tortillería* (tortilla store) operated by the Sociedad de Producción Rural Campo Lima (SCL). A mixed research **methodology** was used to compare key values of the transformation chain of corn grains into nixtamalized tortilla. In addition, interviews with key players and participant observation were used as information tools and included weights, properties, and yields of the *tortillerías*. The **findings** allowed a comparative evaluation of the four corn varieties (Niebla, HS-2, native corn, and Sinaloa) and included the following yield indicators: nixtamalization-to-dough-to-tortilla, nutrient content, sensory perception, and benefit/cost analysis. The hybrid HS-2 (developed by the Colegio de Postgraduados) stood out with the highest average value. A **limitation** was the scarce literature about this type of research carried out in semi-mechanized *tortillerías*. In **conclusion**, the identification and selection of the most efficient and balanced corn input will help the small producers of the Sociedad de Producción Rural Campo-Lima to carry out a better decision-making process and responsibly invest in the creation of a *tortillería*. This step will get them closer to a fair market inclusion, consequently, generating a fair income. This process will add value to the corn they grow and will motivate new generations to continue sowing corn.

Keywords: yield, nutrients, profitability, *tortillería*.

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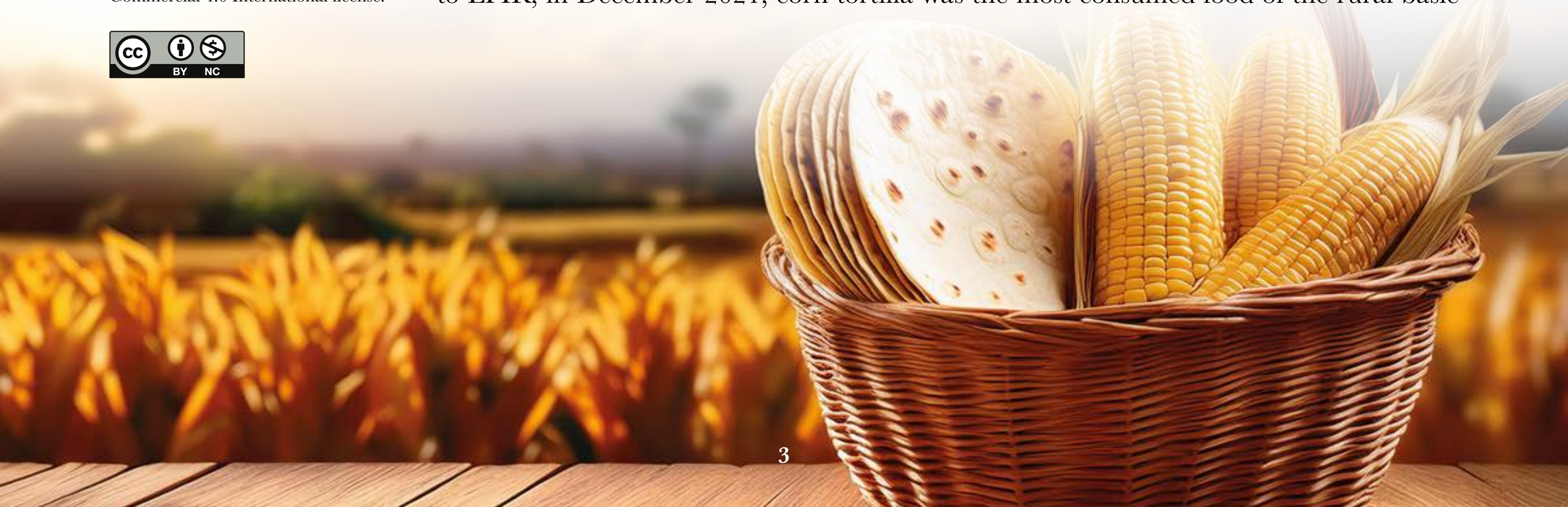
INTRODUCTION

Despite the public policy regarding guaranteed fixed prices for food, the economic situation of most small producers in Mexico has not improved (CONEVAL, 2023). Approximately 94% of the population eats tortillas and —according to the estimations of the CONEVAL database regarding the cost of the basic food basket in the Poverty Line for Rural Income (LPIR)— the average consumption of tortilla per capita in urban areas is 56.7 kg, while in the rural areas it reaches 79.5 kg (an average of 9 tortillas per day). According to LPIR, in December 2021, corn tortilla was the most consumed food of the rural basic



food basket (217.9 grams per day), reaching a monthly cost of MXN$129.78. Regarding the daily nutrient requirements of Mexicans, tortilla provides about 45% carbohydrates, 39% proteins, and 49% calcium. In rural areas, these values are higher, because tortillas are prepared with fresh nixtamalized dough (Rivera Chavira *et al.*, 2021; Colín-Chávez *et al.*, 2020). Flores *et al.* (2007) pointed out that ≈33.6% of the corn produced in Mexico is used to prepare tortillas (8,775,000 t). According to the Directorio Estadístico Nacional de Unidades Económicas (INEGI, 2022), 121,445 establishments are part of the corn grain-to-tortillas transformation chain (*i.e.*, *tortillerías* and mills). Based on the Grupo Minsa (2021) credit ratings developed by HR Ratings, 30% of Mexican *tortillerías* use fresh nixtamalized corn, 20% use enriched flour, and 50% use a mixture of fresh nixtamalized dough and corn flour. In Puebla, Mexico, most consumers (≈65%) chose fresh nixtamalized *tortillas*, produced in nearby mechanized *tortillerías* or buy them in retailer stores (Escobedo and Jaramillo, 2019).

The study area is located in the municipality of Tlaltenango, in the central-western area of Puebla. It borders with the municipality of Huejotzingo (north and west), the state of Tlaxcala (north), San Miguel Xoxtla (east), and Juan C. Bonilla (south). The area is located at 2,200 m.a.s.l. and covers 37 km^2. In 2020, it had 7,425 inhabitants (population density: 355 per km^2). According to the Secretariat of Social Development, the high marginalization and social backwardness of this municipality places it in 38^{th} place out of the 217 municipalities of the state (H. Ayuntamiento de Tlaltenango, 2022). In Tlaltenango, farmers use several corn varieties —such as the native white, blue, red, and yellow corn— and hybrids —such as Niebla, produced by the Ceres company, and HS-2, developed by the Colegio de Postgraduados. HS-2 was created from a cross of several corn types with desirable characteristics. This hybrid has an improved yield and is more resistant to weather and pests (Núñez and Sempere, 2016). The *tortillerías* of Tlaltenango use a mixture of hybrids and corn flour. These hybrids come from Sinaloa and are bought at a very cheap price. Sinaloa corn is grown using a large volume of agrochemicals and a wide variety of pesticides (Cruz and Leos, 2019). According to the interviews with members of the Sociedad de Producción Rural Campo Lima in 2023, only a small percentage of *tortillerías* use the Niebla, native corn, or HS-2 varieties. In addition, most of the regional *tortillerías* and intermediaries pay farmers between MXN$5 and MXN$8 per kilogram of white corn. According to the Anuario de Granos del Sistema Nacional de Información e Integración de Mercados (SNIIM, 2022), the consolidated price of white corn (Sinaloa) in the Central Market of Puebla reached a minimum price of MXN$8.75 and a maximum price of MXN$24 (average: MXN$16.37), while a kg of tortilla cost between MXN$15.72 and MXN$17.67 (SNIIM, 2023). The guaranteed price fixed by the Ministry of Agriculture of Mexico (2022) was MXN$6.8 per kg of corn grain; however, the small corn producers of Tlaltenango believe that MXN$9.50 per kg is a fair minimum purchase price.

In 2023, the situation of the Sociedad de Productores Rurales Campo Lima (SCL) was diagnosed. The results indicated a lag in the income of its members, as a consequence of the low price of corn in the market. Therefore, a responsible investment was suggested to the SCL. The investment should be equally divided among all the members and it should be used to develop, install, manage, and operate a tortillería in Tlaltenango. The aim of this proposal was not just to promote local consumption, but also to help the SCL to transform their corn grains into a fair price tortilla. In order to achieve a responsible investment (FAO-CSA, 2014) the following five strategies were proposed: a) to analyze the yield and the nutritional properties of corn varieties; b) to conduct a marketing study about the small tortillerías in the region; c) to develop a business and investment plan for a *tortillería*; d) to improve the input for sustainable corn production; and e) to develop an organizational-management plan for the SCL. Consequently, this study contributed to three (a, b, and c) of the five strategies. Subsections 3.1 and 3.2 describe how this research meets strategy a. In addition, subsection 3.3 includes a sensorial analysis and interviews conducted with owners and employees of local *tortillerías*. Meanwhile, subsection 3.4 consists of a benefit/cost analysis that advances strategy c. Finally, subsection 3.5 describes a comparative evaluation that will help the SCL to make management decisions, such as the selection of the most suitable corn variety for the production, transformation, and commercialization of the corn-to-nixtamalization-to-dough-to-tortilla chain. In addition, the results will help the SCL to establish a new *tortillería* in Tlaltenango, promoting the rural, local, and sustainable development of the region.

MATERIALS AND METHODS

Inductive and exploratory-descriptive methodologies were used in the analysis. They included qualitative methods, such as the study case and situational participation. In addition, quantitative methods —such as experimental design and comparative analysis— were used (Hernández Sampieri and Mendoza Torres, 2018). The diagnosis and research problem of this study were developed based on 8 interviews conducted with key rural producers of the SCL in Tlaltenango. In addition, the Mexican context was subjected to a documentary review. The corn comparative evaluation methodology used in the study (Table 1) is described from subsection 3.1 to subsection 3.5. The materials and methods used in this research are included in these subsections. This research was carried out from February to July 2023.

Subsection 3.1 of Table 1 shows the mechanized methods used for nixtamalization and the preparation of dough and tortillas, as well as their yields. Twelve employees and 3 owners of *tortillerías* from the rural areas of the valley of Puebla were interviewed. Out of all the *tortillerías* visited for the study, the tortillería that had the most traditional transformation (grain-to-tortilla) method was selected. Its transformation method included nixtamalization, milling, kneading, and cutting. In addition, this *tortillería* uses the type of tortilla machine that is most popular in the Valley of Puebla. In this *tortillería* (a.k.a., "*tortillería* 1"), the transformation process from grain corn into tortilla was carried out thrice, using the 4 corn varieties most used in Tlaltenango (Niebla, HS-2, native corn, and Sinaloa). These three samples were subjected to a comparative analysis between their means and variances (descriptive and inferential statistics), in order to determine the corn grain-to-tortilla process of the four corn varieties. A randomized complete block design with three replicates was used to analyze corn weight at every stage of the transformation process (nixtamalization, dough, and tortilla), to determine significant differences in weight yield (kg). The R software was used to conduct an analysis of variance, in order to compare the mean values resulting from the three transformation processes and to determine if the statistical significance of p-value < is less than 0.05 for the recorded treatments. In addition, statistically significant yield differences between corn varieties were identified, during the nixtamalization, dough, and tortilla stages of the process. Tukey's mean comparison test was used to find differences between means. Meanwhile, in subsection 3.1, additional tortilla samples were used for a sensory perception study: 30 inhabitants of the region participated in a convenient sampling. Cronbach's Alpha was used to determine the reliability of the survey (subsection 3.2). In addition, the samples included in subsection 3.1 were used for a bromatological nutrient analysis (subsection 3.3). Therefore, the study included the benefit/cost analysis of the corn grain-to-tortilla process (subsection 3.4). Finally, the results included in subsections 3.1 to 3.4 were used to compare the indicators (%). These results are included in the tables and graphs (subsection 3.5).

RESULTS AND DISCUSSION

Nixtamalization, dough, and tortilla yields

According to the yield responses of nixtamalization, the highest results (nixtamalization kg/ grain kg) were recorded by Sinaloa (1.878), followed by Niebla (1.837), HS-2 (1.801), and native corn (1.793). Regarding fresh dough, the highest result (nixtamalization kg/ grain kg) was recorded by Sinaloa (1.989), followed by Niebla, HS-2, and native corn. However, the yield varied in tortilla production: the highest result (nixtamalization kg/ grain kg) was recorded by HS-2 (1.486), followed by Niebla, native corn, and Sinaloa (Table 2). These results are similar to the yield rates recorded by Salinas and Aguilar (2010) and Ramírez-Muñoz (2021). However, no references were found about dough-to-tortilla yield calculations made directly in a *tortillería* in Tlaltenango.

Regarding weight increase and loss, Niebla and Sinaloa recorded higher weight increases (84 and 88%, respectively) than HS-2 and native corn (80 and 79%, respectively), during the corn grain-to-nixtamalization transformation. This phenomenon is the result of the medium hardness of Niebla and Sinaloa grains, which produces a flourier endosperm, while HS-2 and native corn have a more vitreous endosperm. Sinaloa recorded the highest loss weight percentage (24%) during the dough-to-tortilla transformation stage, followed by Niebla (21%), native corn (20%), and HS-2 (17%). According to Salinas and Aguilar (2010), this behavior is the result of the capacity of each corn variety to preserve moisture and the high cooking temperature (285 to 300 °C) inside the tortilla machine, where evaporation causes a great moisture loss. Sinaloa recorded the highest moisture absorption during the nixtamalization and dough stages. However, this variety lost the greatest water volume during the tortilla preparation stage and, consequently, it obtained the lowest yield. These results match the findings of Gaytán-Martínez *et al.* (2013).

Nutritional value of white corn tortillas prepared in tortillerías

The tortillas prepared with HS-2 and native corn varieties recorded a lower wet weight in the bromatological analysis (47 and 46%, respectively) (Table 3). In addition, these varieties absorbed less water during the nixtamalization process and lost less water

Table 1. Materials and methods: four corn varieties, from crop to tortilla.

No.	Steps	Description
3.1	Yields of nixtamal, masa and tortilla in a convenience tortilla factory, 3 replications.	
3.1.1	Nixtamalization process	The corn kernels used had a moisture content between 12.9 and 13.1 percent and a weight of 5 kg per corn variety. All grains were harvested in the 3rd quarter of 2022. For cooking, 12 liters of potable water from a municipal well and 50 grams of food-grade lime were used at a temperature of 91° in accordance with NMX-FF-034/1-SCFI-2020.
3.1.2	Milling and kneading process	The nixtamal was transported to the "tortillería 1" mill to be ground into nixtamal flour. Before grinding each variety of corn, it was verified that the stones and the mill were perfectly washed to avoid adding to the weight of the fresh dough. Subsequently, a kneading machine was used for 4 minutes to achieve a homogeneous consistency in the texture of the dough (Serna-Saldivar, 2021).
3.1.3	Die-cutting, cutting and cooking process in tortilla machine	In "*tortilleria* 1", the fresh nixtamal dough was placed in the feeder of the tortilla machine rollers, which flatten the dough and then it is cut into 2 discs of 15 cm in diameter for transport on a belt and baking in an oven at 285 to 300 °C for a time of 30 s (±5). Upon leaving the oven, they are stacked in a container for packaging and refrigeration in hermetically sealed polypropylene vacuum bags for shipment for bromatological analysis (Espinosa-Ramírez *et al.*, 2021). Tortilla samples were separated for the perception surveys.
3.1.4	Measurement of nixtamal, dough and tortilla yields.	Subsequently, the incoming corn product and the outgoing corn product were weighed on an analytical balance for each corn variety. It is clarified that the weight of the tortillas was obtained 5 minutes after processing (Salinas & Aguilar, 2010). The basic hygienic practices of the official Mexican standard were used, NOM-187-SSA1/SCFI-2002 & NOM-120-SSA1-1994.
3.2	Bromatological analysis and nutritional declaration of tortillas	The methods and materials of analysis and the nutritional declaration are described in the Mexican standards: NOM-116-SSA1-1994, "NOM-F-68-S-1980, NMX-F-089-S-1978, NMX-F-066-S-1978, NOM-F-90-S-1978, NMX-F-496-SCFI-2011 and NOM-051-SCFI/SSA1-2010. These analyses were performed at the food laboratory of the Universidad Tecnológica de Huejotzingo (UTH), Puebla, Mexico. Tortilla samples were taken for analysis.
3.3	Tortilla sensory evaluation	A 15-item Likert-scale questionnaire to evaluate the perception of flavor (sweet, bitter, salty, sour), texture (consistency, hardness, viscosity), odor (pleasant whimsical aroma), freshness (recent processing), flexibility (elasticity, softness and rollability) and reheatability in freshly made and unrefrigerated nixtamal tortilla (Escobedo & Jaramillo, 2019).
3.4	Benefit/cost evaluation	Semi-structured interviews of 10 items to the 8 producers of the "Campo Lima"(Ortiz Pech *et al.*, 2020), and to 15 convenience tortilla factories (Boué *et al.*, 2018). As well as sources of information from the National Tortilla Council, FIRA and SNIIM. Some of the items are: a) Minimum price MXN of 1 kg of corn grain; b) Price MXN of 60 thousand corn seeds; c) Cost MXN of sowing, fertilizers, pest control, tillage and harvest in 1 ha; d) Price 1 kg of tortilla in rural areas; e) Cost of production of 1 kg tortilla in rural areas.
3.5	Comparative Evaluation	A table compares the results of steps 3.1, 3.2, 3.3 and 3.4, with percentages of the values obtained, as well as a presentation in a Hexa-radial graph.

Table 2. Grain-to-tortilla yields of the three transformation processes.

Maize Varieties	(3 replicates), 5 kg shelled corn base					
	Mean* nixtamal	Mean* dough	Mean* tortilla	Yield** nixtamal	Yield** dough	Yield** tortilla
Niebla	9.214	9.910	7.269	1.837 [b]	1.976 [b]	1.449 [b]
HS-2	9.059	9.678	7.475	1.801 [c]	1.924 [c]	1.486 [a]
Criollo	9.007	9.599	7.222	1.793 [d]	1.911 [d]	1.438 [c]
Sinaloa	9.437	9.995	7.175	1.878 [a]	1.989 [a]	1.428 [d]

*Mean values are shown in kilograms. **Yield=kg of the result product/kg corn grain. Different letters in superscript indicate significant differences between corn varieties (one-way ANOVA, Tukey's mean comparison test, $p<0.05$).

due to evaporation during their transformation into tortillas. Vázquez-Carrillo (2020) pointed out that this phenomenon is mainly a consequence of their vitreous consistency and harder grain.

According to the proximate composition included in Table 3, tortillas prepared with freshly nixtamalized dough mainly provide carbohydrates, crude protein, crude fat, sodium, and, in a lower proportion, fiber. Consequently, the tortillas with the highest protein content were those prepared with native corn, followed by those prepared with HS-2, Niebla, and Sinaloa. Meanwhile, HS-2 and native corn are the varieties that provide more energy (carbohydrates), followed by Sinaloa and Niebla. Following the proposal of Figueroa *et al.* (2001), the highest ash content and the lowest sodium content were recorded by HS-2. None of the four corn varieties recorded any sugar content. Regarding the total energy content in 100 g of tortilla, native corn recorded the highest results, followed by HS-2, Sinaloa, and Niebla. The results of this bromatological analysis match the findings of Michael Latham (2002), who recorded that corn mainly provides energy as carbohydrates; however, it also has significant amounts of proteins and lower fat/oil, fiber, and micronutrient content (vitamins A, B1, B2, and B3 and

Table 3. Results of the bromatological and physico-chemical analyses.

Parameter Chemical Component	Niebla	HS-2	Criollo	Sinaloa	Unit	Mean
Moisture [1]	51.53	47.00	46.06	50.10	g/100g	48.67
Crude protein [2]	4.40	4.50	4.80	4.20	g/100g	4.48
Ethereal extract (fat) [3]	1.30	1.70	1.60	1.80	g/100g	1.60
Ashes [4]	0.73	0.98	0.89	0.95	g/100g	0.89
Crude fiber [5]	0.20	0.30	1.20	2.00	g/100g	0.93
Sodium chloride (Salt) [6]	11.00	7.30	11.50	10.60	g/100g	10.10
Reducing sugar [7]	0.00	0.00	0.00	0.00	g/100g	0.00

[1]Moisture level determination (NOM-116-SSA1-1994 Mexican Official Standard). [2]Crude protein determination (NOM-F-68-S-1980 Mexican Official Standard). [3]Ether extract determination (fat) (NMX-F-089-S-l978). [4]Ash content determination (NMX-F-066-S-l978). [5]Crude fiber determination (NOM-F-90-S-1978 Mexican Official Standard). [6]Sodium chloride determination (Morh's method) (975.20, AOAC). [7]Reducing sugars determination (NMX-F-496-SCFI-2011).

Ca, P, Fe, Cu, and Zn). The ether extractor or crude fat contains triglycerides, fatty acids, wax, sterols, pigments, and fat-soluble vitamins. Unlike saturated fat and trans-fat, crude fat does not cause health problems. All the tortillas prepared with the four corn varieties under study recorded a low-fat content. Overall, the four corn varieties showed basic micronutrients values conductive to a healthy diet: 50.7 kcal per 25 g of tortilla (INCMNSZ, 2016).

Tortilla sensory perception analysis

The sensory perception for the grain-to-tortilla transformation and commercialization stages was surveyed. The surveys included the following elements of the four tortilla varieties: flavor, texture, color, freshness, flexibility, and reheated. The surveys had a Cronbach's Alpha of 0.842, indicating a good reliability. The sample consisted of n=30 interviewees. Out of this total, 57% were women and 43% were men and their age ranged from 19 to 55 years old, with a mean age of 39. During the first part of the survey, 73% of the interviewees responded with an overall liking to the flavor, texture, aroma, freshness, and flexibility of the tortillas. This stage recorded the following liking percentages: 41% Niebla, 31% HS-2, 18% native corn, and 10% Sinaloa. The remaining 27% of the sample obtained the following results: 35% Niebla, 30% native corn, 23% HS-2, and 12% Sinaloa. Freshly made tortillas were compared with reheated tortillas; in addition, the average of both tortillas was used to determine which was the best. In average, all the evaluated characteristics of tortillas recorded a 95% congruency, which reinforces the reliability of the tool. Consequently, the average results of the two-day surveys indicate that Niebla was the best qualified variety regarding flavor (92%), aroma (74%), and freshness (78%), while HS-2 recorded the best texture (74%), flexibility (70%), and reheated (68%). The tortilla control sample was prepared with corn flour bought in a supermarket and recorded the lowest percentages in all the surveyed characteristics, both for freshly made tortillas and reheated tortillas. These results were expected, as a consequence of the chemical differences in the preparation process between the freshly nixtamalized dough and the corn flour dough.

Benefit/cost analysis of the corn chain, from crop to tortilla

The highest benefit/cost (B/C) was recorded in the production, transformation, and commercialization of tortillas made with HS-2 (1.7 in 5 years). This result shows the feasibility of the proposal made to the SCL about the *tortillería*. A *tortillería* partnership should include at least 8 producers. Each producer should make an initial investment of MXN$37,000 to obtain a net profit of MXN$319,648.99 in 60 months. The *tortillería* should sell 25 kg per partner and per day and the producers should sow an annual total of 6,250 m^2 of HS-2 white corn. The economic benefit would be 8.6 times higher than the initial investment. A larger cultivation would enable the increase of the business, whether the additional tortillas were sold in same *tortillería* or if the producers invested in a new *tortillería*. The partners could focus on the production of corn grains, because the *tortillería* would be managed by employees. If each member of the SCL produced 1.25 ha of HS-2 corn in a year and sold 50 kg of tortillas per day, the 5-year net profit would be MXN$639,297.99 per partner, which would result in a 3.41 B/C ratio (MXN$10,654.97 per month). Minimum estimated values were used in this B/C calculation; therefore, the profit could increase if the market price of tortilla increases. Regarding the abovementioned projection (1.25 ha/5years/50 kg per day, per partner), the B/C ratio of HS-2 would be 23, 43, and 32% higher than Niebla, native corn, and Sinaloa respectively, which makes it the best mid-term sustainable economic choice. Mexicans consume an average of 7 to 8 white corn tortillas per day. According to the *Guía Alimentaria y de Actividad Física en Contexto de Sobrepeso y Obesidad en la Población Mexicana* (Bonvecchio and Fernández, 2015) 19-59 years old persons who exercise lightly should consume 7.5 portion of cereals per day. The Plan de Desarrollo Municipal of Tlaltenango established that this municipality has 7,425 inhabitants and, consequently, a *tortillería* could sell a minimum of 200 kg of tortillas per day. In addition, Tlaltenango is not the only area in which a *tortillería* could sell its product: other selling points could be established in nearby localities of the Izta-Popo valley area.

Comparative evaluation of four corn varieties, from crop to tortilla

The analysis of variance showed statistical differences ($p<0.05$) in the grain-to-tortilla transformation process, using the usual tools and machinery of the tortillerías located in the rural and peri-urban area of Tlaltenango. Out of the four corn varieties, HS-2 recorded the highest yield during the tortilla stage. Taking into account all the nutrient and sensory values, costs of the value and production chain, and the yield of the four corn varieties (Table 4), HS-2 is the most comprehensive, balanced, and complete variety.

Figure 1 shows a comparison between the main value indicators of the production, transformation, and commercialization chain of nixtamalized tortillas in a *tortillería*. The values of the parameters in Table 4 were transformed into equivalent percentages to develop this figure, establishing 100% as the maximum value of corn variety for each indicator. This figure shows that the HS-2 variety recorded the most balanced indicators. However, Niebla recorded the best sensory parameter. Consequently, tortillas should be prepared with a combination of both varieties, because they complement each other.

Table 4. Main indicators of the corn grain-to-nixtamalized tortilla chain.

Parameter	Niebla	HS-2	Criollo	Sinaloa
Tortilla Yield	1.449	1.486	1.438	1.428
Dough Yield	1.976	1.924	1.911	1.989
Protein * (g)	4.4	4.5	4.8	4.2
Carbohydrates * (g)	38.8	45.5	45.5	40.9
Sensory P. %	38	27	24	11
Benefit/Cost**	3.18	3.41	2.98	3.09

Tortilla Yield (tortilla kg/grain kg). Dough Yield (dough kg/grain kg). *=in a 100-g tortilla sample. P=average perception. **=growing 10 ha of corn per year and selling 400 kg of tortilla per day, in a 5-year period.

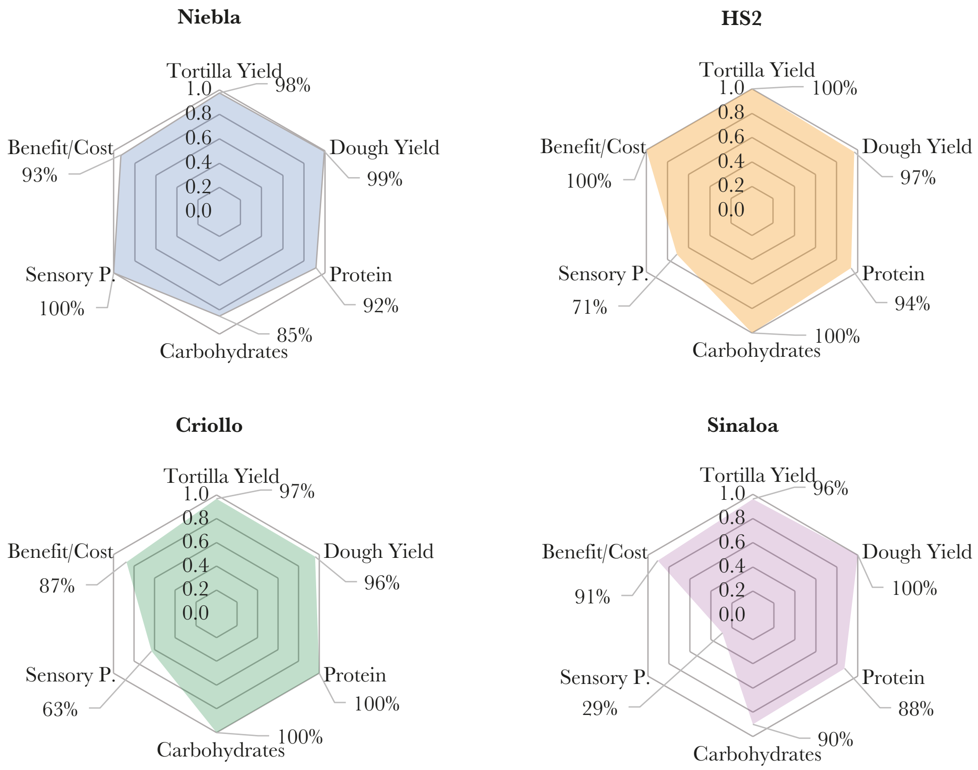


Figure 1. Comparison of the value indicators between the four corn varieties studied.

CONCLUSIONS

This study focused on the generation, analysis, and systematic comparison process of the yield, nutrition, sensory perception, and benefit/cost of tortilla dough prepared with four white corn varieties in Tlaltenango. The results identified HS-2 and Niebla as the two best corn varieties. These findings would help the SCL in the decision-making process and in a responsible investment aimed at the creation of a small company for the transformation of nixtamalized corn into tortillas or the establishment of a *tortillería*. The ultimate aim is to improve the socio-economic conditions of the SCL families. In addition, the balanced nutrients of freshly nixtamalized dough prepared with the HS-2 and Niebla varieties, without commercial corn flour, promotes a healthy diet. Meanwhile, Niebla recorded the best flavor, aroma, and freshness qualifications. However, HS-2 recorded better results regarding texture, flexibility, and reheated. In addition, HS-2 recorded better yield and B/C than Niebla and the other corn varieties. The purpose of this study was to help the SCL to take concrete actions in its consolidation process and to create a company that manufactures and commercializes tortillas. Consequently, the SCL would obtain a better price for its corn grains, avoiding intermediaries and generating a sustainable income with the transformation of corn grains into tortillas. The HS-2 variety is locally produced by the Colegio de Postgraduados and favors endogenous development.

Finally, a 60% HS-2 and 40% Niebla mixture should be evaluated for the preparation of tortillas, because, according to the results of the indicators of this study, they could complement each other in flavor and yield.

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Colegio de Postgraduados

Water Resources Management in Rural Communities of Northern Puebla

Juárez-Lucas, Plácido[1]; **Bustamante-González, Ángel**[2*]

[1] Colegio de Postgraduados campus Puebla. Centro Regional de Formación Docente e Investigación Educativa (CREDOMEX), Estancia posdoctoral CONAHCYT – Col. Barrio de San Antonio, Axapusco, Estado de México. aquilesleon807@gmail.com.

[2] Colegio de Posgraduados Campus Puebla. Santiago Momoxpan, Cholula, Puebla.

* Correspondence: angelb@colpos.mx

ABSTRACT

Objective: To identify the organizational forms that communities use to manage water, establishing the dialogical factors that communities build to strengthen their water-based ties.

Methodology: The study was conducted in eight communities of the Sierra Norte of Puebla. An action research approach was used to study community water management in eight auxiliary boards of the municipality of Ixtacamaxtitlán, state of Puebla.

Results: Seven water sources were identified, including one intercommunity source. The 8 auxiliary boards are built around these sources and they are organized to manage the home and irrigation water supply as a community. Differences in organization were identified depending on the land ownership type of the water source location, water fees, number of users, and years of management of the source.

Study Limitations/Implications: The mining conflicts in the study region limited field work.

Conclusions: Users have more access to water sources in ejidos than in small private properties. In the first case, water is considered a collective resource, while in the second case, water is a private resource.

Keywords: water, community, Sierra Norte.

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INTRODUCTION

Water availability and management in Mexican rural communities have characteristics that set them apart from the urban supply and management system. Community water management is related to a remarkable dissociation from the conventional water management exercised by the government. In rural communities, water management is based on community organizations, particularly water committees (Casas, 2015). Rural life involves a particular communal existence, in which individuals and communities are linked with nature, taking sociocultural actions and generating community organization around natural resources, mainly water (Quecedo and Castaño, 2002).

Rural communities, particularly those located in remote and marginalized regions, use their economic, technical, and human resources to tackle water supply requirements. Given the extremely local natural of these problems, they are seldom taken into account by the government and, consequently, this situation results in the self-management of water. Unlike the conventional water management in urban centers, community water management seeks a fairer water access among its members, even if those conditions sometimes involve water scarcity. Meanwhile, if external individuals try to take over this resource, the locals collectively defend their communal right to water (Sandoval and Günter, 2015).

Given the water-related environmental problem faced by rural communities, the inter-community cooperation and the cooperation with government institutions and academia is fundamental to improve community self-management. Such strategy would build participatory dialogues and actions for water management, based on the different social dimensions (importance, exploitation, and preservation) of water, with the aim of achieving a sustainable-compatible management for towns and communities (Foladori, 1999). The forms that communities use to organize their access to water must be discussed. These forms depend on land ownership, location, number of users, and the regional intercommunity history of the localities (Almagro and Venegas, 2009). Therefore, this research deals with the organizational complexity of eight communities of the municipality of Ixtacamaxtitlán, located in the Sierra Norte de Puebla. The objective was to identify the organizational forms of the community water management, taking into account the dialogical factors that the communities use to build their- water-based community links.

MATERIALS AND METHODS

Eight localities (auxiliary boards) of the municipality of Ixtacamaxtitlán, Puebla, were studied. The municipality of Ixtacamaxtitlán is located at 19° 27' and 19° 45' N and 97° 41' and 98° 03' W, at 2,000-3,400 m.a.s.l. The climate is subhumid temperate with summer rains. The region has leptosols, phaeozem, and lovisols (INEGI, 2010).

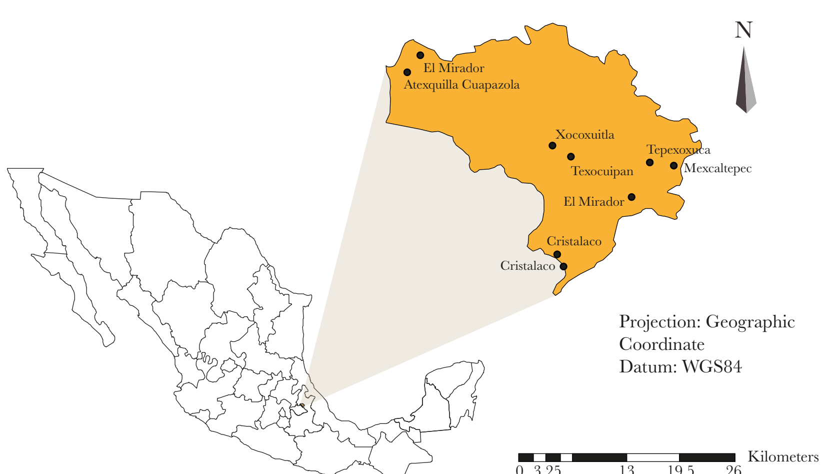

Figure 1. Location of the study area.

Data collection

In order to address the local water management problem, an action research approach was carried out (Fernández and Johnson, 2015). The collection of truthful data through traditional methods was not possible, as a consequence of the location of the study area and the environmental conflict background, related to the exploitation of water and mineral resources. The action research includes both qualitative and quantitative data and, consequently, was considered similar to mixed methods (Creswell, 2012). As part of the study, the research team observed and took part in the following activities: maintenance of pipelines, springs, and channel paths community meetings regarding drinking water and irrigation units; and restoration of channel infrastructure. In addition, community workshop and training activities were carried out. During these activities, the research team shared information leaflets about rights, duties, and sanctions regarding water and other natural resources. In addition, a PowerPoint presentation and videos were included, as part of a collective reflection process about the local water problem.

During the participation of the research team in these activities, authorities, former authorities, and current and former water committee members took part in semi structured interviews. The interviewees included: eight water authorities; eight former water authorities; 40 members of the irrigation committee (a chairperson, a secretary, a treasurer, and two assistants of the auxiliary boards); and 80 members of the irrigation committees from two previous periods. The interview guide was made up of the following variables: auxiliary board to which the interviewee belongs, water source access, water source name, length of use, participation in community committees (position), women participation as water users, awareness about water concessions, land ownership, water management differences between ejidos and small private properties, technical support, local organization, communal regulations about water use, water management, water use conflicts, water abundance or scarcity, and opinion about alternatives for the preservation of natural resources. In addition, data about water supply sources, communal name of the source, fees, land ownership, number of users, and year in which the supply source management started were collected from the community archives.

Data analysis

The information was systematized based on the records gathered from each auxiliary board and each community of the study. The tables provide information about water sources and community organization. The data obtained from the interviews were analyzed according to the subject.

RESULTS AND DISCUSSION

Community water sources and use characteristics

Springs are the water source of most of the communities (Table 1). Four communities (Xocoxiutla, Texocuixpan, Cristalaco, and El Mirador) share the same water supply source (Cerro Grande spring) and have a total of 1,196 users. This source is located in small private properties and, along with the Tzompantla spring, is one of the oldest water exploitation sites of the area. The fees go from MXN$100 to MXN$1,600 per year. In the case of Cerro

Table 1. Water source per auxiliary board. Source: Table developed by the authors.

Community	Water source	Community site name	Water tariff	Land tenure	Number of users	Start date of management
Tepexoxuca	Manantiales	Acatmaniteno	100 Mexican pesos per year	Private	16	1996
		Acatmanitzontan			24	1990
		Tipalan			270	178
Xocoxiutla	Manantial	Cerro Grande	450 Mexican pesos every six months	Private	192	1960
Texocuixpan	Manantial	Cerro Grande	360 Mexican pesos every six months	Private	356	1961
Cristalaco	Manantial	Cerro Grande	480 Mexican pesos every six months	Private	269	1980
El Mirador	manantial	Cerro Grande	200 Mexican pesos bimonthly	Ejido	379	1977
Mexcaltepec	Pozo	La Unión	800 Mexican pesos every six months	Ejido	473	1986
Atezquilla	Pozo	Atezquila	700 Mexican pesos per semester	Ejido	511	1976
Cuatexmola	Manantial	Tzompantla	240 Mexican pesos every six months	Ejido	221	1960

Grande, the annual fee is different for the users of the different auxiliary boards. Well water users pay higher fees, as a result of the higher operation cost of the supply system. These water fees fall into the range reported by Sandoval-Moreno and Günter (2013) for the rural communities in Jalisco (MXN$550-MXN$1,900 per year).

Ejido water management

Based on land ownership, water management has different characteristics in the communities. Ejidos are not just a land ownership type; they also are a particular community and collective organization, that includes water management. Therefore, the use of the natural resources found in ejidos is seen as a human right. Nevertheless, Ayala (2005) pointed out that this is not a right per se, but rather a personal and social duty. The water fees are relatively low; however, fees are compensated to a certain degree when users support the different water management activities.

Unlike water management in private properties, water plays a social cohesion and participation role in ejidos. Water users are more organized and they reach agreements by consensus. Consequently, as traditional participation forms, community meetings are fundamental to follow-up the resulting agreements. In Puebla, this decision-making body reaches consensus, which have a socially primary role in the communities (Reidl, 2012).

A high attendance and expression of opinion were found not just in the meetings, but also in water management community activities. According to these opinions, users timely pay water fees and are collectively open to look for any technical support they require.

Although the ejidos have different water fees, they share a social and participative water management. Water management capacity is a condition developed by towns, based on their internal dynamic and language: community codes are used to communicate with each other and gain access to water. Usually, those codes imply the compliance with certain duties. Consequently, the inhabitants of the region reach agreements in traditional ways (community meetings). The inhabitants themselves call or break up the social participation for any community work that must be done, because they know each other. This phenomenon suggests an arrangement of individuals with a similar mindset and interests. This type of logic usually leads to a power dynamic, where some individuals are more influential than others (Salgado, 2012).

Water management in small private properties

Some water bodies (such as springs) are located within private properties and, in most of the cases, owners do not share them with the rest of the community. For example, two private properties of the San Andrés Tepexoxuca community have springs; however, owners only use water for domestic purposes and do not share it with some nearby families that might need it. The rest of the inhabitants of the community get water from collective springs. Unfortunately, the number of users increases every year, reducing the capacity of the springs to appropriately meet the demand. In addition, the low rainfall rate of the last few years has become a growing concern for the population: they think it is not enough to recharge the springs. The inhabitants are aware of the important role that rain patterns play in water availability. According to the interviewees, the population has enough water during the rainy season, because they collect and store water from house leaks and the springs have a greater water volume. Meanwhile, the spring owners also have access to drinking water from the public water network and, consequently, they have greater water availability. Nevertheless, some owners are willing to share water from their springs with other inhabitants of the community. Members of the community said that this is a sign of humanity from the said owners. According to Abello (2009), more and more inhabitants of the localities are aware of the Ley de Aguas Nacionales. This law establishes that water is a property of the nation and, therefore, public service should be always favored over private water service.

Regarding the irrigation water management, private owners make a more rational use of water in some places. This situation is a result of the highly-efficient irrigation systems —such as pressurized underground irrigation and subsurface drip irrigation systems— employed by land owners.

Water management community organization

Table 2 shows the organizational variables related to community water management. Variations depending on social participation, water availability (domestic and agricultural use), and ongoing conflicts are the main cause of multi-communal social cohesion. In the communities under study, different organizational degrees regarding irrigation and drinking water were recorded. The local authorities of each management structure can occupy different positions such as *tepanero*, water carrier, pump leader, warden, irrigation secretary, drinking water chairperson, irrigation chairperson, network warden, and fee collector. Although the titles are different in every community, their duties are very similar. Based on the water availability of each community, the positions are established per hours, days, weeks, or as a permanent position (Table 2). The positions have been established to guarantee that all the members of the communities receive the same amount of irrigation and drinking water.

A major feature of community water management is the inclusion of women, both as users and decision-makers. Based on the accountability of water committee positions

Table 2. Water management community organization.

Auxiliary boards	Roles en la distribución del agua	Roles in water distribution	Type and frecuency of conflicts	Forms of community brotherhood
Tepexoxuca	Drinking water: Permanent	Mostly men	Damage to the pipeline	Not present
	Irrigation: 3 days, every 15 days per user		2-3 times a year	
Mexcaltepec	Drinking water: pumping every 4 days	Mostly women	Energy surcharges por late payments	Collaboration for forest restauration
	Irrigation: not available		Once a year	
Texocuixpan	Drinking water: pumping every week	Mostly women	Damage to the pipeline	Share trainings
	Irrigation: not available		3 times a year	
Cuatexmola	Drinking water: permanent	Mostly women	Damages to reservoirs	Collaboration against fires
	Irrigation: each week		1-3 times a year	
Cristalaco	Drinking water: every 3 days	Mostly women	Late payments	Collaboration against fires
	Irrigation: not avaliable		4 times a year	
Atexquilla	Drinking water: pumping every 4 days	Mostly women	Damage to pipes	Donation of pumping equipment
	Irrigation: every 20 days		Once per year	
Xocoxiutla	Drinking water: pumping every 2 days	Mostly women	Damages to reservoirs	Support for cleaninf of tanks and pipes
	Irrigation: not avaliable		Once per year	

and performance, a higher transparency regarding community economic resources was detected when women were in charge of the committees. According to Moscoso and Ortiz (2020), this is a key element for an improved water management that should also lead to the full inclusion of rural women in the management and decision-making processes of water organizations.

Water conflicts are frequent between users and communities, including clandestine water intakes and self-assignation of water volumes. Nevertheless, community brotherhood and sisterhood links develop in time, as a result of the distribution, preservation, and defense of water resources.

Water scarcity and adaptation strategies

Well water users from ejidos are more concerned than water spring users about the scarcity that could result from water depletion. Some users employ rainfed cultivation systems in their lands and they pointed out that they would like to change it for another irrigation system to avoid water scarcity. In some regions where water is scarce, people store it in cement or plastic containers to prevent evaporation. Meanwhile, in places where rains are very scarce, people usually work as construction workers, carpenters, blacksmiths, or shepherds, instead of growing vegetables.

Forest exploitation and its relationship with water

Ejidos manage forests based on their internal regulations, which rule the exploitation of common land and resources. Ejidos have governmental authorization for this type of exploitation. The Comisión Nacional Forestal (CONAFOR) is in communication with the regional ejido authorities to regulate and supervise forest exploitation and management. The interviewees are aware that the forest must be exploited depending on the age of the trees. The ejido forests occupy relatively small areas: the Mexcaltepec ejido has 739 ha, El Mirador has 943 ha, Atezquilla has 957 ha, and Cuatexmola has 1,346 ha. Five forest exploitation authorizations were identified in the following hills: Almeya, Cruz de León, Cerro Grande, Timimi, and La Fábrica.

In the case of community forests that are not found in ejidos, the interviewees indicated that the community itself own the forest. In order to exploit forest resources, the civil authorities call a meeting to inform the community that trees must be felled to meet a community need. Consequently, the community creates commissions whose members are in charge of the required tasks. The local population take part in collective activities such as making boards or planks from the trees that are cut down in the forest (Comisariado ejidal Tlalmotolo, 2023).

Community forest exploitation only takes place if the need for timber cannot be met any another way. This is an atypical and infrequent type of exploitation —unlike the ejido exploitation, which involves a relatively frequent management and exploitation. Consequently, forests under community management have more possibilities to regenerate than forests located in ejidos. However, unless a collective need justifies felling trees of an exploitable age, no cutting will take place without the permission of the community meeting.

The schools of the region try to raise awareness in children, youngsters, and adults about the importance of the preservation of forest resources for water conservation. The inhabitants of the communities are aware of the importance of maintaining the forests in good shape to guarantee the recharge of springs and wells. Most of the communities understand the importance of forest preservation and protection. Nevertheless, strong differences were found regarding the actual actions taken to protect the forests. In some localities, the owners of small private properties with small forest areas are concerned about the preservation and restauration of forests. In other communities, where most of the people own plots with hills, stopping excessive logging is not a concern. They argue that they can do whatever they want with their properties. This type of behavior is normal in communities with large forest areas, located at 2,700 m.a.s.l. The forest is the most important natural space in the municipality of Ixtacamaxtitlán. Given the semiarid conditions of most of the municipality, this situation is also a source of concern (Comisariado ejidal, Cuatexmola, 2023).

CONCLUSIONS

In the study region, community water management is based in organizational structures, collective participation forms, and individual traditions, in which women are not yet fully included as users and decision-makers. The diversity of the local water management is associated with the type of ownership of the land in which water sources are located, the type of supply source, and the availability of recharge areas (forests).

Ejidos allow users greater access to water sources than small private properties. The former is considered as a collective resource, while the latter is a private resource. The supply source type influences water fees: well water users pay a higher fee than water spring users.

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Colegio de Postgraduados

Assessing sustainability in Puebla's artisanal mezcal production: Insights from a composite indicator approach

Jaramillo-Villanueva, José Luis[1*]; García-Benítez, Erika[1]

[1] Colegio de Postgraduados, Campus Puebla. Boulevard Forjadores de Puebla No. 205, Santiago Momoxpan, C.P. 72760. San Pedro Cholula, Puebla. México.
* Correspondence: jaramillo@colpos.mx

ABSTRACT

Objective: To assess the sustainability of the artisanal mezcal production system in the state of Puebla using composite indicators.

Methodology: A sample of 42 producers and their artisanal mezcal production facilities, known as palenques were selected using the snowball sampling method. Data were analyzed using variance analysis (ANOVA), multivariate analysis, and regression analysis. The SAFA framework (Sustainability Assessment of Food and Agriculture) guided the selection of 17 indicators grouped into the economic, social, and environmental dimensions, to derive a Composite Sustainability Index (CSI) of each mezcal production unit. Analysis was conducted for the entire sample and clusters generated through cluster analysis.

Result: The average CSI for artisanal mezcal production (and its standard deviation) was 0.45 (0.2033), comprising economic (0.596, 0.2366), social (0.398, 0.2161), and environmental (0.437, 0.196) dimensions. ANOVA revealed significant differences in CSI between groups. The highest value of the CSI was obtained in the group of high-scale producers (0.539), followed by medium-scale (0.427), and low scale producers (0.393).

Conclusions: Artisanal production systems demonstrate low sustainability levels, impacted by limited training, excessive agave usage, and minimal recycling practices for inputs.

Keywords: agave, sustainability index, mezcal.

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INTRODUCTION

The production of artisanal beverages has gained significance in response to new market trends, as informed consumers increasingly seek sustainable products with a strong connection to their place of origin [1]. In this context, mezcal production is socioeconomically and culturally intertwined with the natural landscapes where it is crafted [2]. In Puebla, mezcal production reached nearly half a million liters in 2022, growing from an annual rate of 0.1% in 2014, and 2.5% in 2022, with an increasing share of 2.19%. This positive outlook is encouraging for the mezcal industry in Puebla, aiming to boost production to one million liters [3].

While these figures are economically promising, they also imply increasing environmental pressure on biodiversity, soil, and water resources. For this reasons, the mezcal industry has begun to consider actions to enhance the sustainability of agave and mezcal production [4]. There is a broad agreement that assessing the sustainability of agri-food systems must include social, environmental, and economic dimension [5].

Sustainability assessment

Unlike other methods focused solely on environmental and productive aspects, the SAFA framework offers a comprehensive approach that spans the entire production chain, from the agricultural production unit to the final consumers [6]. It adapts to diverse contexts and farm operation sizes. SAFA is based on three pillars —environmental integrity, economic resilience, and social well-being— that together form a unified definition of sustainability, structured into themes and subthemes for each pillar. Goals are established for each theme, with objectives defined for the subthemes. Within each subtheme, indicators are identified to set measurable criteria for sustainable performance. These indicators, applicable across various company size, types and contexts, provide standardized metrics to guide future sustainability assessments. For a detailed explanation of SAFA, refer to FAO (2014). IN SAFA, sustainability measurements rely on selecting indicator to form a composite index [7]. The rising demand for artisanal mezcal in Mexico and abroad, coupled with the mezcal industry's expansion plans, underscores the need to analyze the sustainability of mezcal production in Puebla. Therefore, this study aimed to evaluate artisanal mezcal production systems using synthetic indicators to create and index reflecting their sustainability levels.

MATERIALS AND METHODS

The research was conducted in rural communities in the state of Puebla, identified by key informants as significant centers of artisanal mezcal production. These communities included Cuautinchán, Tecali de Herrera, San Diego la Mesa Tochimiltzingo, Huehuetlán el Grande, and Tepeojuma.

Data were collected through in-depth interviews with key informants, guided by a structured questionnaire administered to a sample of 42 producers selected using the snowball sampling method. The questionnaire covered the following aspects: i) sociodemographic characteristics: age, sex, education, indigenous language, economic dependents, household members, generational succession, organization, off-farm activities, training, and technical assistance. ii) productive characteristics: production unit size, type of labor, land tenure, cultivation area, agricultural practices, agave varieties, income, and costs. iii) marketing: liters produced, price, marketing channels, and consumption characteristics; and iv) subsidies and support programs: input costs, water and energy used in the production process, as well as challenges and outlooks for mezcal production.

Stages in the construction of the composite indicator

The logical sequence proposed by Gómez-Limón *et al.* [9] was followed to construct the composite indicator, including the following stages:

1. Indicator selection. Seventeen indicators were selected to construct the Composite Sustainability Index (CSI) for the artisanal mezcal production units, integrating the three sustainability dimensions: economic, social, and environmental.
2. SAFA based selection criteria: indicator selection was based on SAFA principles, encompassing social well-being, economic resilience, and environmental integrity, as extensively described by the authors [6; 10; 11].
3. Multivariate analysis: Multivariate analysis was conducted to ensure no significant correlation existed between selected indicators and to identify groups of indicators for similar production units, facilitating result interpretation. Principal Component Analysis and Cluster Analysis were conducted using STATA 18 software.
4. Normalization: "Min-max" normalization was applied to standardize indicators into comparable units, with normalized values ranging from 0-1 [12]. For all indicators, zero indicates lack of sustainability, while higher values represent greater sustainability. Table 1 describes the selected indicator and each sustainability pillars.

Economic indicators

The following economic indicators were considered:

1. Profitability, represented by the benefit-cost ratio.
2. Sales contract, represents security in production sales, with a value of 1 assigned when the producer has a sales contract for their production.

Table 1. CSI indicators in mezcal production.

Index	Indicators	Minimum	Maximum	Media	Std. Dev.
Economic	1. Profit	0.5	2.7	1.78	1.089
	2. Revenue	−236.4	420.9	135.51	109.738
	3. Contracts	0	1	0.45	0.504
	4. Subsidy	0	1	0.64	0.485
	5. Certificated	0	1	0.46	0.447
Social	6. Employment	0	0.9	0.27	0.157
	7. Fam production	0.33	1	0.62	0.229
	8. Intergenerational	0	1	0.57	0.501
	9. Organizational	0	1	0.67	0.437
	10. Training	0	1	0.19	0.283
	11. Security	0	1	0.24	0.431
Environmental	12. Bio-fertilizers	0	1	0.38	0.492
	13. Water	2	50	18.75	9.153
	14. Wildlife	0	0.7	0.2	0.182
	15. Reciclyng	0	1	0.21	0.334
	16. Conservation	0.33	1	0.56	0.231
	17. Energy	0.33	1	0.48	0.279

Source: developed by the authors.

3. Subsidies, indicate the dependency of mezcal production on government supports, with a value of 1 assigned when the production unit does not receive subsidies.
4. Certification, reflects mezcal quality and ensures a better price. A score of 1 is given if the production holds and official certification.

Social indicators

The following social indicators were considered:

1. Family production, represents the degree of family labor used in the production process, measured by the number of family members participating in each stage.
2. Employment, represents job creation resulting from the production and marketing of mezcal; a higher number of family wages per liter produced suggests greater social sustainability.
3. Transgeneration, reflects the likelihood of preserving artisanal knowledge for future generations. If the master mezcalero is actively teaching the process, this indicator is rated highly.
4. Capabilities, represents the development level of the producer's skills in branding, production process, and marketing.
5. Work safety, indicates the likelihood of avoiding workplace accidents. If the palenque has a safety protocol in place along with essential equipment for handling emergencies (*e.g.*, fire extinguisher and first aid kit), this indicator is assigned a value of 1.

Environmental indicators

The following items were used as environmental indicators:

1. Conservation, assesses whether the producer engages in practices for soil conservation, water, and use of organic fertilizers.
2. Use of wild agave, reflects the levels of dependency on wild agave. If the production process does not rely or uses only a minimal amount of wild agave, this indicator receives a high value.
3. Recycling, considers whether the producer implements water recycling, rainwater harvesting, and waste treatment.
4. Energy sources, represents the type of energy sources used, classified by environmental impact level: zero (manual), low (animal or electric), or high (gasoline/diesel).

Production unit stratification

To enhance the analysis, a cluster analysis was conducted to categorize the *palenques*, resulting in three distinct groups.

RESULTS AND DISCUSSION

The results indicate that 93% of those responsible for the *palenques* are male, while 7% female. However, women participate in one or more stages of the production process, representing 50% of labor in tasks, such as collecting firewood, filling the oven, and performing distillation and fermentation activities. On average, 60% of those involved in the entire maguey-mezcal chain are men and 30% are women [13]. This distribution helps explain the presence of a mezcal women's organization in the study region. Additionally, 9.5% of the *palenque* leaders reported speaking an indigenous language.

The average education level was 9.0 years, which is similar to the state average of Puebla, of 9.2 years [14]. The study region also demonstrated a higher education level compared to the mezcal-producing regions in Oaxaca, where most palenque owners have only basic education [15]. This difference may be due to the higher marginalization in Oaxacan municipalities.

Mezcal production is predominantly artisanal, with 91% of mezcaleros following traditional practices. Among mezcal types, young mezcal is the most common (92%), though aged (3%) and ancestral mezcal (5%) varieties were also observed mezcal production relies on a mix of family and hired labor: 48% of production units combines both, 19% rely solely on family labor, and 33% exclusively on hired labor. On average, 248 workdays are required to produce 3,117 liters per year, with an average benefit-cost ratio (B/C) of 1.78. In comparison, a study of mezcal producers in Caltepec, Puebla, reported an IRR (internal rate of return) of 91.98% and a B/C ratio of 1.27 [16], with lower profitability attributed mainly to lower sales price.

Production unit stratification

The multivariate analysis identified three distinct strata of artisanal mezcal producers (Table 2): i) High production producers (PEA), ii) Medium production producers (PMP), and iii) Low production producers (PBP). These groups align with the typology established in previous studies [17]. All three groups share common characteristics, being artisanal producer with traditional production systems.

The PEA group has an average age of 56±13 years, with a maximum of 70. Their education level is above secondary school (9.8 years on average). They produce an average of 6,615 liters of mezcal per year, achieving higher profitability in mezcal sales (B/C of 2.7) compared to the PMP and PBP groups. Family labor represents 10% of their workforce, and this group has a higher training rate than the other two. They use 8.5 liters of water per liter of mezcal produced, with 30% of the agave being wild.

The PMP group has an average age of 47±9 years and education level averaging 8.2 years. They produce 2,514 liters of artisanal mezcal per year, with a B/C ration of 1.9. This group uses 20% wild agave and consumes 15.4 liters of water per liter of mezcal.

The PBP group produces 650 liters annually, with losses (−$128.91 per liter) and a B/C ration less than one, indicating lower profitability relative to the PEA and PMP groups. They use 30.8 liters of water per liter of mezcal, making them the least efficient stratum in this regard. The estimated CSI value for this group was 45.01, composted of economic (59.6), social (39.8), and environmental (43.7) dimensions. The PEA group showed a significantly higher average CSI compared to the PMPM and the PBP strata, which belong to the same group.

Table 2. Descriptive statistics of the stratification variables.

Variable	Estrata	Media	Std. Dev.	Minimum	Maximum
Rate of B/C	PEA	2.7	0.629	1.60	3.70
	PBP	0.8	0.480	0.10	1.40
	PMP	1.9	1.039	0.50	3.50
Profits ($/lt.)	PEA	200	104.95	62.6	420.9
	PBP	−129	229.77	−736.4	61.3
	PMP	59	113.66	−192.6	213.0
Labour use (%)	PEA	0.1	0.044	0.00	0.10
	PBP	0.3	0.206	0.10	0.90
	PMP	0.2	0.102	0.00	0.40
Experience (years)	PEA	26.7	17.951	2.00	56.00
	PBP	13.0	9.739	1.00	30.00
	PMP	33.0	17.236	2.00	55.00
Training index	PEA	0.4	0.348	0.00	1.00
	PBP	0.1	0.204	0.00	0.75
	PMP	0.1	0.137	0.00	0.33
Production volumen (lts)	PEA	6615	6979.59	2000.0	24000
	PBP	650	481.441	100.00	1800
	PMP	2514	1600.412	500.0	5000
Water use (Lt/mezcal lt)	PEA	8.5	5.298	2.0	18.7
	PBP	30.8	26.560	4.0	100.0
	PMP	15.4	9.408	3.5	37.5
Wild agave (%)	PEA	30.0	21.8	20.0	70.0
	PBP	50.0	13.1	30.0	70.0
	PMP	20.0	11.3	10.0	50.0

Source: developed by the authors using data from interviews, 2022.

The sustainability of the study units (*palenques*)

This study reveals substantial variability in sustainability indicators among artisanal mezcal producers. Three distinct strata were identified, differing in production volume, profitability, education, experience, and skills. Similarly, three production systems were identified in Miahuatlán Oaxaca, including subsistence, medium-scale, and low-scale producers, with significant differences observed [18].

The Composite Sustainability Index (CSI) is displayed in Figure 1. Among the dimensions, the economic indicator was significant ($p<0.01$), confirming that the mezcal production is profitable. Regarding the social index, producers' experience —reflected in their knowledge of artisanal mezcal production— showed significant differences in the PBP stratum, with an average subindex of 37.1 ± 18.5, higher in the PEA and PMP group. This resulted in highly significant differences in the overall index among the three groups ($p<0.01$). The environmental dimension also displayed notable differences, with the PMP group showing the highest significance (46.4 ± 23.64). The PEA group achieved

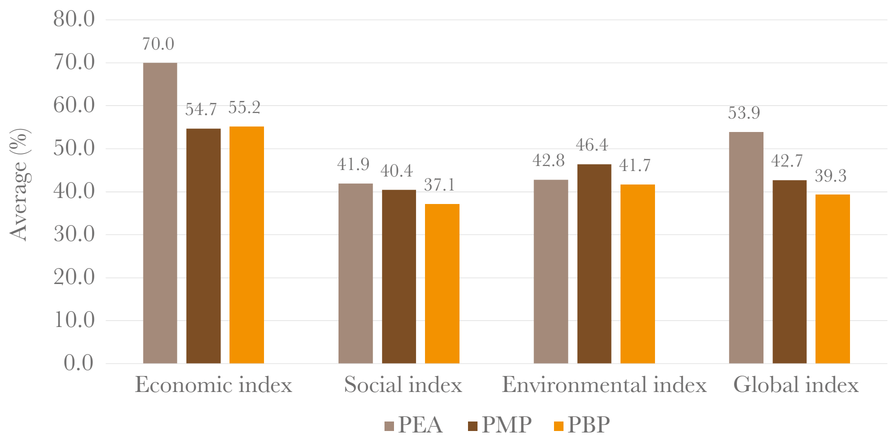

Figure 1. Sustainability index by strata and general (CSI).

the highest general index score (53.9), with a minimum sustainability level of 32.12 and maximum of 82.90.

CONCLUSIONS

Artisanal mezcal production was classified into distinct strata, with significant differences observed in terms of age, education, profitability, production process, and agave type. This diversity among mezcal producers is essential for designing targeted public strategies. The sustainability levels across the three pillars evaluated in this study was found to be low. Several aspects of the production process need substantial improvement, including reducing the reliance on wild agave, adopting more sustainable energy sources, and decreasing water use or implementing recycling processes.

The PEA group was distinguished by its extensive experience, higher profit per liter of mezcal, and lower water usage; however, it showed similar dependency on wild agave as the PMP and PBP groups. The PBP stratum, although producing a lower volume, demonstrated greater returns on investment compared to the PMP group, and utilized more labor in the production process than the PEA and PMP strata. Regarding the overall sustainability index, the PEA stratum scored higher than the PMP and PBP groups. Thus, the production system is in a transitional phase toward improved sustainability.

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Effects of nine monoculture agricultural systems on the fertility of an agricultural soil

Contreras-Ramos, Juan[1*], Díaz-Ruíz, Ramón[1], Pérez-Ramírez, Efraín[1]

[1] Colegio de Postgraduados, Campus Puebla, Boulevar Forjadores de Puebla No 205, Santiago Momoxpan, San Pedro Cholula, C.P. 72760, Puebla.

* Correspondence: jcontrerasr@colpos.mx

ABSTRACT

Objective: Determine and evaluate the effect of monoculture practices on the levels of seven soil fertility indicators.

Design/Methodology/Approach: Nine monoculture agricultural systems were evaluated, in completely randomized blocks with four repetitions, during the 2012-2016 period. The plot was divided into 9 sections with four repetitions, giving a total of 36 plots where the 9 local systems studied were distributed until the conclusion of the experiment in 2020.The SAS VS 9 system was used for the statistical analysis of the results.

Results: The results indicated that the agricultural systems changed the chemical characteristics of the soil, highlighting four monoculture systems that included legumes (beans and fava beans) or the corn-bean (MF) and corn-fava bean (MH) combinations, which improved the organic matter (OM), total N (TN), and P content of the soil.

Study Limitations/Implications: The small plots that were contaminated by the tillage actions of continuous treatments, caused the conclusion of the experiment. Everything indicates that treatments can be reduced and the size of the plots increased.

Findings/Conclusions: The results indicated that the agricultural systems changed the chemical characteristics of the soil, highlighting four monoculture systems that included legumes (beans and fava beans) or the corn-bean (MF) and corn-fava bean (MH) combinations, which improved the organic matter (OM), total N (TN), and P content of the soil.

Keywords: crops, availability, nutrients.

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INTRODUCTION

Soil is the main agricultural resource for the daily production of food, fiber, and other products that are directly required by the growing needs of 8.104 billion human beings and indirectly by pets, livestock, and industries; human population will exceed 9.730 billion in 2050 (FAO and ITPS, 2015). All agricultural soils are part of the ecological environment in which they evolve. Human needs have modified the nature of the soil: cultivation impacts its physical and chemical characteristics, modifies its original biodiversity, and alters its original native state (FAO and ITPS, 2015). Acevedo and Barajas (2022) analyzed the soils of the humid jungle, acahuales (*Helianthus* spp. or *Simsia* spp.), pastures, and crops systems in Chiapas and determined that pastures and crops promoted the degeneration of the original soil, compromising the functionality of the jungle ecosystem and altering the pH, organic matter, Phosphorus (P), and total Nitrogen (N) of the soil. For their part, Sellami and Terribile (2023) point out that agriculture-driven changes in land-use are usually negative, highlighting the intensity of tillage practices and inputs. Monocultures or low crop rotation cause the greatest deterioration in soil health and make agricultural activity more sensitive to climate change.

The Serdán Valley has sandy pumice-like soils, composed of albite and anorthite (with high Ca, Mg, and Na levels) of volcanic origin; their low fertility is not favorable for agricultural production (Pérez-Méndez, 2017). Therefore, local crops must be fertilized annually with N and P. However, the trend towards corn monoculture and the individual practices of producers makes it difficult to estimate the residual effect of chemical or organic additions from previous cycles. Therefore, the objective of this work was to determine and evaluate the effect of monoculture practices on the levels of seven soil fertility indicators.

MATERIALS AND METHODS

The study area consisted of plots located in the Instituto Tecnológico Superior of Ciudad Serdán, Chalchicumula de Sesma, Puebla. In the first 20 cm of depth, the local soils have an average apparent density of 2.4 g cm^{-3}, a cation exchange capacity (CEC) of 8 cmol kh^{-1}, a field capacity of 13%, and a wilting point of 7.2% (Pérez-Méndez, 2017). The organic matter of the soil is variable (0.5-2.5%), depending on the management employed by each producer. Corn monoculture predominates for environmental reasons (reduced rainfall and higher temperatures), incentives provided by government programs, and social and economic profitability.

Nine monoculture systems were studied from 2011 to 2016. The study consisted of completely randomized blocks with four repetitions and the following crops: corn (*Zea mays*), beans (*Phaseolus vulgaris*), fava bean (*Vicia faba*), and peas (*Psitium sativum*). The following treatments were used for this research: 1) ME (corn, 110 N-50 P_2O_5, 5 tons of cattle manure each year); 2) M135 (corn, 135 N-50 P_2O_5); 3) M110 (corn, 110 N-50 P_2O_5); 4) MC (control corn fertilized with 110 N-50 P_2O_5; this method is only applied in even years, because the crops grown on these local soils cannot be more than one cycle without fertilizer); 5) MF (corn-bean combinations fertilized with 110 N-50 P_2O_5); 6) MH (corn-fava bean combination fertilized with 110 N-50 P_2O_5); 7) bean (60 N-60 P_2O_5); 8) fava bean (40 N-40 P_2O_5); and 9) pea with 80 N and 40 P_2O_5 (Ps). The following varieties were used: Synthetic Serdán (corn) and local native varieties (other crops). The fertilization levels of the crops were those recommended in the area. Every year the treatments were applied in the same plots and with the same repetitions to ensure their effect on the soil. In 2011, one soil sample was taken and analyzed in the laboratory. In 2016, four soil samples were taken per treatment. Sampling depths in both periods were 0 to 20 cm and 20 to 40 cm. The NOM-021-RECNAT-2000 Official Mexican Standard (SEMARNAT. 2000) was used to determine the chemical parameters of pH, organic matter (OM), phosphorus (P, using the Bray 2 method), potassium (K), calcium (Ca), magnesium (Mg), and total nitrogen (TN). The statistical analysis of the results of the 2016 soil samples was carried out with the SAS VS 9 software, Tukey's mean differences

(DSH) were determined with an $\alpha=0.05$ probability and a Pearson correlation analysis was performed between the variables.

RESULTS AND DISCUSSION

The statistical analysis of the agricultural systems analyzed showed differences in the increase or decrease of the fertility variables under study. The results were compared with the differences in the means resulting from Tukey's test. The correlation is mentioned according to its importance as a covariate.

Organic matter, total N, pH

Organic matter (OM) had a high correlation with the electrical conductivity (EC, r=0.81) and total N (TN, r=0.93) variables. For this reason, only the OM variable was discussed (Table 1). In this Table 1, shows that the organic matter (T8, T5, T7, T9, and T6) and total N (T8, T7, T5, and T9) variables tend to increase in agricultural systems with legumes by themselves or in association with corn at the two depths studied. Organic matter (OM) was notably lower in the second layer of soil with treatments T6 and T8 (bean by itself or associated with corn) than in the first 20 cm of depth (Table 1). Therefore, the greatest OM increase in these two systems is caused by the loss in the superficial foliage layer (mainly of fava bean). The smallest increase in OM in the second soil layer occurs in T1, indicating that manure application only benefits the surface layer (although it was applied annually).

Phosphorus (P)

Soluble P was analyzed independently, considering the effect of legumes by themselves or combined with other crops on the availability of this nutrient in the soil (Table 2). An increase in soluble P was observed in the plots with the MF (T6) and MH associated crops, with P levels up to 100% higher than the rest of the plots, where corn monocultures predominated.

Table 1. Statistical analysis of the means of the soil fertility variables (pH, OM, and TN) that were studied in Serdán, Puebla (2016).

Variable	Unit	Initial value	Cultivation system studied								
			T1	T2	T3	T4	T5	T6	T7	T8	T9
			ME	M135	M110	MC	MF	MH	F	H	Ps
			Soil depth 0-20 cm								
pH	%	6.6	6.55 abc	6.55 abc	6.43 d	6.41 d	6.51 cd	6.75 ab	6.51 cd	6.67 abc	6.81 a
OM	g^{-Kg}	8.1	14.5 b	8.52 c	9.15 c	9.95 c	16.0 b	14.1 b	15.3 b	22.6 a	15 b
TN	%	0.1	0.13 b	0.08 d	0.08 d	0.08 cd	0.12 b	0.11 bc	0.12 b	0.18 a	0.12 b
Variable	Unit	Initial value	Soil depth 20-40 cm								
			T1	T2	T3	T4	T5	T6	T7	T8	T9
pH	%	6.6	6.85 bc	6.85 bc	6.84 bc	6.94 a	6.75 cd	6.5 e	6.79 bc	6.56 e	6.59 de
OM	g^{-Kg}	3.4	8.2 c	8.8 c	8.4 c	10.6 ab	16 a	9.8 ab	16 a	9.5 c	12.9 b
TN	%	0.06	0.08 c	0.08 c	0.09 c	0.10 bc	0.14 a	0.12 ab	0.14 a	0.09 c	0.14 a

Table 2. Statistical analysis of the means of the Phosphorus variable within the agricultural systems studied in Serdán, Puebla (2016).

Variable	Unit	Initial value	Cultivation system studied								
			T1	T2	T3	T4	T5	T6	T7	T8	T9
			ME	M135	M110	MC	MF	MH	F	H	Ps
			Soil depth 0-20 cm								
P	ppm	19.8	16.5 cd	5.5 d	15.7 cd	16.1 cd	30.7 bc	34.4 ab	45 ab	20.9 bc	46.1 a
			Soil depth 20-40 cm								
		8.96	20 c	8.7 c	19.8 c	21.4 bc	38.6 b	39.2 b	38.1 b	68.7 a	67.13 a

This study recorded a higher P availability in bean (T7) and pea (T9) monocultures. Soil P showed the greatest decrease with T2 in both soil layers, because a high N dose caused a greater removal of this nutrient from the crop. Therefore, not all corn biomass should be removed, given the potential deterioration in soil P levels.

Mohammed *et al.* (2018) pointed out that legumes require large amounts of energy provided by Phosphorus (P) to fix N, particularly in intercropping systems. Therefore, the activity of their root exudates (citrate, phosphatic acid, and release of $H+$ protons) stimulates microbial activity around them and contributes to the solubilization of P from the soil. According to Ibrahim *et al.* (2022), the availability of Phosphorus and other nutrients can be limited or favored by the interaction between the crop and its effect on biological activity, production systems, and cultivation practices. Despite what Lulu Wei *et al.* (2020) point out, the P available in the soil as a result of the application of manure (T1) was below the levels reached with the treatments with legumes by themselves or associated with corn (T5, T6, T7, T8, T9). This result implies the possibility of establishing more profitable corn-legumes-corn rotations or associations (such as MH and MF) to improve P availability.

K, Ca, and Mg

The analysis of means showed differences between the values of these three nutrients (Table 3). Pea (T9) recorded the greatest loss of this three nutrient in the soil: approximately

Table 3. Statistical analysis of the means of the K, Ca, and Mg variables that were studied in Serdán, Puebla (2016).

Variable	Unit	Initial value	Cultivation system studied								
			Soil depth 0-20 cm								
			T1	T2	T3	T4	T5	T6	T7	T8	T9
			ME	M135	M110	MC	MF	MH	F	H	Ps
K	pmm	931	473 ab	475 cb	530 ab	600 a	428 c	509 bc	548 ab	504 bc	301 d
Ca		2634	788 a	652 bcd	689 ab	673 ab	461 e	398 e	539 cd	523 cd	509 de
Mg		1888	538 bc	562 abc	591 abc	642 ab	421 de	349 e	428 ed	669 a	470 cd
			Soil depth 20-40 cm								
K	pmm	695	469 cd	396 d	514 bcd	591 b	585 bc	575 bcd	590 b	713 a	508 bcd
Ca		1139	764 b	729 b	679 b	704 b	1306 a	922 b	1434 a	667 b	1255 a
Mg		888.7	675 cd	575 d	617 d	706 bcd	914 abc	599 d	1015 a	528 d	941 ab

37% less than the original level. According to Akter *et al.* (2020), the flowering and grain filling of peas require adequate levels of K, Ca, and Mg; consequently, these nutrients showed the greatest reduction in this treatment. Therefore, a high availability of P in the soil was observed in the analysis (solubility effect of the roots and less removal by the crop).

In contrast, T9 had a greater loss of the K available in the soil, because this nutrient was not applied during the development of the experiment. The control (T4) recorded the lowest decrease in K, because it achieved the lowest development and yield; the demand for K was reduced, probably the plot was fertilized only once every two cycles. The ME treatment (T1) showed the greatest Ca increases with respect to the rest of the treatments and recorded one of the five best OM increases (Table 3). According to Lulu Wei *et al.* (2022), the continuous application of composted manure provides both nutrients to the crop and soil, improving other physical properties such as moisture retention.

Mg was relevant only for the fava bean monoculture (T8). The soluble Mg difference between beans (T7) and fava beans (T8) shows genetic mechanisms (*e.g.*, the metabolism of each species) that apparently modify the behavior of the roots of these two legumes, releasing this alkaline earth nutrient.

Correlation between P and K

The Ca, Mg, and K correlations were negative, with P/Ca, P/Mg, and P/K ratios of $r=-0.54$, $r=-0.49$, and $r=-0.34$, respectively. Individually, each of these correlations is not decisive, but their effect on the P immobilization in the soil is both individual and collective. Rodríguez-Camacho *et al.* (2021) point out that P moves in the soil solution mainly as primary orthophosphate (H_2PO_4), and secondary orthophosphate (H_2PO_4)= PO_4^{3-}. As organic phosphates enzymes, they are absorbed by the roots; therefore, the availability of this nutrient will be very likely reduced when its free electrons react with the positive charge of Ca or Mg in local soil minerals —including anorthite ($CaAl_2Si_2O_8$), albite ($NaAlSi_3O_8$), and other materials with abundant Ca, K, and Mg.

Comparison with other studies

Sangines *et al.* (2019) studied the long-term effects (1967-2016) on soil properties in an experiment in Agroscope, Switzerland, determining that changes were influenced by series of long wheat, turnip, and corn monoculture periods. Meanwhile, a higher organic matter content was recorded when these crops were grown in constant rotation.

CONCLUSIONS

The agricultural systems under study changed the chemical characteristics of the soil. Four agricultural systems stood out, both in bean and fava bean monocultures and the corn-bean (MF) or corn-fava bean (MH) combinations, improving the organic matter (OM), total N (TN), and soil P (P) content. Corn monoculture systems (T1 to T4) caused the greatest reduction in fertility variables. In conclusion, local monoculture practices will make corn yields increasingly dependent on the external application of nutrients, which is not beneficial, neither for soil nor producer health.

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Colegio de Postgraduados

Effect of bioinputs on milpa production, in three communities of the Sierra Nevada, Puebla

Macías-Laylle, Joaquín A.[1*]; **Sandoval-Castro, Engelberto**[1]; **Ocampo-Fletes, Ignacio**[1]; **Sobal-Cruz, Mercedes**[1]; **Morales-Almora, Porfirio**[1]; **Mendoza-Herrera, Adrián. J.**[2]

[1] Colegio de Postgraduados, Campus Puebla, Boulevard Forjadores de Puebla No. 205, Santiago Momoxpan, Municipio de San Pedro Cholula, C.P. 72760, Puebla, México.
[2] Investigador Asociado al Proyecto PRONACES-CONAHCYT.
* Correspondence: amacias@colpos.mx

ABSTRACT
Objective: To evaluate the effect of the Supermix bioinput on milpa yield, using local technologies practiced by producers from three communities of the Sierra Nevada.
Design/Methodology/Approach: The milpa —a polyculture that consists of maize, beans, and squash— provides a diversity of nutritious foods for families, with production ranges that are constant throughout the region. Applying bioinputs opens the possibility of improving these ranges. The Supermix was applied in five 30-m long rows in 9 producer-managed milpa plots, in order to carry out an exploratory measurement of its effect on the productive levels of the polyculture. For comparative purposes, the average yields of the milpa were estimated, both in the 5 rows in which the Supermix was applied and in the rest of the plot (control).
Results: In the three communities under study, the milpa produced in average 2.51 t of maize, 170.6 kg of beans, and 122.9 kg of squash seed per hectare; meanwhile, the control produced 2.57 tons of maize, 159.3 kg of beans, and 99.6 kg of squash seed. The total yield of the milpa system (sum of all products) to which the Supermix was applied was 2,804 kg ha^{-1}, while the control system recorded 2,828 kg ha^{-1}.
Study Limitations/Implications: Drought, pest damage, and previous bean harvests influenced the results.
Findings/Conclusions: The average yields of beans and squash to which Supermix was applied were higher than with the control, opening opportunities for innovation. Additionally, work in the milpa is mostly carried out by women.

Keywords: family farming, milpa polyculture, natural minerals, weeds.

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INTRODUCTION

Family Farming (FF) is a type of agricultural production that has been implemented since time immemorial and is the basis of the economy of many rural families and communities all over the world. Its main characteristics include: 1) limited access to land and capital resources; and 2) predominant use of family workforce (Rosette and Hernández, 2014). In Mexico, FF is practiced in approximately 81.3% of the Rural Economic Units (SAGARPA, 2012). Through this type of production, farmer families have managed to

develop highly complex production systems, such as the milpa system (MS) —known as the "Mesoamerican triad," because it is mostly composed of maize and several species of beans and squash (INIFAP, 2022), as well as chilis, tomatoes, weeds, and many other regional species (CONABIO, 2016). Several studies have proven the importance of the MS, highlighting its productive, social, economic, and environmental aspects. From a sustainability point of view, Aguilar-Jiménez *et al.* (2011) determined that this dynamic polyculture ecosystem favors beneficial environmental interactions, reflecting traditional agricultural lore and practices and preserving species diversity. Based on a study carried out in the municipality of Jesús Carranza, Veracruz, Ortiz-Timoteo *et al.* (2014) considered that a more efficient management of self-consumption crops could improve milpas. For their part, Ebel *et al.* (2017) determined that all combinations of maize, squash, and beans were superior to monocultures in Piedras Blancas, State of Mexico. Meanwhile, Briones-Aranda *et al.* (2024) studied the sustainability of a maize agroecosystem in Chignautla, Puebla, with two management systems, and determined that, with regard to most of the study variables, the polyculture maize system had better results than the monoculture. They concluded that maize polyculture has a greater tendency towards a sustainable management and highlighted the importance of revaluating this type of agroecosystems, since their productive potential strengthens food sovereignty. Families that participate in the milpa system have access to various nutrient-rich foods, income, and labor, just like in the municipalities of Atzitzihuacan, Cohuecan, and Tochimilco, in the Sierra Nevada, Puebla. According to CONAHCYT (2023), the food sovereignty of those municipalities is guaranteed by the percentage (21.57%) of the cultivation area of the production units (milpas). However, several factors —including the inadequate use of agrochemicals and the loss of soil quality— threaten the productive efficiency of the local milpas. In response to this issue, the aim of this study was to evaluate the effect of the Supermix bioinput on the yield of the milpa system in the Sierra Nevada region. This product is a mixture of ZeoFert™, leonardite, diatoms, and vermicompost. These organic products play a crucial role in agriculture, providing essential nutrients for plant growth and soil health. Aguilera and Morales (2011) produced ZeoFert™ combining zeolite with cattle manure, with the aim of measuring its effect on the yield of common beans and the chemicals properties of the soil. The results showed that its application significantly increased the yield of beans, the P_2O_5, K_2O, and organic matter content, and the pH of the soil. Espinosa *et al.* (2021) concluded that the use of ZeoFert™ increased the yield of tomato by ≈38%, as well as its quality (fruit diameter). Additionally, it increased the N, P_2O_5, K_2O, Ca^{++}, and organic matter content of the soil, as well as its pH values. Salvatierra (2024) studied the origin of leonardite-based humic and fulvic acids, as well as their extractive processes and their agricultural use. He evaluated their application as an alternative source of organic matter for the soil, determining that humic acids have a favorable effect on the development of new roots. Soriano-Rodríguez (2020) points out that diatoms are microscopic fossil algae, composed of a transparent silica cell wall and an internal pectin layer. Properly crushed, the skeletons of this unicellular algae turn into microscopic silicon needles, sharp enough to damage insects. Preciado-Muñoz (2024) points out that silicon nanostructures have become a promising agricultural alternative. Their novel properties optimize the use of the planet's natural resources, making them vehicles for the controlled delivery of active substances to the plant, including pesticides and fertilizers. Chatterjee *et al.* (2021) made vermicompost (VC) from agricultural waste and manure. They found that the application of VC to green chili crops improved their yield and quality; additionally, it improved soil fertility conditions, constantly providing a greater amount of nutrients, during the growth period of the plant. Mantuano-Morales and Zambrano-Gavilanes (2023) conducted an extensive literature review on the effect of VC in 11 crops and determined that VC is a microorganism-rich manure that provides assimilable nutrients to crops. It has positive effects on the soil and plants, allowing a good development and generating high productivity.

MATERIALS AND METHODS

The study was carried out in three communities: San Mateo Coatepec (Atzitzihuacan), San Francisco Tepango (Cohuecan), and Santiago Tochimizolco (Tochimilco). The Atzitzihuacan, Cohuecan, and Tochimilco municipalities have a surface of 130.203, 47.606, and 219.631 km^2, respectively (INEGI, 2017). They had 13,298, 5,283, and 19,576 inhabitants, respectively (Secretaría de Bienestar, 2024). The soil use in all three municipalities is mainly agricultural: 69.44% (Atzitzihuacan), 76.36% (Cohuecan), and 43.89% (Tochimilco). The study area is located in the foothills of the Popocatepetl volcano, in the Sierra Nevada of Puebla, a transitional zone between the subhumid temperate climate and the warm weather regions. Its favorable climatic conditions allow the growth of maize, beans, amaranth, chia, sorghum, and other crops. An agreement was reached in 2023 with 9 producers (4 men and 5 women) from these communities to generate direct field data, with the aim of following-up the management that farmers do to their milpa system plots. Each of these plots were labelled as Milpa Follow-Up Plots (MFP). As part of the second "task", the Supermix was applied to five 30 m long furrows in each of the nine MFP, to identify any differential response in the production levels. The Supermix was prepared with the following commercial products and doses: a) 500 kg ha^{-1} of ZeoFert™; b) 200 kg ha^{-1} of leonhardite; and c) 100 kg ha^{-1} of diatoms. The doses were taken from the technical information of each product provided by the manufacturer (Zeolitech, 2020). The three products were mixed with 2.5 t ha^{-1} of vermicompost. Table 1 shows the mineral content of the four products.

A series of variables (related to the maize, bean, and squash yield) were physically estimated in each of the 9 MFP to analyze their production, following the methodology proposed by Domínguez-Torres *et al.* (2022). The yield and plant density (DP) were estimated both in the 5 furrows treated with the Supermix and in the rest of the plot managed by the producer, using the control treatment.

RESULTS AND DISCUSSION

In average, the producers of the FF units were 53 years old (age range: 41 to 59 years). In terms of their education, 2 and 6 producers finished primary school and junior high school, respectively, while only one graduated from high school. All the producers stated that they were farmers, although 3 out of the 5 participating women declared that they were "homemakers/farmers". The nine participants sowed in average 0.37-ha milpas, with

Table 1. Mineral content of each component of the Supermix (kg ha^{-1}).

Product/ composition	N	P_2O_5	K_2O	CaO	SO_3	SiO_2	MgO	Humic and fulvic acids
Zeofert	19	47	10	80	15	0	17	0
Leonhardite	8	0	9	3	0	0	2	36
Diatoms	0	0	0	0	0	82	0	0
vermicompost	15	47	45	0	0	0	38	250
Total	42	94	64	83	15	82	57	286

Source: Table developed by the authors based on the technical information for each product.

a maximum of 1.2 ha and a minimum of 0.10 ha. In fact, 4 producers sowed a single 10-ha "task," while 2 producers sowed 5, 4, and 3 "tasks," equivalent to 0.50, 0.40, and 0.30 ha, respectively. Regarding fertilization, 7 producers informed that they used Diammonium phosphate (DAP) in the first "task" and urea in the second. Two producers used cattle and sheep manure mixed with the NPK formula known as "Triple 16". The producers applied various fertilizer doses: 72 to 230 N units, 36 to 180 P_2O_5 units, and 0 to 36 K_2O units. The average NPK doses was 157-84-06. Given the exploratory nature of this study, no field demonstration of the effect of the Supermix was carried out. However, one producer requested information about the bioinput and how to get hold of it. The producer was informed that, during the first year, the research team would help the producers to get hold of the commercial products and would train them in the preparation of the mix. Since the economic aspect was not part of the study, the Supermix and the control treatments were not compared in this regard. Nevertheless, the mix would cost $1,316 Mexican pesos per "task" (0.10 ha). Meanwhile, in terms of production results, the plant density per ha fluctuated between 28,500 to 55,000 maize plants, 1,500 to 22,917 bean plants, and 320 to 3,000 squash plants. The yield per ha ranged from 0.99 to 7.54 t of maize, 20 to 365 kg of beans, and 26 to 243 kg of squash seed (Table 2).

Table 3 shows the yields and average range per crop achieved with the Supermix and control treatments in the three communities. The average maize yield was similar under both conditions: 2.57 t ha^{-1} (control) and 2.51 t ha^{-1} (Supermix). Finally, the average yield of maize and beans in San Mateo were higher than in the other two communities, unlike the yield of squash.

The average difference between beans in the three communities does not seem to be significant with the Supermix (170.6 kg ha^{-1}) and the control (159.3 kg ha^{-1}). However, the atypical data recorded in Tochimizolco (282 kg ha^{-1}) perturbed the average results. For its part, the response of beans to the Supermix in San Mateo was higher in all cases (340 kg ha^{-1}) and was 45% higher than the control (190 kg ha^{-1}). In the case of the average yield of squash in the three communities, the Supermix recorded more seeds (122.8 kg ha^{-1}) than the control (99.66 kg ha^{-1}). Based on the analysis of the yield data per treatment and community, production almost doubled with the Supermix, both in San Mateo and Tepango. Meanwhile, the highest average yield of squash seed in Tochimizolco was obtained with the control: the plant density (PD) of squash in plot No. 7 recorded 2,000 specimens with the Supermix treatment, while the control reached 3,000 plants (Table 3). Based on

Table 2. Plant density and yields per crop and treatment in the 9 MFP (2023 agricultural cycle).

Community	Number of MFP/treatment	Maize plants ha^{-1}	Maize t ha^{-1}	Beans plants ha^{-1}	Beans kg ha^{-1}	Number of squash ha^{-1}	Pumpkin seed kg ha^{-1}
San Mateo	1 Supermix	48,367	7.54	16,531	**	1,224	99
San Mateo	1 control	38,095	6.08	16,190	**	952	77
San Mateo	2 Supermix	31,667	3.02	17,917	315	1,250	101
San Mateo	2 control	36,957	3.72	16,522	190	435	35
San Mateo	3 Supermix	42,083	1.61	22,917	365	667	54
San Mateo	3 control	44,800	1.77	22,400	190	320	26
Tepango	4 Supermix	40,889	2.03	12,000	123	***	***
Tepango	4 control	41,333	2.37	12,000	125	***	***
Tepango	5 Supermix	50,000	1.58	*	*	2,500	203
Tepango	5 control	55,500	1.54	*	*	1,000	81
Tepango	6 Supermix	33,778	0.99	8,000	**	*	*
Tepango	6 control	36,444	1.01	9,333	**	1,778	144
Tochimizolco	7 white maize Supermix	45,333	1.47	12,000	58	*	*
Tochimizolco	7 control	42,000	2.14	10,667	127	*	*
Tochimizolco	7 red maize Supermix	37,000	2.73	*	*	2,000	162
Tochimizolco	7 control	43,000	2.69	*	*	3,000	243
Tochimizolco	8 Supermix	41,500	1.31	9,000	20	500	41
Tochimizolco	8 control	32,381	1.11	8,571	79	*	*
Tochimizolco	9 Supermix	28,500	2.32	1,500	69	500	41
Tochimizolco	9 control	35,714	2.94	8,095	282+	476	39

Source: Table developed by the authors based on field data from the 9 MFP. *Not sown/Undetected. **Previously harvested. ***Damaged by badgers. +Atypical data.

the analysis of the average production in all the milpa systems of the three communities, the Supermix (2.804 t ha^{-1}) and the control (2.828 t ha^{-1}) treatments were determined to have similar results, through the summation of the grain yields for the three species. However, the treatments per community and between communities have major differences. The Supermix and the control treatments recorded the highest results in San Mateo, with 4.485 and 4.096 t ha^{-1}, respectively. The yields were similar in Tepango. Meanwhile, in Tochimizolco, control was apparently higher than Supermix; however, both the bean and squash yields in this community were atypical, as a consequence of the specific conditions of the follow-up plots. Given the management of each MFP under natural conditions, crops faced several major limitations. Additionally, various circumstances influenced the study cases. In Tepango, more than half of the plot was damaged by badgers (*Nasua narica* L.). Some producers did not sow some of the crops. Other producers harvested beans earlier, in response to atypical rains in late autumn. A control treatment in a plot from Tochimizolco recorded an atypically high bean yield. Another major event that impacted the production results was the severe drought that took place in September, when bean pods were still growing and maize was fully developing its grains. This drought mainly impacted the municipalities of Cohuecan and Atzitzihuacan.

Table 3. Yields and average range of the milpa polyculture per treatment and community (2023 agricultural cycle).

Cultivation/Treatment	San Mateo	Tepango	Tochimizolco	Average yield for the three communities
Maize Supermix (t ha^{-1})	4.06	1.43	1.96	2.51
Ranges	1.6-7.6	1.0-2.03	1.29-2.75	1.0-7.6
Maize control (t ha^{-1})	3.86	1.64	2.22	2.57
Ranges	1.8-6.1	1.01-2.35	1.11-2.92	1.01-6.1
Beans Supermix (kg ha^{-1})	340.0	123.0	49.0	170.6
Ranges	315-365	123-123	20-69	20-365
Beans control (kg ha^{-1})	190.0	125.0	162.70+	159.3+
Ranges	190-190	125-125	58-282+	58-282
Pumpkin seed Supermix (kg ha^{-1})	84.81	202.50	81.33	122.9
Ranges	54-101	144-203	41-162	41-203
Pumpkin seed control (kg ha^{-1})	46.10	112.51	140.78+	99.7
Ranges	26-77	81-81	39-243	26-243
Milpa polyculture Supermix Total grain production (t ha^{-1})	4.485	1.755	2.090	2.804
Milpa polyculture Control Total grain production (t ha^{-1})	4.096	1.877	2.524+	2.828+

Source: Table developed by the authors based on field data from the 9 MFP. +Atypical data.

Based on the analysis of the data of the 9 MFP, the total yield of the milpa system with the control treatment was 2.828 t ha^{-1}; meanwhile, the Supermix bioinput reported 2.804 t ha^{-1}. Therefore, control had a favorable difference of 76 kg. The milpa species of each plot obtained the following average yields: 2.54 t ha^{-1} of maize, 0.165 t ha^{-1} of beans, and 0.111 t ha^{-1} of squash seed. For comparison purposes, the results for squash seeds were converted into squash fruit, obtaining a 2.8 t ha^{-1} yield, based on an average 0.041 fruit-to-seed conversion factor. In this context, Ebel *et al.* (2017) proved that the maize, beans, and squash (fruit) polyculture can yield up to 7.9, 1.9, and 6.2 t ha^{-1}, respectively; therefore, the results for the 9 MFP were below the figures reported by the said research team. For their part, Rojas-Victoria *et al.* (2017) studied the yield of the association of ayocote beans and maize and, based on the number of plants per plot, determined that plant density improved the yield of both crops and that, in terms of production levels, milpas recorded better results than monocultures. Therefore, studying several technical management variables in Sierra Nevada may result in significant innovations for family farming. Since this was an exploratory study, checking management variables was discarded. Given the importance of milpas in the Sierra Nevada region, the yield obtained by local producers was documented and compared with the yield resulting from the application of the Supermix in a part of their plots. Finally, the plant density and the yield of beans and squash had a positive relation. In the case of maize, MFP 1 recorded 7.54 t ha^{-1} with the Supermix, while control reached 6.08 t ha^{-1}, resulting in a difference of 1.47 t ha^{-1} in favor of the former. The MFP 1 producer used an improved maize variety in her plot. Therefore, her production averages were also much higher than the averages of the rest of the producers. The analysis of the overall milpa system (three-crop sum) showed an analogous grain production in the whole system, except for one community. Therefore, the Supermix bioinput would seem to have no effect at all. However, the community and intercommunity analysis showed that the said input does have positive effects. During the knowledge exchange workshop, one of the producers (Judith Torres, 2023, personal communication) said that: "The use of organic fertilizers is effective for the milpa, although it is a little slow, it is very beneficial for human health, because my family consumes a 100% of fresh products and grains that I harvest from my plot." Meanwhile, another producer (Victor Casique, 2023, personal communication) considered that "…using organic products is important for soil recovery, if we use chemical fertilizers or products every year, the soil becomes thinner, higher doses will be required every time to obtain a satisfactory effect in the soil, meanwhile, organic products have more benefits, because, for starters, the soil can recover, and we improve it, so we can get better harvest in the following years, as the life in the soil increases..."

CONCLUSIONS

The Supermix and the control treatment had a similar result regarding the total yield of the milpa. However, the bioinput had a positive effect on bean and squash yields. In the case of maize yield, the Supermix only had a positive effect in the plot of the producer who sowed an improved variety. Additionally, women had a major participation in the management of the milpas in the region. In view of the results, further experimental studies must be carried out under the natural conditions of the Sierra Nevada producers, in order to develop local production technologies. This type of participatory experiences with producers leads to an enhanced productivity, through good agroecological practices, and contributes to the safekeeping of both their livelihood and the cultural hold of the milpa system in the region.

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Thrips species (Thysanoptera: Thripidae) and their abundance on avocado (*Persea americana* Mill.) in Tetela del Volcán, Morelos, Mexico

Jerónimo-Hernández, Fabiola[1]; Morales-Galván, Oscar[2]; Gutiérrez-Rangel, Nicolás[1]; Cruz-Hernández, Javier[1]; Duran-Peralta, Elisa[1]; Huerta-de la Peña, Arturo[1*]

[1] Colegio de Postgraduados – Campus Puebla. Maestría en Desarrollo e Innovación en Fruticultura Familiar, Bulevar Forjadores de Puebla Núm. 205. Santiago Momoxpan. Municipio de San Pedro Cholula. C.P. 72760, Puebla, México.

[2] Universidad Autónoma Chapingo, Departamento de Parasitología Agrícola, km 38.5 Carr. México-Texcoco, Chapingo, Edo. de México C.P. 56230.

* Correspondence: arturohp@colpos.mx

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ABSTRACT

Objective: To determine the thrips population behavior found in two avocado orchards and their distribution over time.

Design/Methodology/Approach: Twenty trees were sampled from each orchard. Four 1.5-2 m tall inflorescences or plant sprouts (covering all four cardinal points) were taken randomly from each tree. Insects collected in the field were quantified and characterized in the laboratory. Thrips were identified based on their morphological characteristics. Analysis of variance and comparison of means were carried out. Various simulations were also performed to determine the number of predatory thrips that should be released to control the pest population.

Results: Two phytophagous thrips species (*Frankliniella difficilis* and *Scirtothrips perseae*) and two predatory thrips species (*Frankliniella difficilis* and *Leptothrips* sp.) were identified in Orchard 1. In Orchard 2, only phytophagous thrips *(Frankliniella difficilis* and *Scirtothrips perseae*) were identified. Releasing 525 predatory thrips would control the initial pest population in the study orchards.

Study Limitations/Implications: Further research should be carried out regarding the use of morphological identification, which by itself may result in an underestimation of the specific diversity of thrips.

Findings/Conclusions: Only phytophagous thrips species were initially identified in this study, while predatory thrips species were subsequently observed. The simulation indicated that the number of predators was insufficient to control the pest population.

Keywords: predatory thrips, *Franklinothrips* sp., *Leptothrips* sp., phytopathogenic thrips.

INTRODUCTION

Avocado (*Persea americana* Mill.) is a highly sought-after crop in Mexico and across the globe. Its production is impacted by various factors, including climate, soil type, water availability, fertilization, and pest management (CESAVEM, 2010). One of the main insect pests is order *Thysanoptera*, which can be divided into four major species: *Frankliniella*, *Neoliydatothrips*, *Scirtothrips*, and *Pseudophilothrips* (Urías-López *et al.*, 2007). At high densities, thrips can damage leaves, flowers, and fruit. They induce leaf rolling and defoliation and hinder fertilization and cause flower drop. When they attack fruit at an early stage, they can cause scarring, deformation, and fruit drop (Ascensión, 2000). The most common method for controlling this pest is the

use of chemicals (Dughetti, 1990). However, this approach has led to the emergence of resistance and a negative environmental impact. Therefore, alternative strategies should be considered, including the introduction of predators, which can satisfy their nutritional requirements and compete for space on the plant (Lacasa and Llorens, 1998). In Mexico, the ten species of predatory insects known to infest avocado agroecosystems include *Aelothrips mexicanus*, *Franklinothrips vespiformis*, and *Leptothrips mcconnelli* (Johansen *et al.*, 1999). Thrips have six or more generations per year (University of California and Natural Resources, 2008). Thrips population behavior should be anticipated to implement an effective control strategy (López *et al.*, 2022). Thrips that attack avocado plantation have natural thrips predators, which enables the development of biological control strategies. The objective of this study was to determine the population behavior of thrips species found in two avocado orchards, as well as their distribution over time.

MATERIALS AND METHODS

Thrips were collected in two Hass avocado orchards in Tetela del Volcán, Morelos. The first orchard was located at 18° 52' 46" N, 98° 42' 48" W, and 2,130 m.a.s.l. The second was located at 18° 54' 38" N, 98° 42' 19" W, and 2,400 m.a.s.l. The specimens were identified in the entomology laboratory of the Department of Agricultural Parasitology of the Autonomous University of Chapingo. Weekly samplings began on January, with the objective of recording the presence or absence of thrips. Once the populations were detected and collected, they were taken to the laboratory, where they were counted per sampling date and classified into families, genera, and species. Three monthly samples were taken from February to April, 2023. Foliage samples were collected to determine the thrips population behavior associated with avocado. Samples were taken from five rows with four trees each. Trees between four and eight years old, in vegetative growth and flowering stage, were selected. The distance between the trees was 5×4 meters (m). Four 1.5-2.0 m tall inflorescences or plant sprouts, distributed across all cardinal points, were randomly selected from each tree. The inflorescences were sprayed with a 9:1 solution of water and Vel Rosita® fabric softener. The dripping from each tree was collected in a plastic tray and subsequently poured into a bottle containing 70% methanol. The samples collected in the field were transported to the laboratory, where they were sieved to recover and count the captured specimens. They were then quantified according to the date of evaluation (February 26, March 5, and April 1, 2023). From each jar, thrips were separated and counted, mounted in a slide with Canada balsam in accordance with the Mound and Marullo technique (1996). The thrips were identified based on their morphological characteristics, at the suborder and family levels, using the taxonomic keys of Triplehorn and Johnson (2005). The genera and species taxonomic keys proposed by Mound and Marullo (1996) were used to define the species. The observations and population size counts were made in accordance with the number of phytophagous and predatory species collected per sample. The proportion of thrips species was calculated using the row count. The error normality and homogeneity of variance were also verified before the analysis of variance. The analysis considered two sources of variation (thrips species and counting date). The results showed differences in both sources. Consequently, a comparison of means was performed using the LSD (Least Significant Difference) method. Statistical analysis was carried out with R and RStudio software. A simulation of the growth of *Franklinothrips* and *Scirtothrips* on avocado was also conducted, incorporating data on daily maximum and minimum temperatures, obtained from the weather data reported by a National Meteorological Service station located in the municipality of Tetela del Volcán, Morelos.

Simulation

The Fortran Simulation Translation (FST) software was employed to simulate the dynamic predator-prey model for *Franklinothrips* and *Scirtothrips* on avocado (López *et al.*, 2022). The model input variables employed were daily maximum and minimum temperatures. Using this data, the model calculates the daily temperature dynamics (T, °C) and subsequently the development, oviposition, and mortality rates. The initial conditions for the simulation were the number of eggs or adults in both populations (*e.g.*, 1,000 phytophagous thrips and 500 predatory thrips) and zero individuals for the other developmental stages.

RESULTS AND DISCUSSION

In February, the presence of *Frankliniella difficilis* was confirmed in orchard 1. One month later, the presence of *Frankliniella difficilis* and *Scirtothrips perseae* was recorded, along with the predator *Franklinothrips* sp. Finally, in April, *Frankliniella difficilis*, *Scirtothrips perseae*, *Franklinothrips* sp. were still present, accompanied by *Leptothrips* sp. In contrast, only the *Frankliniella difficilis* and *Scirtothrips perseae* phytophagous thrips were observed in orchard 2. The latter species, native to Mexico, is widely distributed in Hass avocado orchards in Michoacán, Mexico, and in California, USA (Rugman-Jones *et al.*, 2006).

This study identified one of the biological control species, *Leptothrips* sp. In a taxonomic review of 41 *Leptothrips* species in the Americas, Johansen (1987) identified the scarcity of immature individuals in the wild as the main challenge for the study of its biology.

The orchard under study was free of weeds, as a result of the agronomic management of the grower. Valle de la Paz *et al.* (2003) pointed out that thrips species diversity is associated with weeds in avocado orchards, particularly Asteraceae flowers —such as *Tithonia tubiformis* (79- 920 thrips per head) and *E. karvisnkianus*, (30-102 individuals per head).

On the first day that thrips were found in the orchard, an average of 9 phytophagous thrips were recorded per shoot sampled (*i.e.*, 720 thrips on the sampled trees). Some predatory thrips were also found during the study. Based on the total number of pests and biological control thrips, various simulations were run to determine the number of predatory thrips that would need to be released to control the pest population. Therefore, to control the initial pest population, 525 predatory thrips should be introduced in the sampled orchard. This figure is dependent on the biological control efficiency of the predator species in question. *F. orizabensis* is a generalist predator of arthropods and attacks first and second instar larvae of *S. perseae*. It can consume approximately 20 larvae in a 24-hour period; however, it also feeds on avocado pollen in the absence of prey (Hoddle, 2003). The release of *F. orizabensis* does not achieve the desired preventative pest control when *S. perseae* populations are low (<5 larvae per leaf). The insects died with 14 to 23 accumulated degree days, when food was absent or present in small quantities. Therefore, Hoddle *et al.* (2004) did not recommend preventative releases of mass-reared *F. orizabensis* for the control of low densities of *S. perseae* in avocado orchards in southern California.

Laboratory and field studies have proven that *F. orizabensis* dies when it feeds on avocado leaves treated with insecticides exhibiting translaminar activity (Hoddle, 2003).

The analysis of variance shows significant discrepancies between the two sources of variation for the thrips species and dates (Table 1). A comparison of the means for the various thrips species revealed two distinct groups (Table 2). Group A consisted of a higher proportion of the *Frankliniella difficilis* species, while the other species were included in Group B. A similar comparison by sampling date also resulted in two groups (Table 3). Group A showed the highest presence of thrips in the February sampling date, while Group B included the March and April sampling dates.

Figure 1 illustrates the simulation of the behavior of the *Scirtothrips* sp. phytophagous thrips and the *Franklinotrips* sp. predatory thrips, based on the initial population of these species observed during the sampling. Therefore, the population of phytophagous thrips initially increases and the predatory thrips subsequently emerge and its population increases in line with field observations made during the study. After approximately 30

Table 1. Analysis of variance of thrips species and sampling dates in Tetela del Volcán, Morelos.

Source	Degrees of freedom	Sum of squares	Mean square	F	P-value	
Species	3	24168	8056	37.320	3.36e-13	***
Sampling date	2	1908	954	4.419	0.0167	*
Residual	54	11657	216			

Significance level: 0‘***’ 0.001‘**’ 0.01‘*’ 0.05‘.’ 0.1‘’

Table 2. Comparison of means per thrips species.

Species	%	Groups
Frankliniella difficilis	47.27	a
Scirtothrips perseae	2.27	b
Franklinothips sp.	0.53	b
Leptothrips sp.	0.07	b

*Same letter in a column means that there is no significant difference.

Table 3. Comparison of means of sampling dates.

Date	%	Groups*
February	18.75	a
March	13.75	b
April	5.10	b

*Same letter in column means that there is no significant difference.

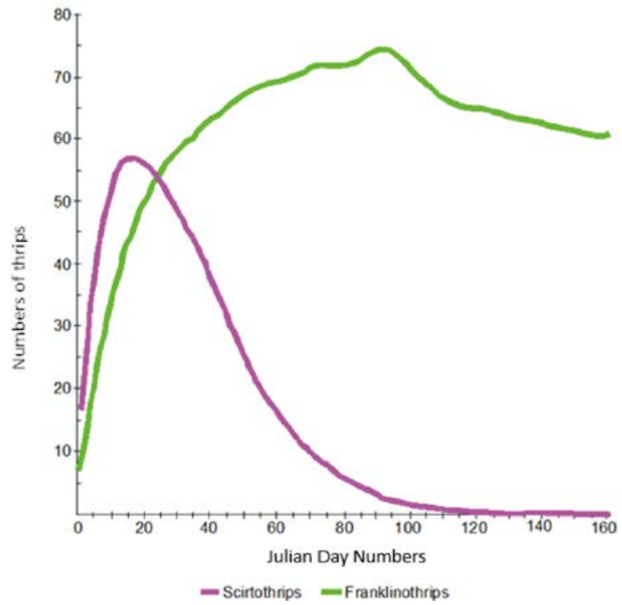

Figure 1. Simulation of phytophagous thrips (*Scirtothrips* sp.) and predatory thrips (*Fraklinotrips* sp.), considering the population recorded in the sampling.

days, the number of pest insects and predatory thrips is roughly equal. Finally, the pest population begins to decline. The predator population continues to grow for a few days, but it also starts to decrease, in the face of the absence of its prey.

CONCLUSIONS

The initial findings of this study indicated the exclusive presence of phytophagous thrips species, while predatory thrips species were detected in subsequent observations. The simulation demonstrated that the number of predatory thrips was insufficient for an effective control of the pest population. The *Frankliniella difficilis* and *Scirtothrips perseae* phytophagous thrips species, as well as the *Franklinothrips* sp. and *Leptothrips* sp. predators, were identified in the field. Further laboratory and field studies are required to assess the effectiveness of predator species. The simulation determined the number of predatory thrips required to control the initial population of thrips pests. This research must be followed up, as using only morphological identification may have underestimated the specific diversity of thrips.

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Colegio de Postgraduados

Behavior and management of thrips population using biorational insecticides in avocado (*Persea americana* Mill.) trees

Figueroa-Gallardo, Josué E.[1]; **Duran-Peralta, Elisa**[1]; **Aragón-Gutiérrez, Carlos**[1]; **Huerta-de la Peña, Arturo**[1]; **Morales-Galván, Oscar**[2]; **Gutiérrez-Rangel, Nicolás**[1*]

[1] Colegio de Postgraduados – Campus Puebla. Maestría en Desarrollo e Innovación en Fruticultura Familiar, Buulevar Forjadores de Puebla Núm. 205. Santiago Momoxpan. Municipio de San Pedro Cholula. C.P. 72760, Puebla, México.

[2] Universidad Autónoma Chapingo. Departamento de Parasitología Agrícola, km 38.5 Carr. México-Texcoco, Chapingo, Edo. de México C.P. 56230.

* Correspondence: ngrangel@colpos.mx

ABSTRACT

Objective: To evaluate the effectiveness of biorational insecticides to control thrips and to provide alternatives that reduce the negative environmental impact of chemical pesticides on the management of avocado tree.

Design/Methodology/Approach: Using a randomized complete block design with four replicates, the following five treatments were evaluated: T1) control (water); T2) chicalote (*Argemone mexicana* L.) extract; T3) neem (*Azadirachta indica*) oil extract; T4) potassium soap (potassium salts); and T5) Spinosad (Spinosyn A and Spinosyn D). Each product was applied in its own row. Treatment rows were separated by a row of trees to which no treatment was applied. Samples were taken in different dates from plant and floral sprouts of four randomly selected avocado trees. Each tree was an experimental unit.

Results: The data obtained did not comply with the normality test and the homogeneity of variance; consequently, the data were subjected to a General Additive Model (GAM). The most efficient treatments were neem oil extract and Spinosad.

Study Limitations/Implications: Different orchards, with different initial pest populations, should be evaluated to determine the level of infestation in which the application of biorational products is still feasible for pest control.

Findings/Conclusions: Plant extracts have high potential to control thrips in open-air avocado plantations; consequently, they could be an alternative to the application of synthetic insecticides for pest management.

Keywords: Sustainable management, pesticides, pests, plant extracts.

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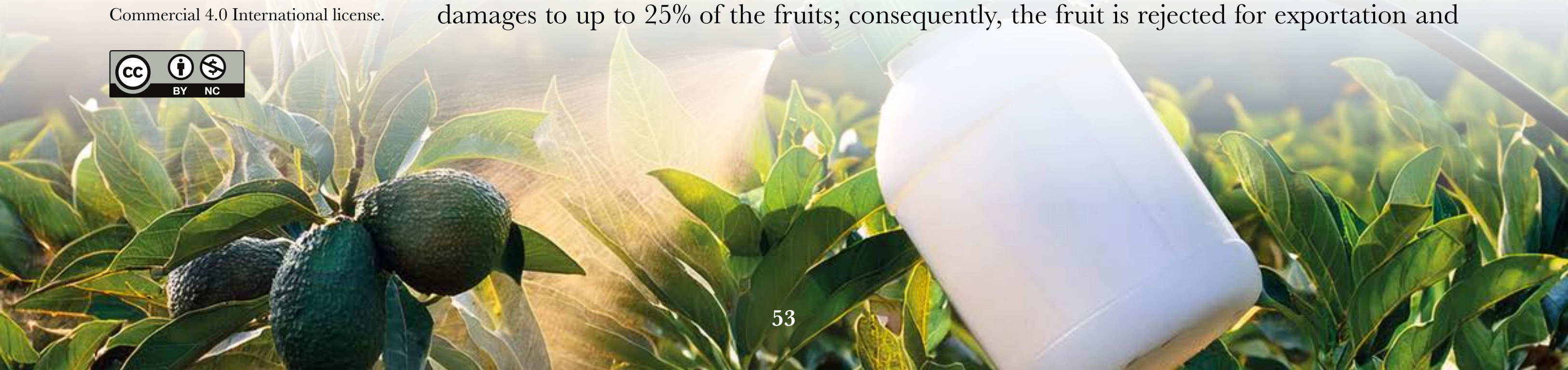
INTRODUCTION

Mexico supplies one third of the avocados (*Persea americana* Mill.) that reach the international markets (SADER, 2024); however, avocado production is impacted by multiple factors, including pests. Thrips (Thysanoptera: Thripidae) are a major pest of avocado trees: they feed on leaves, sprouts, flowers, and fruits, causing direct (sap sucking) and indirect (disease transmission) damage (Ávila-Quezada *et al.*, 2005). Thrips cause damages to up to 25% of the fruits; consequently, the fruit is rejected for exportation and



its price is reduced by half in the domestic market (Coria-Ávalos, 2003). Currently, the pest is mainly controlled with agrochemicals. Therefore, the selection of inputs to control pests should be improved and new alternatives to prevent environmental damage should be proposed (Torres and Capote, 2004). The application of plant extracts to control agricultural pests is an ancient practice used by different cultures and regions before the development of synthetic pesticides (FIDA-RUTA-CATIE-FAO, 2003). Plant extracts are liquid or powder preparations with active ingredients obtained with methods that concentrate substances from the root, leaves, flowers, and seeds of several species. The extracts are mainly rotenoids, pyrethroids, alkaloids, and terpenoids. These substances can have a severe and variable impact on the metabolism of insects, such as food aversion or reduction, consequently, preventing the development of pests (Do Nascimento *et al.*, 2008). Neem (*Azadirachta indica*; Meliaceae) has been the plant with the highest development in recent years. Its seeds have compounds that act against more than 200 insect species of the orders Coleoptera, Diptera, Homoptera, Himenoptera, Lepidoptera, and Thysanoptera. In addition, it impacts three mite species, five nematodes, and one crustacean species (Rodríguez, 2000). Furthermore, neem is not toxic for mammals and beneficial insects (Schmutterer, 1990). Currently, other plants, extracts, and compounds have been identified as potential pesticides for the control of thrips. Therefore, the objective of this study was to evaluate the effectiveness of biorational insecticides to control thrips and to provide alternatives to reduce the negative environmental impact of chemical insecticides used to manage avocado trees.

MATERIALS AND METHODS

The study took place from January to June 2023 in a 1-ha Hass avocado orchard, located in Tetela del Volcán, Morelos, at 18° 52' 45.8" N and 98° 42' 48.0" W, and 2,126 m.a.s.l. The area had a sprinkler irrigation system. The trees were arranged according to the topology (in a 5×4 m square planting) and were between four and eight years old.

Five treatments were evaluated: T1) control without pesticide (water); T2) 1 L of chicalote (*Argemone mexicana* L.; 90%) extract in 200 L of water; T3) 400 ml of neem (*Azadirachta indica*; 80 %) oil extract in 200 L of water; T4) 1 L of potassium soap (potassium salts; 35%) in 200 L of water; and T5) 40 ml Spinosad (Spinosyn A and Spinosyn D; 11.60%) in 200 L of water. The doses were based on previous trials (unpublished data) and technical recommendations for the commercial products. The products were applied thrice in each treatment. The tree foliage was sprayed in the morning (7:30-8:30 a.m.), when temperatures were lower and the wind speed reached 0-6 km h^{-1}. A Willy® motorized pump and a high-pressure hydra pistol (300 psi), calibrated at 200 L ha^{-1}, were used for this purpose.

A randomized complete block design with four replicates was used; the blocking factor was the age of the trees (4 and 8 years old). Each block was made up of ten contiguous trees in their plant growth and flowering stages. Four trees were randomly selected and marked as sampling specimens. The experimental unit was made up of a tree, from which four plant and floral sprouts were selected, based on their phenological development. Each sprout was selected from a different cardinal point. A row of trees without application was placed between the treatment rows to prevent derivative errors and contamination between treatments. The treatments were randomized within each block, using the design. ab procedure of the R statistical software (R Core Team, 2018).

The weather information (maximum, minimum, and mean temperatures) from 2023 were retrieved from: https://es.weatherspark.com/.

Treatment evaluation

In order to estimate the initial distribution of the pest, each plant or floral sprout from the marked trees were sampled at the beginning of the study. Subsequently, three evaluations were carried out at 7, 14, and 28 days after the first application. Evaluations were conducted from January to June to determine the natural population dynamic of thrips in the four T1 (control) trees. Four random inflorescence or plant sprout samples were taken from each marked tree at a height of 1.5-2.0 m. The sampling process covered the four cardinal points. Each tree was sprayed with a 9:1 water and fabric softener (Vel Rosita®) solution. The dripping of the trees was collected in a plastic tray and subsequently poured into a bottle with 70% ethanol. Afterwards, sieves were used to collect and count the captured specimens in the lab. The specimens were placed between a microscope slide and a slide cover with Canada balsam. They were then observed in a Master Olympus® compound microscope. The illustrated keys developed by Soto and Retana (2003) for the genus Thysanoptera were used for the taxonomic identification of the samples.

Statistical analysis

First, box-and-whisker plots were developed for the visual comparison of the evaluated treatments. Afterwards, a generalized additive model (GAM) was used to analyze the counting data in the R Core Team (2018) software. A mean comparison of the treatments (T) and the dates (D) was performed with the least significant difference (LSD) method.

RESULTS AND DISCUSSION

Population fluctuation in the control treatment

Figure 2 shows the natural behavior of thrips populations in the control trees (February-June); it also includes the two regression models employed to predict the said behavior. The thrips population started to increase on late February and early March, along with the increase of temperature; likewise, it started to diminish in June, at the beginning of the rainy season (Figure 1). These results match the findings of Ramírez Dávila *et al.* (2013), who pointed out that thrips populations in Morelos started to increase in March, reached their maximum peak in May, started to decrease in June, and finally reached their minimum point in September. Maximum and minimum temperatures in March reached 78 °F and 50 °F, respectively. According to Hoddle and Mound (2003), thrips can develop at a minimum temperature of 8 °C. Scarce precipitation favors the development of thrips populations in plant tissue (Díaz *et al.*, 2012).

Regarding the adjustment of population fluctuation models shown in Figure 2, the lineal model clearly was not the appropriate model to explain the data. However, the highest value of R^2 showed that the quadratic model had a better adjustment and, consequently, it achieved a better description of the natural dynamics of thrips populations. A quadratic

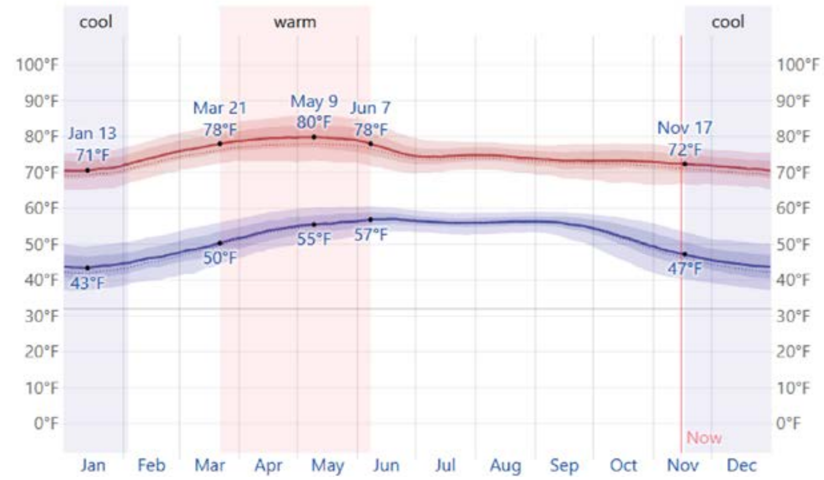


Figure 1. Maximum, minimum, and mean temperature in Tetela del Volcán, Morelos. Historical data retrieved from: https://es.weatherspark.com/.

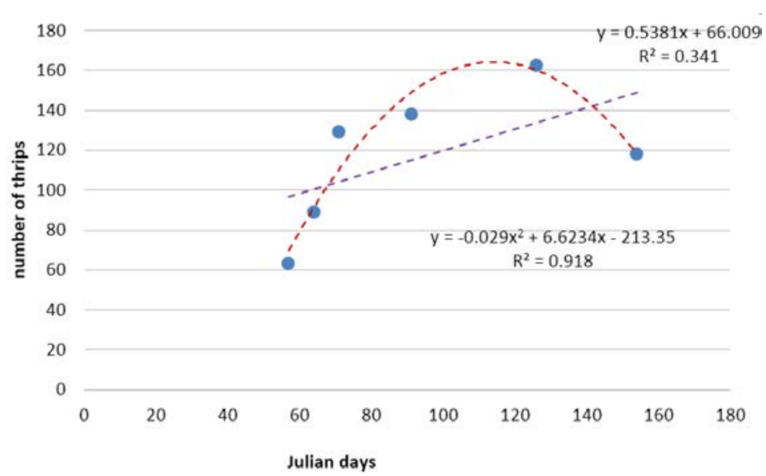


Figure 2. Natural fluctuation of the thrips populations in avocado trees in Tetela del Volcán, Morelos (2023).

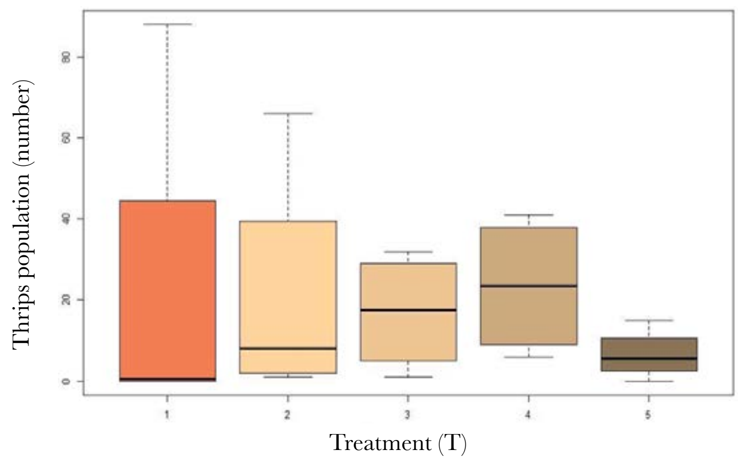
model can be used to study the response of population dynamics to environmental changes, to forecast the future of the population, and to evaluate the impact of the pest control on the said population.

The genera *Frankliniella* and *Scirtothrips* were found in the area. According to Urías-López *et al.* (2007), they are phytophagous species of the avocado plantations.

Efficiency of the treatments

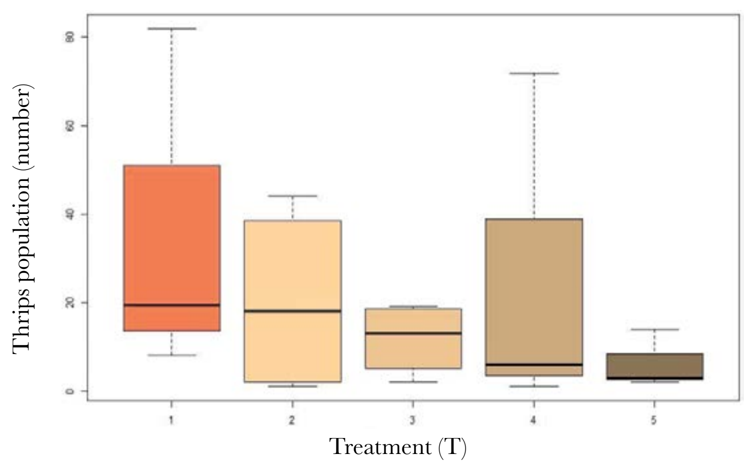
During the first sampling (seven days after the first application), all the plant extracts were able to control thrips populations. However, Spinosad recorded the best control, followed by neem (Figure 3). Control registered the highest data dispersion.

Based on the mean result of the treatments, Spinosad and neem were still the best treatments during the second sampling, while chicalote recorded a better control than potassium soap (Figure 4).



1=control, 2=chicalote, 3=neem, 4=potassium soap, 5=Spinosad.

Figure 3. Box-and-whisker plot of the five treatments during the first sampling date in Tetela del Volcán, Morelos (2023).



1=control, 2=chicalote, 3=neem, 4=potassium soap, 5=Spinosad.

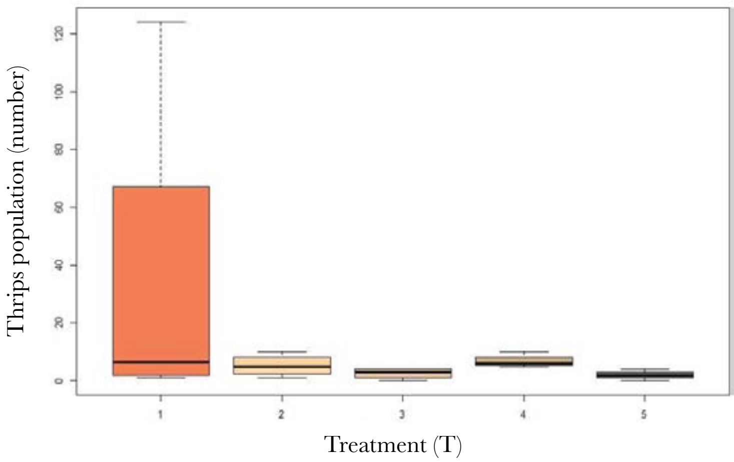
Figure 4. Box-and-whisker plot of the five treatments during the second sampling date in Tetela del Volcán, Morelos (March 12, 2023).

According to the statistical analysis, Spinosad and neem were still the best treatments during the third sampling date; in addition, no differences were recorded between chicalote and potassium soap (Figure 5).

Figure 6 shows that control recorded very diverse amounts of thrips during the experiment. This phenomenon contrasted with the results obtained from the other treatments which, as the sampling dates went by, recorded a significant interquartile range decrease.

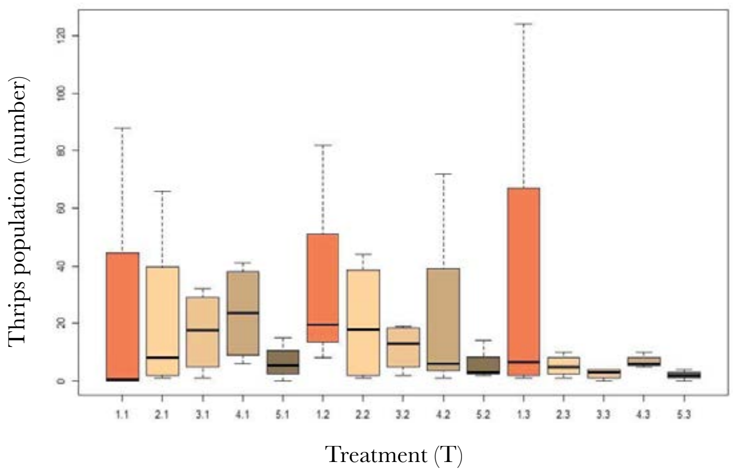
Differences were recorded based on the treatments and the sampling dates; in addition, an analysis of variance was conducted to determine the statistical difference between the effects of the different treatments.

Based on the analysis of variance of the GAM, a significant difference was verified between treatments and application dates.



1=control, 2=chicalote, 3=neem, 4=potassium soap, 5=Spinosad.

Figure 5. Box-and-whisker plot of the five treatments during the third sampling date in Tetela del Volcán, Morelos (April 01, 2023).



1=control, 2=chicalote, 3=neem, 4=potassium soap, 5=Spinosad.

Figure 6. Box-and-whisker plot of the five treatments during the three sampling dates. The first number indicates the sampling date, while the second indicates the treatment (Tetela del Volcán, 2023).

Analysis of variance of the GAM

According to the mean comparison test, the best treatment was Spinosad, followed by neem (Table 3). Spinosad is used in different crops to control thrips and mites (Grové *et al.*, 2002; IRAC, 2007). Its neurotoxicity activates nicotinic acetylcholine receptors.

A correlation analysis explained the positive or negative effect of the dates and treatments and the presence of thrips in the avocado trees (Figure 7). The results were negative for both treatments and dates. As a result of the application of the treatments, the presence of thrips decreased in time.

Table 1. Mean comparison parameters.

	Estimate	Std. Error	Z value	Pr(>|z|)	
(Intercept)	4.10120	0.10078	40.696	<2e-16	***
TREATMENT	−0.32609	0.02481	−13.142	<2e-16	***
DATE	−0.25488	0.04086	−6.238	4.43e-10	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
R-sq.(adj)=0.0518 Deviance explained=14.5%
UBRE=21.158 Scale est.=1 n=60

Table 2. Values obtained with the analysis of variance of the GAM.

MSerror	Df	Mean	CV	t.value	LSD
23.21912	57	15.46667	31.15488	2.002465	3.939238

LSD t Test for TRIP; Mean Square Error: 23.21912; TRA, means and individual (95 %) CI.

Table 3. Mean comparison of the last sampling date of the evaluation of biorational insecticides used to control thrips in avocado plantations in Morelos, Mexico (2023).

Treatment	Thryps (average)	Group
1: Control	29.66	a
4: Potassium soap	17.16	b
2: Chicalote	15.41	b
3: Neem	10.41	c
5: Spinosad	4.66	d

Alpha: 0.05; DF Error: 57; Critical Value of t: 2.002465; Least Significant; Difference: 3.939238; Treatments with the same letter are not significantly different.

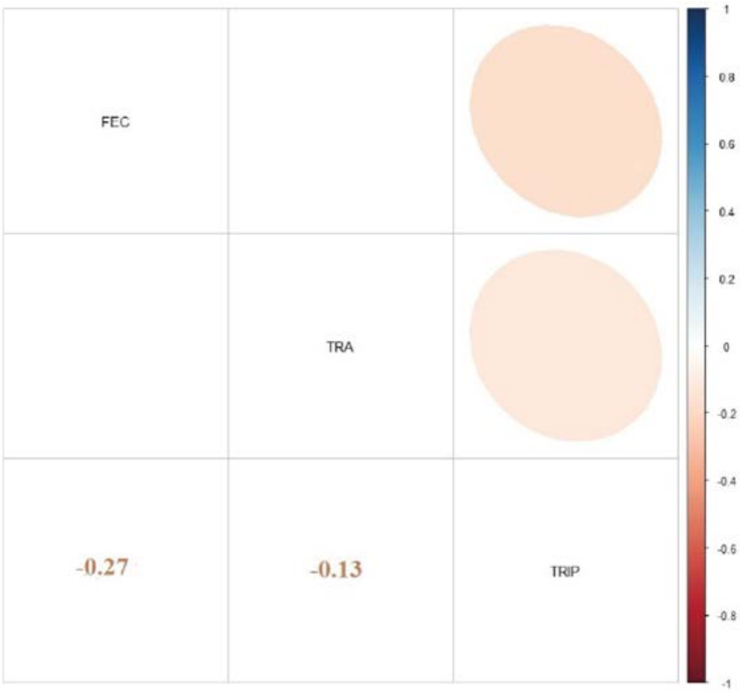


Figure 7. Correlation between the thrips presence and the dates and treatments.

CONCLUSIONS

The neem (*Azadirachta indica*) and chicalote extracts (*Argemone mexicana* L.) controlled and reduced thrips populations with greater efficiency than control. Although their action was slower than the effect of chemical products, they nevertheless controlled the pests. Consequently, they can be used in a comprehensive management program of avocado plantations.

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Colegio de Postgraduados

Biodiversity in family backyard systems of the municipality of Calpan, Puebla

Blanca-Bautista, Martina[1]; Díaz-Ruiz, Ramón[1]; Ocampo-Fletes, Ignacio[1]; Pérez-Ramírez, Efraín[1*]; Contreras-Ramos, Juan[1]

[1] Colegio de Postgraduados Campus Puebla. Santiago Momoxpan, Municipio de San Pedro Cholula, Puebla, México. C.P. 72760.

* Correspondence: eperezr@colpos.mx

ABSTRACT

Objective: To determine the social usefulness of the backyard system biodiversity for rural families in the municipality of Calpan, Puebla.

Design/Methodology/Approach: One-hundred questionnaires were applied to informants of the selected families. The selection was based on a non-probability snowball sampling, using saturation to generate the maximum amount of data. The SPSS software was used to analyze data.

Results: Backyard systems have a great biodiversity, including vegetables, fruits, ornamental plants, medicinal plants, and animal species. Women carry out most of the work (65%), using biodiversity as a strategy to produce food, generate income and jobs, and preserve medicinal and other plants used for spiritual development.

Study Limitations/Implications: The lack of family backyard records hindered the accurate calculation of the sample size.

Findings/Conclusions: The collection and preservation of local biodiversity is the basis of backyard systems where vegetables, medicinal and ornamental plants, and animal species are produced as part of a family strategy.

Keywords: family agriculture, contributions, benefits.

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INTRODUCTION

The following proposals should be taken into account to achieve food security, nutrition improvement, and sustainable agriculture promotion: doubling agricultural production and productivity of small producers (Argueta and Toledo, 2023); maintaining the genetic diversity of seeds, crops, and farm animals; promoting the use of genetic resources and lore; and driving the operation of basic food product markets (Naciones Unidas and CEPAL, 2018). These characteristics are inherent in family agriculture, which has been managed by small producers and their families for centuries (Pérez, 2013). Consequently, the objective of this study was to determine the social usefulness of backyard systems biodiversity for rural families in Calpan, Puebla, Mexico.

MATERIALS AND METHODS

The research was conducted in the municipality of Calpan, located in central-western Puebla, at 19° 06' 36" and 19° 41' 12" N and 98° 23' 54" and 98° 32' 24" W. Calpan has an area of 66.9 km^2. Its territory is divided as follows: 71% is comprised of agricultural lands, 16% is a forest, and 13% is an urban area (INEGI, 2020). The climate is temperate subhumid with summer rains (85.11%) and semi-cold subhumid with summer rains (14.89%), with a 12-18 °C mean annual temperature (INEGI, 2020). The area has a wide biodiversity as a result of its varied soils: arenosol (38%), phaeozem (26%), leptosol (13%), cambisol (8%), andosol (8%), and luvisol (7%) (INEGI, 2020).

Research methods and techniques

A non-probability snowball sampling was used to identify informants and to generate data. This method was used given the lack of a census or register of families with backyard systems; only the total number of the local inhabited households (3,197) was available (INEGI, 2020). One hundred questionnaires were conducted in the following auxiliary boards: San Lucas Atzala (20), San Mateo Ozolco (10), San José Pueblo Nuevo (10), and San Andrés (60). The municipal seat of San Andrés was chosen because the highest number of backyard systems are located in its skirts. Male and female heads of families were interviewed. The interviews were arranged based on the following categories and number of questions: family characteristics (8), backyard system history (11), backyard system elements (22), benefits (10), environmental technology (7), global warming (10), and potential improvements (8). The results were registered and analyzed with the Statistical Package for the Social Sciences (SPPS) v. 22 software and Excel.

RESULTS AND DISCUSSION

Social characteristics of the families

The results of the interviews indicate that 65% of women and 35% of men work in backyard systems. The role of women was highlighted by the interviewees, because they spend more time in their homes than men and are usually in charge of backyard systems. In addition, women are fond of medicinal and ornamental plants inherited from their mothers, mothers-in-law, and grandmothers. The main activities of the interviewees included: housewives (58%), farmers (25%), laborers (7%), professionals (3%), taxi drivers (2%), shopkeepers (2%), students (2%), and pensioners (1%). Zamudio *et al.* (2004) pointed out that, besides housework, rural women manage and commercialize backyard products. They solve unexpected situations when their husbands are not around. These authors also mentioned that women work all year round, both in the house and in the backyard. The individuals in charge of the backyard systems were in average 52 years old (maximum: 95 years; minimum: 16 years). However, the age range of most of the interviewees was 40-70 years old. Youngsters are not interested anymore in backyard systems. All over the world, youngsters abandon family farms and migrate to urban areas (FAO, 2014).

Family use of backyard biodiversity

The interviewees had different opinions about the nature of backyard systems. However, they agreed that it is a place behind the house, used to grow plants and raise animals. Backyard systems are part of their identities: they love, respect, are grateful to, identify with, and value their backyards. Montañez-Escalante *et al.* (2012) mentioned that backyard systems have other names, such as plot, farmyard, orchard, parcel, and home. Backyard systems have an average of 225 m^2 (3.0-2,500 m^2 range). González (2013) recorded average areas of 601 m^2 (120-1,200 m^2 range). The oldest backyard system in the region is 85 years old, while the newest is one year old. Backyard systems have been preserved from generation to generation and only the newest are located in recently built houses. In Calpan, backyards preserve local agrobiodiversity and provide families with >50% of their daily food consumption. In addition, biodiversity creates, maintains, and develops culture, preserving the beauty of the landscapes and the environment (Van der Ploeg, 2014). In Central America, family agriculture is the main source of basic food for families. In addition, family agriculture is key to guarantee food security and to fight the degradation of ecosystems and landscapes resulting from climate change. Furthermore, it preserves natural resources and biodiversity (FAO, 2014).

Plant and animal diversity and medicinal plants

One-hundred-two plant species and nineteen animal species were recorded in this study. Table 1 shows the most important medicinal plants of the backyard systems in the study area, including: chamomile (90%), spearmint (85%), oregano (78%), epazote (66%), common rue (65%), arnica (60%), bougainvillea (55%), and prickly pear (52%). The most commonly grown plants are those used for mild diseases, such as stomach ache and headache. Poor people usually take home remedies before going to a doctor. The results of the interviews showed that 90% of the families grow medicinal plants: 97% grow plants for self-consumption and 3% sell the products of their backyards. Medicinal plants and vegetables are available all year round. Fifty-five percent of the people used them to prepare tea, 16% use them as spices, and 24% used them for both purposes. Common rue is used for limpias (purification rituals) (5%).

Fruit trees

Table 1 shows 14 types of fruit trees found in the area, including: peach, pear, walnut, avocado, *tejocote*, lemon, pomegranate, and fig. The area has optimal conditions (temperate weather) to plant this type of fruit trees. Tropical fruits were also found in the region, but they are grown to a lesser degree. These fruits include grape, mulberry, tangerine, banana, white sapote, and Barbados nut. Eighty-seven percent of the families use fruit trees for self-consumption, both as food and for medicinal purposes. Thirteen percent of the families sell their fruits in the main local markets: Huejotzingo, Cholula, and Calpan.

June, July, and August are the main harvesting months of peach, pear, nuts, pomegranate, capulín, fig, plum, guava, apple, quince, white sapote, and avocado. Meanwhile, tejocote, soursop, grape, mulberry, Barbados nut, tangerine, banana, and orange are harvested in October, November, and December.

Table 1. Uses of medicinal plants and fruit trees in the backyard systems of Calpan, Puebla, Mexico.

Common name Medicinal plants	Scientific name	Uses		Presence (%)
		Alimentary	Medicinal	
Chamomile	*Matricaria chamomilla*	x	x	90
Spearmint	*Mentha sativa*	x	x	85
Oregano	*Origanum vulgare*	x	x	78
Wormseed	*Chenopodium ambrosioides*	x	x	66
Rue	*Ruta graveolens*		x	65
Arnica	*Arnica montana* L.		x	60
Bougainvillea	*Bougainvillea glabra*		x	55
Prickly pear cactus	*Opuntia ficus*	x	x	52
Aloe	*Aloe vera*		x	45
Wormwood	*Artemisa absinthium*		x	40
Fruit				
Peach	*Prunus persica*	x		50
Pear	*Pyrus communis*	x		48
Walnut	*Juglans regia*	x		46
Avocado	*Persea americana*	x		45
Mexican hawthorn	*Crategus pubescens*	x	x	45
Lemon	*Citrus Lemon*	x	x	41
Pomegranate	*Punica granatum*	x		40
Fig	*Ficus carica*	x		40
Sweet lime	*Citrus aurantifolia*	x		32
Capulin cherry	*Prunus salicifolia*	x		30
Guava	*Psidium guajava*	x		30
Plum	*Prunus domestica*	x		25
Apricot	*Prunus armeniaca*	x		20
Apple	*Malus domestica*	x		20

Vegetables

A total of 6 vegetables are grown in the area. The most cultivated species include: chayote (*Sechium edule*; 46%), bean (*Phaseolus vulgaris*; 34%), zucchini (*Cucurbita* pepo; 30%), black seed squash (*Cucurbita ficifolia*; 28%), smooth pigweed (*Amaranthus hybridus*; 26%), and tomato (*Solanum lycopersicum*; 23%). Bean and broad bean are pulses included in the vegetable category. In addition, a lower percentage of other species were found in the area, including: strawberry (*Fragaria×ananassa*), cabbage (*Brassica oleracea* L.), carrot (*Daucus carota*), Swiss chard (*Beta vulgaris* L.), rocoto chili (*Capsicum pubescens*), poblano pepper (*Capsicum annuum* L.), and coriander (*Coriandrum sativum*). The seeds of these crops are not easily found in the local communities and, therefore, producers must buy them elsewhere. Ninety-two percent of the families use their produce for self-consumption, while the rest sells it in nearby markets. However, the main use of the backyard production is for self-consumption.

Ornamental plants

Table 2 shows the wide variety of the most frequently grown ornamental plants in the region, including: roses (*Rosa gallica*; 45%), calla lilies (*Zantedeschia aethiopica*; 26%), geraniums (*Pelargonium graveolens*; 25%), bougainvilleas (*Bougainvillea* spp.; 23%), lady's eardrops (*Fuchsia* spp.; 16%), and daisies (*Bellis perennis*; 6%). Ninety-eight percent of these colorful and aromatic plants are used for self-consumption. Flowers are also used to embellish gardens. Only 2% of the total ornamental flowers produced in the region are sold and their prices range from MXN$5.00 to MXN$10.00 per bunch. Ornamental flowers are sold among the neighbors all year round. These flowers are mainly used as decoration

Table 2. Ornamental plants found in the backyard systems of Calpan.

Common name	Scientific Name	Uses
Rose	*Gallic rose*	Adornment
Earring	*Fuchsia* sp.	Adornment
Geranium	*Pelargonium graveolens*	Adornment
Alcatraz	*Zantedeschia aethiopica*	Church
Bougainvillea	*Bougainvillea* spp.	Ornament, medicinal
Lily	*Iris germanica*	Adornment
Giant	*Tithonia tubiformis*	Adornment
Poinsettia	*Euphorbia pulcherrima*	Christmas
Gladiolus	*Gladiolus* spp.	Church, deceased
Common yarrow	*Achillea millefolium*	Adornment
Daisy	*Bellis perennis*	Adornment
Snapdragon	*Antirrhinum majus*	Ornament, sale
Heliconia	*Heliconia* spp.	Adornment
Elephant ear	*Xanthosoma robustum*	Adornment
Fern	*Pteridium aquilinum*	Ornament, floral arrangements
Violet	*Viola* spp.	Adornment
Tulip	*Tulipa* spp.	Adornment
Impatiens	*Impatiens walleriana*	Adornment
Asparagus	*Asparagus officinalis*	Adornment
Quaking grass	*Briza* spp.	Adornment
Hydrangea	*Hydrangea*	Adornment
Poinsettia	*Euphorbia pulcherrima*	Christmas
Carnation	*Dianthus caryophyllus*	Adornment
Common privet	*Ligustrum vulgare*	Adornment
Mourning bride	*Scabiosa atropurpurea*	Adornment
Angel Wing	*Begonia gracilis*	Adornment
Night blooming cestrum	*Cestrum nocturnum*	Adornment
Angel's trompet	*Brugmasia arborea*	Adornment
Lady's slipper orchid	*Cypripedium irapeanm*	Adornment
Lydia genista	*Genista lydia*	Adornment

Source: Table developed based on surveys conducted in 2014 and [17] Arredondo, Ávila, and Muñoz (2012). *Fact sheet of 52 ornamental plants*. INIFAP; [18] Marchesi, E. 1969. Ornamental plants.

(59%), but they are also used to embellish church altars (41%). In addition, some of these plants have medicinal uses. López *et al*. (2013) studied backyard systems in the San Nicolás de los Ranchos community in Puebla and found 12 ornamental plant species. These results closely match the findings of this study.

Animals

The most important animals in the backyard systems of the region were: chickens (*Gallus gallus domesticus*; 90%), pigs (*Sus scrofa domesticus*; 70%), sheep (*Ovis aries*; 45%), and cows (*Bos taurus*; 40%). The less frequent animals in the area included: tilapia (*Oreochromis niloticus*), doves (*Columba livia*), and bees (superfamily Anthophila). Chicken and eggs are the main source of food of the families. This species can be handled by children and elders and requires little infrastructure and management. These findings match the reports of Gutiérrez (2008), who pointed out that backyard livestock is a system characterized by raising a group of animals such as birds, cattle, pigs, goats, sheep, and horses. Out of the total of animals found in the region, 47% is sold and 53% is used for self-consumption. The most sold and consumed species is poultry. Debnath *et al*. (2011) mentioned that backyard chicken production is a subsistence strategy. In addition, Ahuja and Sen (2007) pointed out that poultry production improves food security and the nutrition of the poorest households. These findings match the results of this study. Rabbit is not widely produced, because the inhabitants of this area do not usually consume its meat.

Multiple correspondence analysis (MCA)

Multiple correspondence analysis (MCA) is a statistical technique used to analyze the relationship between several qualitative variables. This technique can be used to establish the interaction of variables with a complex interrelation. Codification can show qualitative variables as numerical variables. The analysis of the main components and correspondence is used to identify patterns and relationships between the variables. They are reduced to two dimensions to facilitate their visualization, through factor scores. The resulting observations and categories identify patterns or data clustering.

In this case, the aim was to determine the relationship between the characteristics of the family: age, gender, education, work, plant, vegetable, and fruit cultivation, and animal raising. Figure 1 shows that the activities of the production unit depended on gender. The local women that carry out these activities mainly attended elementary school, are in average between 40 and 51 years old, and are housewives that grow vegetables and raise animals. Meanwhile, local men are between 52 and 63 years old and they work as laborers and farmers. In addition, they spend less time growing vegetables and raising animals in their backyards than women. This phenomenon can be the result of their higher education level and jobs with better wages. Likewise, they go to other places to carry out their activities.

Backyard system benefits

The first benefit of backyard systems is food —chicken, pig, cow, and sheep meat and milk, eggs, and cheese. The second benefit are fruit trees and their by-products, such as

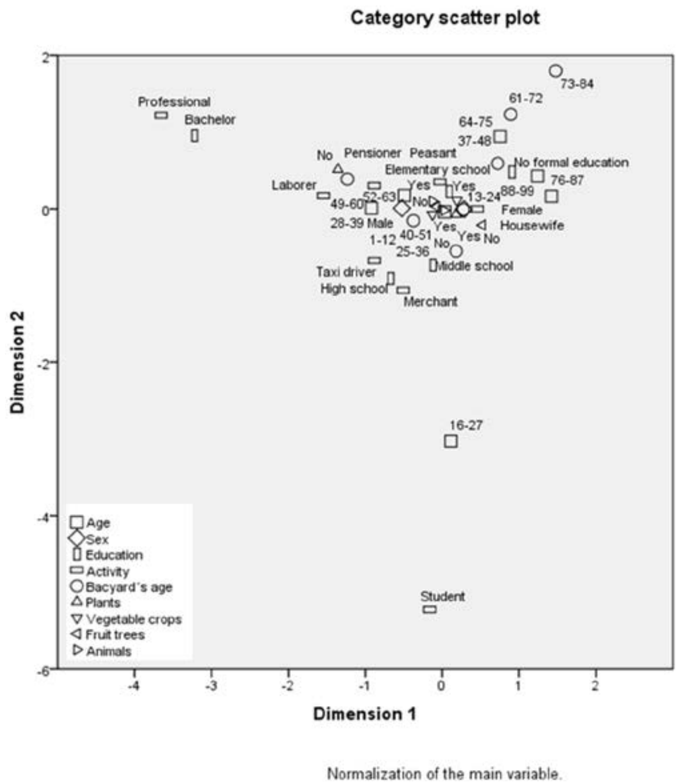

Figure 1. Multiple correspondence analysis of the characteristics of families and the biodiversity of their backyard systems.

marmalade, sweets, preserves, quince jelly, and liquors. The third benefit are the vegetables and medicinal and ornamental plants. Ornamental plants are mainly used to embellish churches, houses, and cemeteries. Most of the interviewees use backyard products for self-consumption and only a few sell them. Consequently, families save a significant amount of money, because they do not buy these products in markets. In this regard, López *et al.* (2013) pointed out that backyard systems are a survival strategy of farmers, because they complement family consumption and income in rough times. Backyard systems allow elders to help the family. Olvera *et al.* (2017) mentioned that backyard production helps to strengthen social relationships, as a result of barter (exchange of goods) that takes place in several communities of Calpan. The authors also mention that, as a sign of social commitment, some products are given away.

CONCLUSIONS

Backyard systems are important for the dynamics of family agriculture. They are mainly managed by women. Backyard products complement the diet and income of the families. Backyard systems provide food, medicinal products, and ornamental plants and promote the preservation of biodiversity. Consequently, they should be maintained and rescued. In addition, further research should be carried out to deepen the understanding of their operations.

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Colegio de Postgraduados

Inclusion of amaranth (*Amaranthus* sp.) as a protein source in the diets of lactating dairy goats

Castro-González, Numa P.[1]; **Calderón-Sánchez, Francisco**[2*]; **Galindo-Reyes, Anahy**[1]; **Soni-Guillermo, Eutiquio**[1]

[1] Facultad de Ciencias Agrícolas y Pecuarias, Benemérita Universidad Autónoma de Puebla, Av. Reforma 167, C.P. 73900. Tlatlauquitepec, Puebla, México.

[2] Colegio de Postgraduados Campus-Puebla. Boulevard Forjadores de Puebla No. 205, Santiago Momoxpan, Municipio de San Pedro Cholula, C.P. 72760, Puebla, México,

* Correspondence: fsanchezs@colpos.mx

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ABSTRACT

Objective: To determine the productive performance and milk quality of goats, including two levels of popped amaranth in their diet.

Methodology: Forty-five lactating goats, randomly distributed into three groups of 15, were studied. Each group was allocated a treatment that matched the isoenergetic and isoproteic diets with increasing percentages of popped amaranth grain, in replacement of soybean meal: T1, 0%; T2, 20%; and T3, 30%. Data were collected across three intervals during the 45-day experimental period. Milk production was recorded, along with its crude protein (CP), fat, and total solids (TS) content.

Results: Milk production differed significantly ($p<0.05$) between treatments, increasing as the amount of amaranth in the diet increased, with values of 1.35, 1.38, and 1.65 kg d^{-1} for T1, T2, and T3, respectively. Milk composition did not record any difference between treatments, with averages of 28.07, 32.89, and 113.7 g kg^{-1} of milk for crude protein (CP), fat, and total solids (TS), respectively.

Study Limitations/Implications: Given the exploratory nature of this study, determining the functional components of milk is required to complement the study.

Conclusions: Amaranth grain can be used as a protein source in animal feed. Including 30% of amaranth in the diet of dairy goats has been proven to increase production compared to conventional protein sources. However, no changes were observed in the main milk components.

Keywords: Goats, milk, amaranth, protein, family production.

INTRODUCTION

Both amaranth and goat milk significantly benefit human nutrition, as a result of their nutritional value, the presence of functional compounds that promote health, and the diversity of their by-products. However, their production and effective dissemination must be promoted to encourage their consumption (Ayala *et al.*, 2016). According to SIAP (2024), amaranth is produced in six states of central Mexico, with 3,173.21 ha harvested in 2023 and a yield of 5,660.81 tons of grain —88.25% of which was produced in Puebla

and Tlaxcala. The grain is mainly popped with heat to produce traditional sweets (Espitia, 2012). The unpopped grain and/or residual popped grain is an important protein source in family production units that raise animals, such as dairy goats.

Studies on the use of amaranth to feed ruminants have primarily focused on the use of the plant as fresh and ensiled forage or as stubble. Peiretti (2018) determined that amaranth has high nutritional value both as forage and grain, partly attributed to the fact that its protein is resistant to ruminal degradation. However, this author also mentions that, depending on the amaranth species and the plant's vegetative stage, forages can include antinutritional compounds, such as tannins, saponins, lectins, and trypsin inhibitors. These compounds are reduced during the ensiling process and when the grain is subjected to the heat treatment.

Consequently, feeding dairy goats amaranth grain by-products, foliage, and crop residues is a potential strategy for the comprehensive use of the crop to generate healthy and nutritionally valuable products. To date, the use of amaranth grain in ruminant feeding has been the subject of a limited number of studies. Therefore, the objective of this study was to determine the productive response and milk quality of goats, resulting from the inclusion of two quantities of popped amaranth in their diet.

MATERIALS AND METHODS

Experiment location

The study was conducted in the municipality of Libres, Puebla, where goat milk production is a traditional and important activity, predominantly carried out in family production units. It is located at 19° 27' 38" N and 97° 38' 57" W, at 2,357 m.a.s.l. The prevailing climate is semiarid with summer rains, an annual precipitation that can range from 400 to 800 mm, and an average monthly temperature of 12 to 18 °C (INEGI, 2023).

Animals used and treatments

Forty-five dairy goats representative of the region were used. They included multiparous specimens from crossbreeds of the Alpine French and Saanen breeds, with 90±10 days of lactation, and an average weight of 45±6 kg. Prior to the experiment, they were internally dewormed and randomly distributed into three homogeneous groups of 15 animals. Each group was fed a diet with a different percentage of amaranth, according to the treatments evaluated: T1, 0%; T2, 20%; and T3, 30%. Amaranth replaced soybean meal as the primary conventional protein source. The amount of feed provided to the goats was estimated at 4% of live weight (1.8 kg goat^{-1} day^{-1}). Commercial mineral salts were mixed into the feed and water was provided *ad libitum*.

The popped amaranth was purchased in the municipality of Altzayanca, Tlaxcala, and the other ingredients were sourced from regional distributors. The isoenergetic and isoproteic diets (Table 1) were formulated for dairy goats, according to the nutritional requirements for the second third of the lactation period (NRC, 2001).

The experimental diet was analyzed following the AOAC methods (2007). Dry matter (DM) content was determined drying the sample in a forced-air oven for 24 hours at 105 °C. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed according to

Table 1. Percentage composition and nutritional value of the diets with amaranth provided to dairy goats.

Diet Composition (%)	T1=n15	T2=n15	T3=n15
Ground corn stover	63	60	60
Amaranth	0	20	30
Soybean meal	17	10	7.5
Dried orange peel	17.5	7.5	0
Urea	0.5	0.5	0.5
Minerals	2	2	2
Total	100	100	100
MS (%)	91.6	91.4	92.1
PC (%)	14.5	14.4	14.4
PD (%)	70	70	70
PND (%)	30	30	30
ENL (Mcal/kg)	1.64	1.62	1.63
EM (Mcal/kg)	2.6	2.6	2.6
TND	71.9	72.1	72.1
FDN	57.6	57.1	56.2
FDA	24.3	23.6	23.8
Ca	0.8	0.8	0.8
P	0.4	0.4	0.4
Non-protein nitrogen (NPN)	0.07	0.07	0.07

DM (MS)=dry matter; CP (PC)=crude protein; DP (PD)=degradable protein; UDP (PND)=undegradable protein; NEL (ENL)=net energy for lactation; ME (EM)=metabolizable energy; TDN (TND)=total digestible nutrients; NDF (FDN)=neutral detergent fiber; ADF (FDA)=acid detergent fiber.

the method of Van Soest *et al.* (1991). Crude protein (CP) content was obtained using the Kjeldahl method, proc. 988.05 (AOAC, 2000), ether extract (EE) was determined using the Soxhlet method, proc. 920.39 (AOAC, 2005), and ash content was measured using a muffle furnace at 550 °C, proc. 942.05 (AOAC, 2000).

Experimental period and goat management

The 45-day experiment was divided into three 15-day measurement periods. During the 10-day adaptation period to which all goats were subjected, the amounts and ratios of diet ingredients were gradually adjusted for each group. The feed was offered twice daily (at 8:00 a.m. and at 4:00 p.m.). Water was provided *ad libitum*. The animals were housed in comfortable pens that protected them from external factors. They were milked manually once a day between 7:00 and 8:00 a.m.

Variables evaluated

Dry matter intake (DMI). The weight of feed offered (FO) and feed refused (FR) was recorded daily for each group of goats, using a Wild® electronic scale with a capacity of 200 kg. The daily dry matter intake (DMI) was calculated as the difference between FO and FR and the result was then divided by the 15 goats to estimate their individual daily intake (kg day^{-1}).

Milk production. Each goat was measured individually on two consecutive days, at the start of the experiment and again in each experimental period. On the first measurement day of each experimental period, 150 mL milk samples were collected from each goat, placed in a cooler at 4 °C, and transported to the laboratory of the Faculty of Agricultural and Livestock Sciences of the Benemérita Universidad Autónoma de Puebla for its analysis. Chemical composition of the milk. The evaluated variables were crude protein (CP), fat, and total solids content. CP was measured using the Kjeldahl method, proc. 988.05 (AOAC, 2000). Fat content was determined using the Goldfisch method, proc. 989.05 (AOAC, 2000). For total solids (TS), 20 mL milk samples were placed in Petri dishes and weighed on a digital scale. The samples were then placed in a forced-air oven for 48 hours at 60 °C. Finally, the following equation was used:

$$TS = (m1 - m)/(m2 - m) * 100$$

where: $m1$=weight of the Petri dish with solids, $m2$=weight of the Petri dish with milk, and m=weight of the empty Petri dish (NOM-116-SSA1-1994).

Statistical analysis

A completely randomized experimental design with three treatments and seven replications was used for this study. The results were analyzed using the GLM procedure of the Statistical Analysis System software (SAS, 2002). An analysis of variance was performed for each recorded variable, followed by a comparison of means using Tukey's test ($p<0.05$). For the intake variables, a repeated measure analysis of variance was conducted over three periods.

RESULTS AND DISCUSSION

Dry matter intake

Dry matter intake (DMI) was similar ($p>0.05$) between the treatments evaluated, with an average of 1.79, 1.76, and 1.60 kg day^{-1} for T1, T2, and T3, respectively. However, there were significant differences ($p<0.05$) in the first and second intake periods (Table 1). The DMI decrease in T3 (which included 30% amaranth) may have been caused by the palatability of amaranth, as it is known to contain phenolic compounds and phytic acid (Solano, 2002), which could cause animals to initially reject it. However, the results of the study did not reflect this effect, possibly because the animals fully adapted to the palatability of amaranth over time, making all diets equally consumable and accepted by the goats.

With the average daily intake per animal of 1.71 kg of DM, the experiment recorded a daily intake per animal of 246 g of CP, 972 g of NDF, and 4.45 Mcal of ME. These results match the findings of other authors who used a different set of ingredients (Martínez *et al.*, 2012; Emami *et al.*, 2016; Rúa *et al.*, 2017). This reference supports the findings of this study.

Table 2. Dry matter intake of lactating dairy goats fed diets with increasing levels of amaranth (kg day^{-1}).

Period*	T1=n15	T2=n15	T3=n15	DSH (0.05)
1	1.89^{a}	1.91^{a}	1.72^{b}	0.21
2	1.92$_{a}$	1.89^{a}	1.65^{b}	0.29
3	1.56^{a}	1.49^{a}	1.44^{a}	0.10
Average	1.79^{a}	1.76^{a}	1.60^{a}	0.20

* 15-day period; T1: 0%, T2: 20%, T3: 30% (amaranth). HSD (DSH)=Honest Significant Difference (0.05). Means with the same letter are not significantly different.

The main protein source used in milk production is soybean meal. Completely replacing soybean meal with amaranth would not be feasible, given the economic implications of this proposal. At current prices, a kilogram of soybean meal costs MXN$13.10 and contains 42% protein, while amaranth costs MXN$35.00 per kilogram and contains 17% protein. Soybean protein costs MXN$30.95 per kg, while amaranth protein costs MXN$176.00. However, the purpose of this proposal is to provide information for production units, workshops, or industries where amaranth residues are generated.

Milk production

Significant differences ($p<0.05$) were observed in milk production among the treatments. T3 recorded the highest milk production ($p<0.05$) at 1.65 kg day^{-1}, recording an increase of 18% and 16% compared to T1 and T2 (1.35 and 1.39 kg day^{-1}, respectively). Meanwhile, T2 had a 3.0% difference ($p<0.05$) with regard to the control treatment (Figure 1). This response is likely due to the high digestibility (93%), balanced amino acid composition (Pisarikova *et al.*, 2006), and greater supply of limiting amino acids (*e.g.*, lysine and methionine) of amaranth protein (Algara *et al.*, 2016). Other qualities of amaranth protein —such as its carbohydrate content and functional compounds— may positively impact the animal's health and the quality of the milk produced. Arco *et al.* (2017), Sari *et al.* (2009), and other authors have studied alternative feeding sources, finding the same

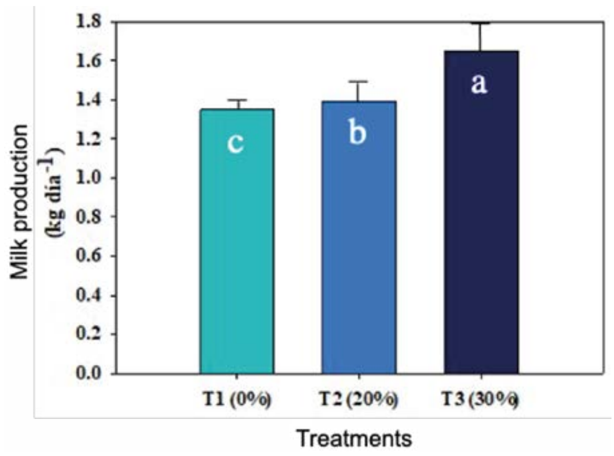

Figure 1. Milk production (kg day^{-1}) of goats fed increasing amounts of amaranth. Letters (a, b, c)=($p<0.05$). The lines above the bars belong to the standard deviation.

range of values as those of this study; those studies have thereby expanded the knowledge about the potential use of other local resources for milk production.

Physicochemical quality of goat milk

Table 3 shows the chemical composition, including no differences (P>0.05) between treatments. Based on the comparison of the data obtained in this experiment with the NMX-F-728-COFOCALEC-2007 standard —which specifies that goat milk must contain a minimum of 28% protein and 30% fat—, values fall within the parameters of this standard, except for T3, which has a slightly lower protein content.

Crude protein (CP)

In their analyses of several studies, Morand-Fehr *et al.* (2007) mention that the protein content in milk does not record great variability between different feeding systems and seasons of the year. The change of ingredients reflects this principle and the recorded values are similar to those reported in other studies (Avondo *et al.*, 2015; Schmidely and Andrade, 2011).

Fat

Milk fat is a component that can be manipulated based on the diet provided to goats and cows, with a greater response to fiber content. (Morand-Fehr *et al.*, 2007). In this study, the source and amount of fiber in the diet were consistent across treatments and, consequently, the fat content remained acceptably similar between the three treatments.

The fat yield reported in this study was similar to the results (32 g kg^{-1}) reported by Avondo *et al.* (2015), who included broad beans (*Vicia faba*) in the diet of Girgentana goats. Similarly, Shi *et al.* (2015) reported slightly lower fat yields (29.7 g kg^{-1}) in Xinong Saanen goats fed 30 g kg^{-1} DM of extruded flaxseed.

Total solids (TS)

The total solids (TS) in milk match the sum of its main components: protein, fat, lactose, and minerals. On the one hand, the values found in this study are similar to those reported by Caroprese *et al.* (2016), who recorded 130.5 g kg^{-1} in grazing Garganica goats supplemented with 0.15 kg day^{-1} of flaxseed. On the other hand, Kholif *et al.* (2018) reported 124.0 g kg^{-1} of TS in Anglo-Nubian goats fed a diet containing 20% sesame seed meal. Both cases showed values similar to those reported in this study.

Table 3. Chemical composition of milk from goats fed increasing amounts of amaranth.

Content	T1=n15 0% amaranth	T2=n15 20% amaranth	T3=n15 30% amaranth
Protein (g kg^{-1})	28.4±12.67^{a}	28.17±1.78^{a}	27.5±1.30^{a}
Fat (g kg^{-1})	32.1±7.53^{a}	32.89±7.63^{a}	33.7±12.25^{a}
Total solids (%)	108.0±14.0^{a}	110.3±13.1^{a}	123.0±25.7^{a}

Means with the same letter are not significantly different (p>0.05).

CONCLUSIONS

In conclusion, amaranth grain is a viable alternative source of protein in animal feed. As the percentage of amaranth inclusion in the diet increased, milk production was significantly higher than with conventional sources. The feed intake in the evaluated treatments was similar and did not lead to changes in the milk components. An additional in-depth research should be conducted about the content of peptides, fatty acids, and other nutritional and healthy compounds that could benefit both consumers and the animals themselves.

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Colegio de Postgraduados

Farmers' Response to Disasters: A Study in Three Municipalities of the Sierra Nevada of Puebla

Blanca-Bautista, Martina[1]; Ramírez-Valverde, Benito[1*]

[1] Colegio de Postgraduados Campus Puebla. Santiago Momoxpan, Municipio de San Pedro Cholula, Puebla, México. C.P. 72760.

* Correspondence: bramirez@colpos.mx

ABSTRACT

Objective: This study aimed to analyze the types of disasters affecting family agriculture and to understand the strategies implemented by producers to mitigate damage to crops and the economic well-being of farming families in three municipalities of the Sierra Nevada region in Puebla.

Design/Methodology/Approach: The information used in this research was derived from secondary sources and key informants from the municipalities of Calpan, Domingo Arenas, and San Nicolás de los Ranchos in Puebla.

Results: The Sierra Nevada region is characterized by family-based subsistence agriculture, practiced on smallholdings. In response to the frequent climatic disasters that occur throughout the year —such as frost, hail, drought, strong winds, and excessive rainfall— local farmers have developed various strategies. One such strategy is the introduction of new crops, such as berries and grapes, which are better adapted to the changing environmental conditions. These crops are easier to manage and have shown strong market demand, providing farmers with a viable alternative to traditional crops.

Study Limitations/Implications: Some key informants declined to provide information.

Findings/Conclusions: Family-based agriculture is highly vulnerable to a range of disasters with varying intensities, which negatively impact the living conditions of rural populations, especially those living in poverty. In response, rural communities have developed strategies to mitigate the effects of these disasters and adapt to the changing environmental conditions.

Keywords: Family agriculture, food security, climate change

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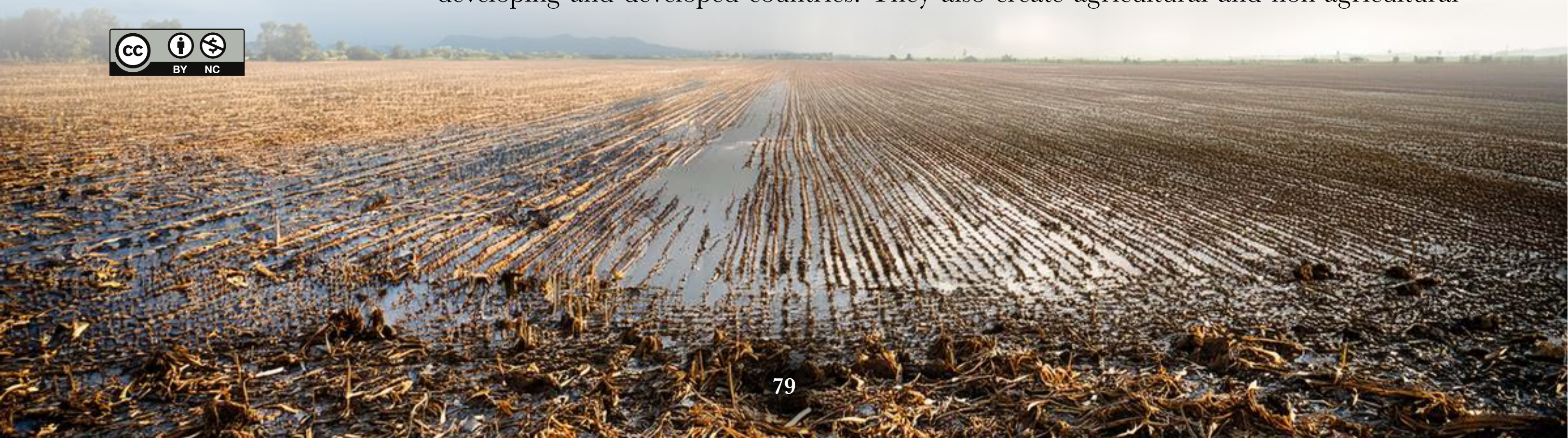
INTRODUCTION

Family agriculture refers to the managed cultivation of land, a practice that dates back over 10,000 years (Rosales, 2016). It involves the production of both plant-based and animal-based foods, relying predominantly on the labor of family members, including both men and women. Family farmers play a crucial role in providing healthy, diverse, and culturally appropriate food, producing the majority of the world's food supply in both developing and developed countries. They also create agricultural and non-agricultural



employment opportunities, contributing to the growth of rural economies. Furthermore, family agriculture helps preserve and restore biodiversity and ecosystems. Through sustainable production methods, family farmers are positioned to mitigate or prevent the risks associated with climate change (Obschatko, 2016). In addition, we are also facing climate change, which affects family agriculture and threatens the food security of farming families. This forces producers to confront increasingly atypical conditions year after year, dealing with various climatic disasters and developing strategies to mitigate these phenomena, as their agriculture is primarily rain-fed. Global warming is expected to lead to weather events that will negatively impact agricultural production (Altieri and Nicholls, 2009). On the other hand, the FAO estimates that by 2050, food production will need to increase by 70% compared to current levels to meet the demands of a growing population and its need for improved diets (FAO, 2014). This situation puts at risk the food security and quality of life of farming families, with quality of life understood as the state or sense of well-being derived from the assessment of a person's satisfaction in various dimensions of life (Urzua, 2008).

In the context of global warming, weather phenomena are expected to negatively impact agricultural production and, consequently, the populations that depend on this sector (Salazar & Godoy, 2018). Climatic disasters refer to natural events that occur as part of meteorological cycles and can cause physical, social, economic, and environmental damage in a given area. Examples of such disasters include hurricanes, droughts, wildfires, floods, strong winds, heatwaves, torrential rains, hailstorms, and frosts (WMO, 2021). The aim of this study was to analyze the types of disasters affecting family agriculture and to examine the strategies employed by producers to mitigate damage to crops and the economic well-being of farming families in three municipalities in the Sierra Nevada region of Puebla.

MATERIALS AND METHODS

Socioeconomic Characteristics of the Study Area

This research was conducted in the municipalities of Calpan, Domingo Arenas, and San Nicolás de los Ranchos, located in the central-western part of Puebla state (Figure 1). The majority of the arable land in this region is dedicated to rain-fed agriculture, with maize and beans being the predominant crops (INEGI, 2017). Maize is particularly significant, occupying 73% of the total cultivated area (INEGI, 2017). Additionally, the area is characterized by a diversified traditional agricultural production and marketing system, which includes the cultivation of indigenous fruit varieties (Mendoza *et al.*, 2010).

The population of the municipality of Calpan in 2020 was 15,271 inhabitants, according to the Population and Housing Census, with 48% being men and 42% women (INEGI, 2020). For San Nicolás de los Ranchos, the population was 11,780, comprised of 51.3% women and 48.7% men. Domingo Arenas has a total population of 7,982, with 52% women and 48% men. Among the residents, 1,847 speak an indigenous language (Nahuatl) [11] (INEGI, 2020). These municipalities are characterized by high poverty rates: 82.5% in Calpan, 86.3% in Domingo Arenas, and 83.5% in San Nicolás de los Ranchos (INEGI, 2020). Furthermore, crops in this region have suffered damage due to climatic disasters,

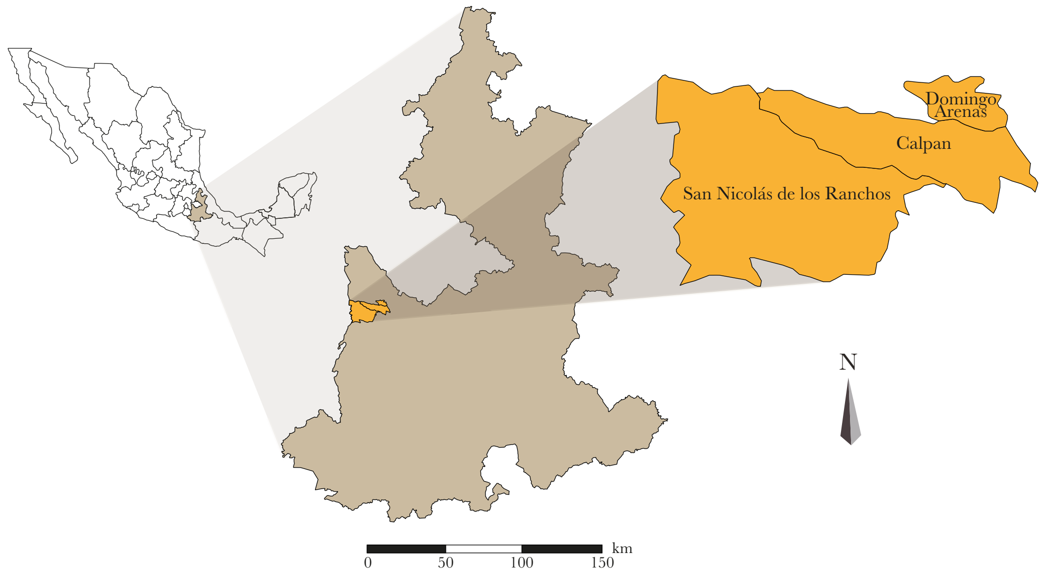


Figure 1. Geographic Location of the Municipalities of Calpan, San Nicolás de los Ranchos, and Domingo Arenas, Puebla, Mexico. Source: Created by the authors, based on: [10] INEGI, 2023. Municipal Political Division, Scale 1:250,000.

particularly maize and beans, resulting in losses of up to 800 tons in both crops (SIAP, 2022), which severely affects the living conditions of farming families.

Research Methods and Techniques

To gather information, 22 semi-structured interviews were conducted, along with direct observation using a non-probabilistic snowball sampling method. Prior to the interviews, a field survey was carried out in the municipalities to identify the families to be interviewed. The results obtained were recorded and analyzed using the ATLAS.ti software.

RESULTS AND DISCUSSION

Social Characteristics of Families

The Sierra Nevada region of Puebla is characterized by family-based rain-fed agriculture, with producers ranging in age from 18 to 98 years. They are often compelled to engage in multiple activities, with 35% working as merchants, 20% as drivers, 25% as construction workers, and 10% in professional occupations.

Due to their reliance on rain-fed agriculture, producers face various climatic disasters throughout the year. The most common are droughts (90%), frosts (51%), hailstorms (45%), strong winds (15%), and excessive rainfall (10%). López-González *et al.* (2020) report that the main disasters in the area are drought, hail, and frost, which aligns with our findings. However, our study also identifies two additional disasters that, although occurring at lower frequencies, are already causing damage to family farmers. Recently, producers have begun introducing new crops into their family units, particularly berries and grapes, due to their nutritional and economic benefits as well as their ease of management. Unfortunately, some producers in the region are now facing a new threat:

volcanic ash, due to the proximity of the municipalities to the Popocatépetl volcano. This has particularly affected berry producers, as their crops are often exposed in open fields or are grown in backyards, leading to losses of up to 45% in production, especially for blackberries.

Furthermore, the climatic disasters have necessitated changes in planting and harvesting schedules. Families that once planted in March are now delayed until May due to insufficient rainfall, resulting in harvests that were previously completed in November now occurring as late as January. This has led to food security issues for these families. Martínez-Corona (2020) notes that changes in planting calendars and production impacts are consequences of disasters such as frost and drought. Another significant impact has been the loss of varieties of pears, apples, and plums, with the *panochera* apple being at the highest risk of extinction, according to producer testimonies. This is particularly concerning as it is a key ingredient in the preparation of *chiles en nogada*, a signature dish of the region that serves as a vital source of income for families.

"*Previously, we had apple orchards, but due to rising temperatures, we have lost varieties of apples, plums, and pears, like San Juan pears and Reyna pears, which are now nearly extinct*," (Producer: Fredi Marcos, San Lucas Atzala, Calpan, 2024).

Finally, the overall production of crops such as wild cherry, peaches, apricots, blackberries, maize, and beans has declined due to the experienced disasters. These climatic events vary from year to year, preventing producers from being adequately prepared or taking preventive measures. "*We no longer know when it will frost or hail. We used to have a better understanding of the months, but now we can have frost in February and hail in October. Moreover, the rains have been significantly delayed, making it impossible to plant in March as we used to*," (producer: Alejandro Alonso from San Andrés Calpan, 2024).

According to Ulloa (2008), each culture has its own perceptions of nature, climate, and the environmental changes they experience, making it essential to understand their processes of perception and adaptation. In this context, the crops most affected by disasters have primarily been maize, beans, apples, plums, mexican hawthorn, peaches, pears, and wild cherry. This aligns with the findings of Pérez-Magaña *et al.* (2021), which identified maize, beans, apricots, plums, and peaches as the crops most impacted by such events. The increasing damage to fruit crops in recent years can be attributed to the intensification and lack of control over these disasters.

To identify the most important themes during the interviews, a word cloud was generated using the ATLAS.ti software (Figure 2). The most frequently mentioned words were "apple," "varieties," "cold," and "temperature," which is consistent with our findings. Apples were the fruit most affected by disasters, alongside significant losses of varieties of apples and other fruits due to rising temperatures in recent years. These conditions have led to prolonged droughts and a lack of chill hours, which are essential for the proper development of certain varieties.

Agroecological Practices

In response to these phenomena, producers have developed various strategies, including agroecological practices that help mitigate certain disasters. For instance, 53% of them

Figure 2. Word Cloud Created using Atlas.ti software.

routinely practice Amogotar with their maize (Figure 3). This technique involves cutting the grass and gathering it in different spots across the property to clear the land. The goal is to conserve soil moisture when the first rains come, as otherwise, the grass would block the rainwater from being absorbed. Additionally, this practice helps make the harvest process quicker and less physically demanding.

Another common practice is the formation of cajetes (42%) (Figure 4). This technique involves digging a circular depression around the base of fruit trees, approximately 30 cm deep, to capture rainwater for the trees. This method helps prevent landslides and soil erosion, ensuring better water retention for the fruit trees.

Figure 3. Amogote of Maize in San Andrés Calpan, Puebla.

Figure 4. Formation of Cajetes around Fruit Trees.

To mitigate damage caused by excessive rainfall and strong winds, 35% of producers build live barriers (Figure 5). These barriers are made using plants such as colorín, maguey, and carrizo, among others, to prevent soil erosion and crop loss.

Additionally, producers have opted to incorporate organic fertilizers (24%) instead of chemical products that harm the soil and biodiversity. In this regard, [9] López-González *et al*. (2020) highlight the importance of implementing agroecological practices across various management systems, as these practices support adaptation and mitigation in response to climate change.

Figure 5. Live Barriers

CONCLUSIONS

Smallholder family farming is increasingly exposed to various types of climatic disasters year after year, which adversely affect the living conditions of rural populations, particularly those living in poverty and extreme poverty. Disasters in the region jeopardize the food security of farming families due to the significant losses in their production. In response to this situation, rural populations have been forced to develop strategies to reduce the impact of these disasters, mainly by introducing new crops and agroecological practices.

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Biosecurity in livestock farming: strategic use of lime by-products to prevent infectious diseases and improve animal health

Olloqui, Enrique J.[1]**; Pérez-Escalante, Emmanuel**[2,3]**; Hernández-Hernández, Aldahir**[4]**; Pérez-Flores, Jesús Guadalupe**[5]**; Martínez-Carrera, Daniel**[1*]

[1] Colegio de Postgraduados, Campus Puebla, Centro de Biotecnología de Hongos Comestibles, Funcionales y Medicinales (CB-HCFM), Boulevard Forjadores de Puebla no. 205, Puebla 72760, Mexico
[2] Universidad Autónoma del Estado de Hidalgo, Área Académica de Química, Instituto de Ciencias Básicas e Ingeniería, Carretera Pachuca-Tulancingo km 4.5, Mineral de la Reforma, Hidalgo 42185, Mexico
[3] Universidad Autónoma Metropolitana Unidad Iztapalapa, Avenida San Rafael Atlixco 186, 09340 Iztapalapa, Ciudad de México, México
[4] Universidad Politécnica de Francisco I. Madero, Domicilio conocido s/n, C.P. 42660 Tepatepec, Mexico
[5] Universidad Autónoma del Estado de Hidalgo, Área Académica de Enfermería, Instituto de Ciencias de la Salud, Circuito Ex Hacienda La Concepción S/N, Carretera Pachuca-Actopan, 42060 San Agustín Tlaxiaca, Hidalgo, Mexico.
* Correspondence: dcarrera@colpos.mx

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ABSTRACT

Objective: To provide an expanded understanding of lime and its strategic uses, promote best-use practices, and reduce problems associated with livestock diseases. These measures will strengthen biosecurity in the livestock sector and protect public health.
Design/Methodology/Approach: A systematic review was carried out to update essential knowledge for everyone interested in the livestock sector, strengthening biosecurity in livestock farms and safeguarding public health.
Results: Lime and its by-products are some of the most widely used disinfectants to prevent and control infectious livestock diseases. As one of their action mechanisms, lime-based disinfectants can affect vital components of bacterial cells, reducing the risk of antimicrobial resistance.
Study Limitations/Implications: Applying different disinfectants depends on environmental factors and animal and human safety considerations.
Findings/Conclusions: Applying biosecurity measures throughout the production chain reduces the risk of introducing and spreading new pathogens on livestock farms. Meanwhile, the affordability of lime and its by-products facilitates disinfection and carcass management in facilities. Lime slurry and lime water are useful as remarkable facilitators of carcass decomposition and space disinfection.

Keywords: Livestock biosecurity, infectious diseases, lime, disinfectants.

INTRODUCTION

Livestock farming is one of the primary activities of the agricultural sector, focusing on raising domesticated animals and producing by-products for human consumption. This activity plays a significant role worldwide, accounting for 40% of agricultural production (Herrero *et al.*, 2015). In Mexico, livestock farming is one of the most important economic activities (SIAP, 2017).

However, one of the most significant challenges to livestock farming lies in controlling infectious diseases. Not all of these diseases can be tackled through preventive medicine (vaccines, bacterins, dewormers), which adds a layer of complexity to animal health management in this sector. In this regard, effective biosecurity —whose implementation encompasses practices and measures aimed at preventing the entry, spread, and transmission of pathogens, such as viruses, bacteria, and parasites— not only helps to reduce mortality among livestock but can also increase productivity and decrease the use of antibiotics (Maye and Chan, 2020). Furthermore, various animal-source foods (*e.g.*, meat, eggs, and milk) have been linked to the transmission of pathogens responsible for zoonotic diseases that impact consumers (Libera *et al.*, 2022).

Overall, infected animals can excrete a high load of viruses, bacteria, and parasites through nasal discharge, saliva, urine, feces, and even their carcasses, facilitating the spread and contamination of farms, urban settlements, and the environment in general (Stephens *et al.*, 2019). An additional risk of cross-contamination is present in farms through surfaces such as shoe soles, work clothing, and various materials (plastic, wood, metal, or textiles) that can be sources of infection for up to four days after contamination (Alam *et al.*, 2018). Therefore, cleaning and applying disinfectants are essential for the control of these diseases.

Three key elements must be considered to ensure optimal biosecurity in the agricultural industry: preventive medicine, hygiene, and the application of disinfectants (Maye and Chan, 2020). In this context, lime is a highly relevant resource that substantially benefits the prevention and control of infectious diseases due to its antibacterial properties and economic accessibility. Furthermore, the direct use of lime is recommended for organic matter. Lime can be found in various standard forms —such as quicklime (calcium oxide), slaked lime (calcium hydroxide), lime slurry, and lime water (aqueous suspensions)— all of which have disinfectant capabilities. The appropriate choice will depend on the surface and specific purpose —whether it will disinfect facilities or handle contaminated carcasses and objects (Maillard and Pascoe, 2023).

Therefore, this review explores the importance of biosecurity in livestock farming. The appropriate selection and strategic application of disinfectants and lime products will contribute to the prevention and control of infectious diseases in livestock. Additionally, the review will provide general knowledge on best practices for applying disinfectants and lime products in the agricultural sector for anyone interested in the subject. The review aims to strengthen the biosecurity of livestock operations, reduce risks to animal health, and safeguard public health.

Uses and properties of lime in animal breeding

Lime is a mineral product widely used worldwide and is fundamental to animal husbandry (Matsuzaki *et al*., 2021). Due to its antibacterial properties and low cost, it is used to combat infectious diseases in the livestock, poultry, and swine industries (Yamanaka *et al*., 2020). The resistance of microorganisms to biocides is based on their type and unique physiological characteristics. Figure 1 shows the susceptibility of different types of microorganisms to disinfectants. The intrinsic mechanisms of vegetative bacteria, bacterial endospores, and biofilms (multicellular and sessile bacterial communities) can be considered separately (Maillard and Pascoe, 2023).

Considering critical properties is essential for the selection of lime. Such properties include its specific surface area —which influences its adsorption capacity and reactivity to trap gaseous pollutants— and particle size —which accelerates reactions (Rashad, 2022).

Quicklime (calcium oxide), a by-product of the calcination of limestone, is widely used in livestock farming as a prophylactic measure against infectious diseases, primarily due to its low cost. Its action mechanism is based on its capacity to saponify fats and coagulate microbial membranes and other cells. Additionally, quicklime dehydrates tissues to the point of destruction, preventing the spread of pathogens and reducing the odors from decomposing organic matter (Maillard and Pascoe, 2023). It also prepares caustic and scarifying solutions that eliminate cattle pustules, warts, and excrescences (Maksimović *et al*., 2017).

Hydrated lime contains more than 65% calcium hydroxide (Ca(OH)) that looks like a fine white powder, is slightly soluble in water, and is used to inactivate pathogens (Thammakarn *et al*., 2015). Mixed with water, it releases a significant amount of heat. It is also known as slaked lime because calcium oxide is "slaked" upon contact with water, releasing great heat. This situation should be considered during handling.

Hydrated lime disinfects inert objects and surfaces, destroying a wide variety of microorganisms (Maillard and Pascoe, 2023). However, it is sensitive to atmospheric carbon dioxide, which converts it into calcium carbonate. Therefore, it should be stored correctly

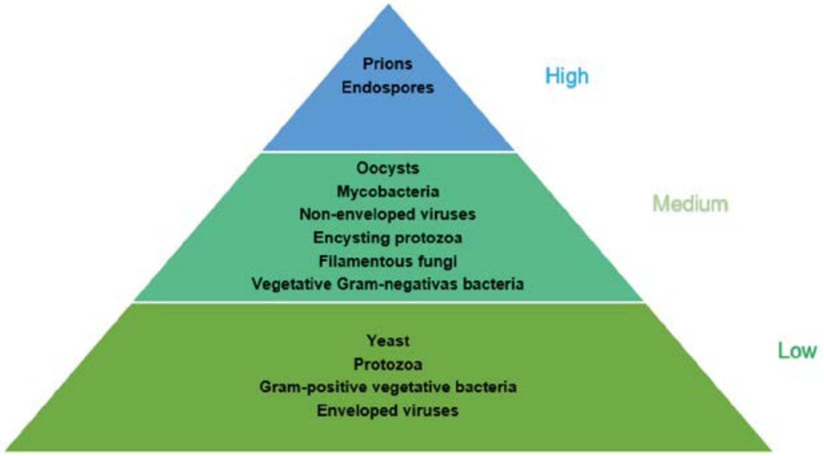

Figure 1. Susceptibility of microorganisms to disinfectants. Adapted from Maillard and Pascoe (2023).

in an airtight container protected from light or in a sealed vial with an oversaturated solution (using distilled water) (Oates, 2000).

According to Mohammadi *et al.* (2012), calcium hydroxide impacts bacterial cells in the following ways: it damages the cytoplasmic membrane of bacterial cells, denaturates proteins, and damages microbial DNA.

Damage to the cytoplasmic membrane of bacterial cells

The cell membrane plays several vital roles. It provides selective permeability, enables the transport of substances, facilitates oxidative phosphorylation in aerobic strains, contributes to enzyme production, and enables the transport of the molecules required for DNA biosynthesis, cellular polymers, and membrane lipids. When hydroxyl ions released from calcium hydroxide reach the cell membrane, they trigger a lipid oxidation process, forming free radicals and destroying phospholipids, structural components of cell membranes. Free radicals initiate a chain reaction that leads to the loss of unsaturated fatty acids and the deterioration of cell membranes.

Denaturation of proteins

The alkaline environment generated by calcium hydroxide leads to the denaturation of proteins. This process involves the destruction of the ionic bonds that hold together the protein structure. In an alkaline environment, the polypeptide chains of enzymes combine randomly, resulting in disordered and non-functional structures. These changes often lead to the loss of the biological activity of enzymes and the disruption of cellular metabolism.

Damage to microbial DNA

Hydroxide ions trigger reactions that lead to the cleavage of microbial DNA and cause gene damage, interfering with the DNA replication process. Furthermore, the radicals generated by these reactions can also induce destructive mutations in the genetic material (Mohammadi *et al.*, 2012).

Meanwhile, the resistance of microorganisms to pH changes since most of them multiply within a 6 to 9 pH range; however, some strains can survive with 8 or 9 pH, and they often cause secondary infections.

In Japan, the use of hydrated lime is recommended for sterilizing facilities. Farmers often use it —on its own or combined with quaternary ammonium compounds (Kabir *et al.*, 2021; Hassan *et al.*, 2022) or with cresol and sodium hypochlorite (Ruenphet *et al.*, 2019)— in footbaths to inactivate viruses and bacteria found on boots during the freezing season. However, hydrated lime may take 3 to 6 hours to inactivate pathogens (Bashandy *et al.*, 2016). Additionally, hydrated lime creates a sterile layer on the surface of remains or carcasses. When exposed to air, it absorbs carbon dioxide and releases water, hardening and forming a crust of solid calcium carbonate. This method has been applied to human remains, animal carcasses, and slaughterhouse waste to reduce the pathogen load, decrease putrefaction odors, and deter pathogen dispersion by scavengers (Bowden *et al.*, 2023).

To properly handle animal carcasses, two layers of hydrated lime should be applied in a pit (one beneath and one above the carcass), and the pit should be covered with soil. The manufacturer's safety instructions must be followed when handling hydrated lime to avoid direct contact with skin, eyes, or mucous membranes. Handlers should wear gloves at all times. After the dead animals have been buried in the ground, a new layer of hydrated lime should be applied over the entire surface and up to 2 meters around the sanitary pit to seal the pit. This procedure helps to reduce the pathogen load and to maintain environmental hygiene. Finally, alterations by scavenger animals should be prevented, as they can negate its effect (Bowden *et al.*, 2023).

Lime slurry and lime water

On the one hand, the lime slurry is usually prepared by mixing one part hydrated lime with nine parts water (1:10), resulting in an opaque white suspension. On the other hand, lime water is obtained by filtering the lime slurry, and this alkaline solution quickly becomes turbid due to the absorption of atmospheric carbon dioxide and the formation of insoluble calcium carbonate (Oates, 2000). These dispersions are commonly applied in the decomposition of carcasses, and their residues are buried close to where the animals died, preferably in elevated areas rich in silica or calcium. This measure is recommended when cremating the carcasses is challenging or even impossible —given the scarcity and high price of the firewood required to reduce the carcasses to ashes (Sánchez *et al.*, 2008).

In addition, lime slurry and lime water are used to disinfect spaces such as premises, stables, chicken coops, and pens. Organic matter and food residues that have been in contact with infected animals or carcasses that will be incinerated should be removed from those facilities before they are disinfected. A 10% lime slurry can be applied for at least two hours to disinfect residues with high moisture content. Similarly, disinfection with a complete internal application of sodium hypochlorite and an external application of lime is effective against salmonellosis, classical swine fever, and scrapie (Gosling, 2018; Park *et al.*, 2020; Alarcon *et al.*, 2021). Subsequently, lime slurry is used to "whitewash" walls and wood. In addition to its bactericidal effect, it gives a cleaner appearance to poultry houses and chicken coops (Franz *et al.*, 2020). For this procedure, 10 kg of quicklime, 500 g of sodium chloride, and 10 L of water are commonly used to increase the solubility of lime slurry (Saipullaev *et al.*, 2020). Recently, Wang *et al.* (2024) found that pig excreta can be soaked for a longer time in anaerobic digestion systems to inhibit the impact of lime, consequently enhancing biogas production efficiency through the improvement of acidification and hydrolysis. A similar effect can be achieved by applying carbon dioxide bubbles (Li *et al.*, 2024).

Ultimately, in its various forms, lime plays a crucial role in animal husbandry and health promotion in the livestock industry. Due to its antibacterial properties and ability to neutralize pathogens, lime has become an invaluable tool for preserving health and hygiene in breeding environments and handling animal remains. However, it must be used with care, following recommended safety guidelines. The versatility of lime makes it a fundamental resource, both in disease prevention and in the disinfection of spaces, consequently contributing to the well-being of animals and the cleanliness and health of livestock environments.

CONCLUSIONS

This review provides essential knowledge for anyone interested in strengthening biosecurity in livestock operations, reducing risks to animal health, and safeguarding public health. The responsible and appropriate use of lime by-products was comprehensively addressed to avoid undesirable consequences. Additionally, the properties and uses of lime in animal husbandry were explored, highlighting its relevance for the disinfection of facilities, the management of carcasses, and the reduction of the pathogen load. Lime has emerged as a versatile and affordable tool that significantly contributes to biosecurity in the agricultural industry. Correctly applying disinfectants and having a comprehensive understanding of the processes involved are fundamental steps toward a safer and healthier future in livestock and agricultural production.

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Date estimation for the control of avocado (*Persea americana* Mill.) anthracnose (*Colletotrichum* spp.)

Duran-Peralta, Elisa[1]; Huerta-de la Peña, Arturo[1]; Acuayte-Valdes, Consuelo[2]; Núñez-Tovar, Ramón[1*]

[1] Colegio de Postgraduados – Campus Puebla. Maestría en Desarrollo e Innovación en Fruticultura Familiar, Bulevar Forjadores de Puebla Núm. 205. Santiago Momoxpan. Municipio de San Pedro Cholula. C.P. 72760, Puebla, México.

[2] Ingeniería en Agronomía-Nova Universitas. Carretera a Puerto Ángel km 34.5, Ocotlán de Morelos, Oaxaca. C.P. 71513. Tel. 55 16086172.

* Correspondence: nunezt@colpos.mx

ABSTRACT

Objective: To generate a program that estimates the dates or times for the control of avocado anthracnose, based on the meteorological conditions required for the infection, establishment, and development process.

Design/Methodology/Approach: An Excel program was developed to estimate temperature (T), relative humidity (RH), dew point (PR), leaf wetness (LW), and probability of precipitation (PoP) and to evaluate, on an hour-per-hour basis, the fulfillment of the climate thresholds required for the establishment and development of *Colletotrichum* spp. The maximum and minimum daily temperature must be determined with an 80% probability of occurrence and the probability of precipitation. This information was obtained from the daily records of the CONAGUA (National Water Commission) weather stations for three avocado-producing municipalities in Puebla during a 16-year period (2007-2022).

Results: The resulting program estimates the meteorological variables for the following ten days. The conditions in January were not optimal for the onset and development of avocado anthracnose in the three municipalities of Puebla taken as a case study. On the contrary, June had optimal temperature and relative humidity, as well as a higher probability of precipitation.

Study Limitations/Implications: Accurate data on the meteorological conditions of the orchards under study are required to increase efficiency.

Findings/Conclusions: The program will help producers to determine application dates, developing a more user-friendly and efficient management proposal for controlling avocado anthracnose.

Keywords: weather, Colletotrichum, forecast.

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INTRODUCTION

Avocado is native to Mexico and Central America (Williams, 1977). The oldest avocado fossils (7,000-years old) were found in a cave in Coxcatlan, Puebla (Smith, 1966). The greatest diversity of both plants and pathogens can be found in this region of the world. This situation is key for genetic improvement or biological control programs. Mexico's main exports include avocado, tomato, berries, tequila, and beer. Mexico supplies 45% of the world export market for avocado (FAOSTAT, 2022). Most of the produce is harvested

from October to February, with a medium offer from March to May and a low production from June to September (Barrientos, 2010). This phenomenon opens a window for sales from states in which avocado production has been recently introduced, including Puebla, Morelos, and the State of Mexico.

Anthracnose is one of the major avocado diseases and it diminishes both the quality and quantity of the production. It has been recorded both before and after the harvest. Determining the weather conditions that contribute to the onset and development of fungi and inputting them into a software enable research teams to verify which dates and conditions are favorable for the onset of the infection process. These results enable a timely decision-making regarding preventive control and the use of biological control, biorational insecticides, or other environmentally-friendly controls that do not involve worked or consumer health.

The *Colletotrichum* and *Glomerella* fungi (in their asexual and sexual phases, respectively) cause the death of flowers, as well as sunblotch, brown spots, purple patches, and other general avocado anthracnose syndromes (Figure 1). The indiscriminate use of agrochemicals to control these fungi has caused the selection of resistant fungus populations. Some products prevent spore germination and inhibit the development of appressoria or haustoria; however, they must be applied at the right time to achieve a good pathogen control. Duran *et al.* (2017) determined the infection thresholds for the

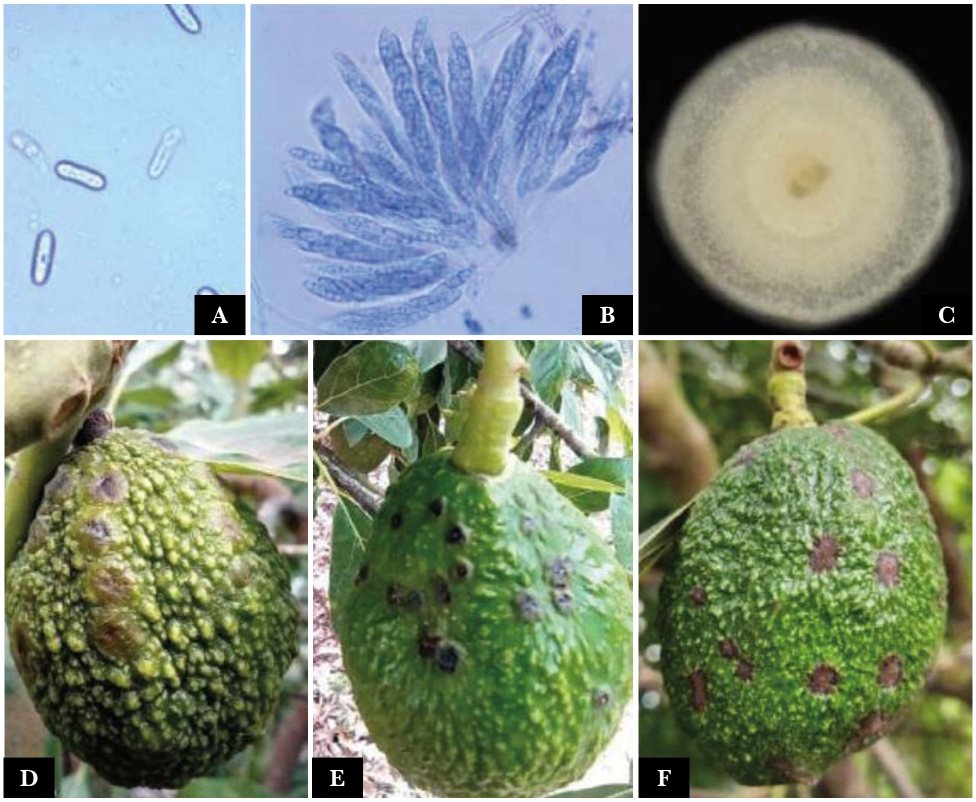

Figure 1. A) *Colletotrichum* sp. conidia (A). B) *Glomerella* sp. asci and ascospores. C) *Colletotrichum* sp. colony in a Petri dish. D), E), and F) *Colletotrichum* sp. symptoms in avocado.

onset and development of avocado anthracnose. The aim of this study was to develop a program that estimated the appropriate dates or time for the control of avocado anthracnose, based on the meteorological conditions required for the establishment and development of the disease.

MATERIAL AND METHODS

An Excel program was developed to estimate temperature (T), relative humidity (HR), precipitation (PR), leaf wetness (LW), and probability of precipitation (PoP) and to evaluate, on an hour-per-hour basis, the fulfilment of the climate thresholds required for the establishment and development of *Colletotrichum* spp. The daily maximum and minimum temperature must be determined with an 80% probability of occurrence and the probability of precipitation. The data were obtained from the daily records of the CONAGUA weather stations from 2007 to 2022 for three avocado-producing municipalities in the state of Puebla: Chilchotla (station 21067), Zacatlán (station 21107), and Atlixco (station 21012). The resulting program estimates the meteorological variables for the following ten days.

Based on the maximum and minimum temperature forecast, the program determined the hourly temperature using the method developed by Linvill (1990) and the relative humidity, dew point, leaf wetness, and precipitation based on their probability of occurrence. Four continuous hours are required to achieve the optimal conditions for the development of anthracnose. When those conditions are met, the program informs, through a written message, that the infection thresholds of *Colletotrichum* spp. in avocado have been exceeded. Based on the optimal conditions for the onset of the infection (Duran-Peralta *et al.*, 2017), the program points out the potential date(s) in which the favorable conditions for the development of the disease will be met.

The method developed by Linvill (1990) was used to determine hourly temperature, based on the minimum and maximum temperature of the day in question and the minimum temperature of the following day.

A lineal function was estimated for the relative humidity, based on the behavior of hourly data of the day in question, using the 2003-2020 records of the CONAGUA weather stations in Atlixco, Chilchotla, and Zacatlan. Relative humidity was estimated with a 79% probability of occurrence, using the following formula:

$$RH = -0.0015 * H4 + 0.0839H3 - 1.3536H2 + 5.1597H1 + 1.131RH$$

Where: RH=relative humidity; $H4$=relative humidity at hour 4; $H3$=relative humidity at hour 3; $H2$=relative humidity at hour 2; $H1$=relative humidity at hour 1.

The dew point was estimated based on the temperature and relative hourly humidity resulting from the following equation:

$$DP = 8RH * 112 + 0.9 * T + 0.1 * T - 112100$$

Where: DP=dew point; T=temperature in °C; RH=relative humidity.

Historical records were consulted to estimate the probability of occurrence (p=0.80) of precipitation (0=no and 1=yes). This information was obtained from the 2007-2022 daily records of the CONAGUA weather stations located in the avocado-producing municipalities of Atlixco, Chilchotla, and Zacatlán.

The leaf wetness criteria were based on the behavior of weather data: a 35 min LW was estimated with precipitation; a 1.2 to 0.7 difference between temperature and dew point was calculated at 50 min LW; an estimated < 07 difference means a 60 min LW; and other data indicated a 0 LW. The hours of solar radiation were estimated with the Witt method (1995), which considers the sunrise time and the latitude of the orchard.

The resulting program was used to estimate the dates in which the optimal conditions for the onset and development of the disease would be fulfilled. The results were compared with the anthracnose symptoms recorded in two avocado orchards in each of the municipalities under study. The data for the evaluation period were arranged per week and input into the R software to determine their correlation coefficient.

RESULTS AND DISCUSSION

The program forecasts and describes the behavior of the minimum and maximum temperature, dew point, precipitation, relative humidity, and leaf wetness for the following ten days. The conditions were not optimal during January in the orchards from the three municipalities used as study cases; meanwhile, temperature and relative humidity were optimal in June, when rains also recorded a greater probability of occurrence. The program issues an alert every time that the conditions for the onset or development of the fungi are met. In certain times of the year, adequate conditions prevail for a very long time and therefore many alerts are issued in some weeks (Table 1). Risk models based on weather variables can be used to optimize application dates and to reduce to a minimum the number of times that spray should be applied to control the disease (Guzmán-Plazola, 1997).

The Instituto de Investigaciones Agropecuarias (INIA, 2019) developed an information platform which models meteorological data recorded by the INIA automated weather stations in southern Chile, in order to determine favorable conditions for the development of the *P. infestans* infection. This highly-efficient platform has diminished

Table 1. Evaluation of the anthracnose detection program in avocado orchards in Atlixco and Chilchotla (2023 production cycle).

Information	Atlixco		Chilchotla	
	Orchard 1	Orchard 2	Orchard 1	Orchard 2
Evaluation period	04 april to 20 august		28 march to 26 october	
First alert	04-apr		28-march	
First detection of symptoms	10-apr		3-apr	
Numbers of days with alerts	64		75	
Numbers of days with symptoms	24	22	32	
Correlation coefficient	0.8313	0.8135	0.8019	0.8058

the number of applications by 50%, achieving a similar control of the disease than a fixed schedule program (Acuña and Gutiérrez 2019). MELCAST is another alert system based on weather conditions; it is used to control leaf diseases in melons and watermelons, diminishing the application of fungicides by 20% (Egel and Latin, 2012).

Comparing the dates in which the optimal conditions for the onset and development of the disease are met and the dates in which symptoms were recorded in the field resulted in an R^2 of 0.83 and 0.81 in Atlixco and an R^2 of 0.80 in both orchards in Chilchotla (Table 1). Since Zacatlan has very varied weather conditions and drastic changes were recorded between nearby orchards, the weather data taken from the local weather stations were not considered representative of the evaluated orchards.

Humidity involves relative humidity, leaf wetness, and precipitation (Gillespie and Sentelhas, 2008). Temperature can be evaluated as environmental temperature, soil temperature, plant temperature, and dew point. Studying the relation between meteorological variables and pest and disease development —as a tool to forecast major agricultural events— is part of a comprehensive management (Badnakhe *et al.*, 2018; De Oliveira-Aparecido *et al.*, 2020).

Meteorological models alert producers about potential disease outbreaks; therefore, agrometeorology contributes to the management of diseases (Gillespie and Sentelhas, 2008). Additionally, disease forecasting could favor a lower use of pesticides and reduce their economic and environmental consequences (De Wolf and Isard, 2007). Vizcaino *et al.* (2021) developed a list of fungicides that have been authorized for the control of avocado anthracnose; this list includes active ingredients that have been authorized for their exportation to the USA (Table 2). Producers should alternate between products with different action modes to prevent the selection of resistant populations. Copper fungicides and strobilurins are commonly used to control anthracnose in the field, since they inhibit spore germination; meanwhile, Fluazinam® inhibits mycelial growth and spore germination, but is not effective in the field (Everett *et al.*, 2005). Copper and systemic fungicide mixes are promising treatments for producers whose plants require a healing effect (Vizcaino-Ríos *et al.*, 2021).

This study estimated the dates in which the meteorological requirements for the infection of avocado plants by *Colletotrichum* spp. were met in three municipalities of Puebla. Researching the environmental factors that make up or influence the infection and the disease cycle is essential to understand the onset and establishment of the disease (Evans *et al.*, 1992). The program is a guide for scheduling fungicide applications: However, common sense should also be applied. If the disease exercises a strong pressure on the orchard, the producers should return to the 15-day fungicide application schedule.

CONCLUSIONS

The system developed in this research describes and forecasts the behavior of minimum and maximum temperature, relative humidity, leaf wetness, dew point, and precipitation for the following ten days. During January, the conditions were not optimal in the orchards evaluated in the three municipalities used as case studies; however,

Table 2. List of fungicides recommended for the control of anthracnose in avocado orchards (APEAM, 2020).

Technical name	Classification for resistance management	
	Chemical group	Action mode
Azoxystrobin	Metoxi-acrilatos	Respiración (C3. Complejo III: citocrom bc1 (ubiquinol oxidasa) on site Qo (gen cyt b)
Azufre Elemental	Inorgánicos	Contact action Multi-site
Azufre elemental + Oxicloruro de Cobre	Inorgánicas + Sales orgánicas de cobre	Contact action Multi-site
Boscalid + Pyraclostrobin	Piridina-carboxamida + Metoxicarbamato	Succinate inhibitor deshidrogenasa + inhibidores de quinone
Cyprodinil+Fludioxonil	Anilinopyrimidina + Fenilpirrol	It acts by inhibiting the biosynthesis of metionine +TIt acts in the actúa in y the transport associated to glucose phosphorylation
Folpet	M 04	Contact action Multi-site
Fluoxastrobin	Dihidro-dioxazinas	Complejo III del breathing process
Cupric Oxide	Sales Inorgánicos de cobre	Contact action Multi-site
Copper Hydroxide	Sales Inorgánicos de cobre	Contact action Multi-site
Hidróxido Cúprico + Folpet	Sales Inorgánicos + Ftalimidas	Contact Action Multi-site
copper oxychloride	Sales inorgánicas de cobre	Contact action Multi-site
Cuprous oxide	Inorgánico	Contact action Multi-site
Octanoato de Cobre	Inorgánico (electrófilos)	Acción de contacto Multi-sitio
Pyraclostrobin	Metoxicarbamato	inhibidores de quinona
Propiconazol	Triazoles	ergosterol biosynthesis
Copper Sulfate Pentahydrate	Inorganic copper salts	Contact action Multi-site
Copper sulphate	Inorganic copper salts	Contact action Multi-site
Tiabenzadol	Bencimidazoles	Inhibitors of mitosis and cell division
Tribasic Copper Calcium Chloride	Inorgánic	Multi site
Thiram	Ditiocarbamatos	It acts on the enzymatic systems, causing an accumulation of pyruvic acid that prevents the germination of spores.

Source: Table developed by Vizcaino-Ríos *et al.* (2021).

the weather conditions in June were favorable for the onset of the infection and the development of *Colletotrichum* spp. in avocado.

The chemical control of avocado anthracnose involves the application of fungicides that have been authorized by APEAM, the Mexican association of avocado producers, packers, and exporters. The frequency of the application depends of the residual efficacy of fungicides. According to the program, a systemic fungicide can be applied at the moment when the onset of the disease is expected —to diminish the initial inoculum and to delay the start of the pandemic— and a contact fungicide can be applied as a response to anthracnose alerts and when the protective effect of fungicide has ended. Systemic fungicides can be applied at the start of the rainy season, when the program indicates that the environmental factors have been met. Contact products can be applied again after the rainy season is over, on the dates determined by the program and the residual efficacy of fungicides. Determining application dates helps to develop an improvement program for the efficient control of avocado anthracnose. The program can be applied in other avocado-producing zones. The only requirements are the temperature and humidity data for the orchard under study provided by a weather station and an evaluation of the development threshold of the pathogen. The program will help avocado producers to optimize application time, based on temperature and humidity conditions, instead of applying fungicides every 15 days.

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Physico-chemical properties of the soil and effect of chemical fertilizers on the nutritional quality of *ayocote* runner bean (*Phaseolus coccineus* L.)

Taboada-Gaytán, Oswaldo Rey[1*]; López-León, Itzel[2]; Juárez-Ventura, Oliver Ricardo[2]

[1] Colegio de Postgraduados, Campus Puebla. Boulevard Forjadores de Puebla núm. 205, Santiago Momoxpan, San Pedro Cholula, Puebla. México. C.P. 72760.

[2] Universidad Politécnica de Puebla, Tercer Carril del Ejido, Serrano s/n, Cuanalá, 72640 Puebla, Puebla, México.

* Correspondence: toswaldo@colpos.mx

ABSTRACT

Ayocote runner bean (*Phaseolus coccineus* L.) is a pulse native to the temperate areas of Mexico. A high bean yield can be obtained through the proper combination of variety, environment, and agronomical practices.

Objective: To determine the physico-chemical properties of the soil, as well as the effect of six chemical fertilizer formulas applied in the field on the soluble carbohydrate and protein content of *ayocote* runner beans in three municipalities of Puebla.

Design/Methodology/Approach: Twenty representative pods were collected per site where each fertilizer formula was applied. One-hundred seeds were ground to quantify in triplicate the soluble carbohydrate and protein content. Soil samples were subjected to a granulometry process prior to their chemical analysis. The ANOVA and mean test procedures of the SAS software were used for the statistical analysis of the information.

Results: *Ayocote* runner bean samples recorded the best physical and nutritional properties in Calpan, where the soil had remarkable physical and bio-chemical properties at a depth of 20-40 cm. The best nutritional characteristics in seeds were recorded with the 80-60 N-P kg per hectare formula.

Study Limitations/Implications: More sites should be studied to assess with greater accuracy the environmental effect.

Findings/Conclusions: Evaluation environments recorded variations in soil texture and the nutrient and organic matter content required for plant nutrition. Fertilizer formulas with high N and P contents favor the protein and soluble carbohydrate content, consequently improving the nutritional quality of the seeds.

Key words: *Phaseolus coccineus*, environmental effect, physical and nutritional properties, soil type, beans.

INTRODUCTION

Ayocote runner bean (*Phaseolus coccineus* L.) is a pulse native to the temperate regions of Mexico. It has a great productive potential and it is mainly used as food, although the whole plant (flowers, pods, seeds, and forage) can be used (Rojas *et al.*, 2017). The seed yield (SY) of a given crop depends on several factors, including: soil type, weather, cultivar, crop management, plant density (which can determine the SY increase), cycle

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length, growth behavior of the crop, fertilization, and water availability (Rojas *et al*., 2017). *Ayocote* runner bean is known as *ayecotli*, *frijolillo* ("little bean"), *frijol de risa* ("laughter bean"), *yexixima*, and *frijolón*. It is widely distributed in the Valley of Mexico, from 2,300 to 3,000 m.a.s.l. It can be found in pastures, scrublands, and pine and oak forests (Vargas *et al*., 2013).

In the municipalities of Libres and Serdán, Puebla, ayocote runner bean is sown as a monoculture, while, in the states of Hidalgo, Mexico, and Tlaxcala, it is sown under a polyculture system (along with corn or common bean). *P. coccineus* is also grown and consumed in the highlands of the state of Chiapas. Meanwhile, in the states of Chihuahua, Durango, and Zacatecas, *patol* (*ayocote* runner beans with white seeds) is produced along with the common seasonal bean; its seeds have diverse and dotted patterns, depending on the state (Vargas *et al*., 2011; Vargas *et al*., 2013).

The main problems faced by bean cultivation in Mexico are diseases, pests, drought, and low temperatures. Fungi that take part in endomycorrhizae can reduce the damage caused by pests (including nematodes) or pathogenic fungi (Garza *et al*., 2003). Bean plants inoculated with mycorrhizae (specifically, *Glomus mosseae*) grow more and have a greater yield in soils with low P availability (Khalil *et al*., 2015).

A high seed yield can be achieved with the proper combination of variety, environment (temperature and relative humidity), and agronomic practices (García *et al*., 2003). Bean cultivation requires the application of several macronutrients, including N, P, and K. N usually has a greater impact on growth, yield, and quality; meanwhile, P plays an important role during seedling germination and development, root development, fertilization, and the start of fruiting; finally, K is important for the permeability of cell membranes, intracellular acid-base balance, development and accumulation of reserve materials, and the regulation of the water status of crops (Ancín, 2011.).

The aim of this research was to determine the physico-chemical properties of the soil and the effect of six chemical fertilizers, applied in the field, on the nutritious quality of ayocote runner beans, in three municipalities of the state of Puebla.

MATERIALS AND METHODS

Study area

The soil and black runner bean samples (classified as Population 89) were collected in the following sites: Calpan, municipality of San Andrés Calpan; Santa María Tianguistenco, municipality of San Miguel Huejotzingo; and Santa María Zacatepec, municipality of Juan C. Bonilla (Figure 1) (INEGI, 2009 a,b,c). Several N (60 and 80 units) and P (40, 60, and 80 units) levels were evaluated per hectare (ha), resulting in six fertilization formulas: 1) 60-40; 2) 60-60; 3) 60-80; 4) 80-40; 5) 80-60; and 6) 80-80. The plant density (80,000 and 100,000 plants per ha) resulted in a total of 12 treatments with 3 repetitions each, established in the field under an experimental design with a 6×2 factor. The experimental plots were identified at the time of harvest and a five-plant sample was taken from each of the three repetitions for each fertilizer formula. One-hundred seeds were extracted from representative pods of each sample. The beans were subsequently ground, used to produce flour, or analyzed.

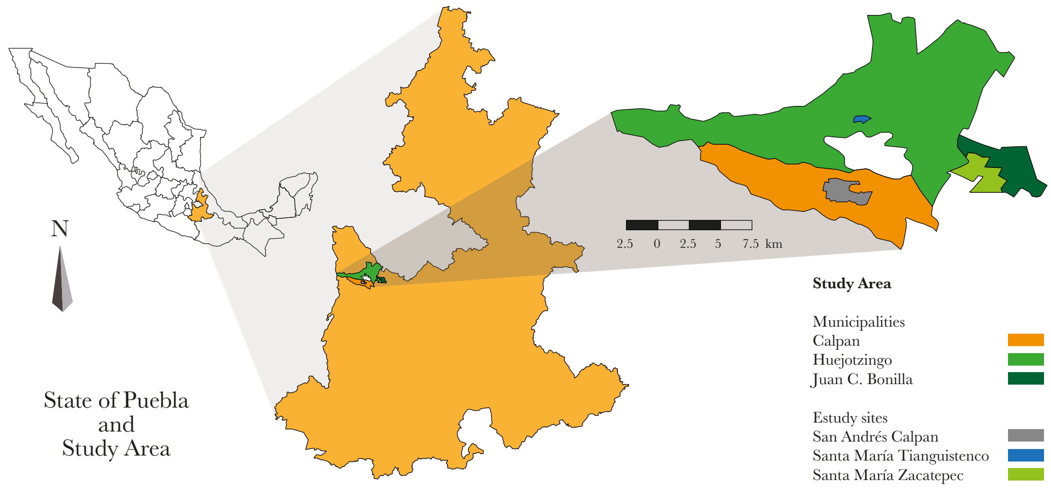

Figure 1. Study sites.

Physico-chemical properties of the soil samples

A homogenous sample was prepared from five subsamples taken from five squares at two depths (0 to 20 and 20 to 40 cm). The following soil variables were evaluated: granulometry (no. 4, 10, 20, 40, and 200 meshes), field humidity, residual humidity, texture determination (Bouyoucos method), total N, mineral N, organic matter (ashes and oxidizable organic matter), pH (Conductronic® PC18 potentiometer), electrical conductivity (RCYAGO® C-600 ph meter), TDS (Total Dissolved Solids), RP (Reduction Potential), salinity, and Ca and Mg availability in the soil (NOM-021-RECNAT-2000; Mendoza and Espinoza 2017). All determinations were made in triplicate.

Characteristics of runner beans

One-hundred seeds per fertilizer formula were analyzed per evaluation site. The seeds were ground and put in sealable bags and a Thermo-Scientific™ Evolution 300 UV-Vis spectrophotometer was used to determine the soluble carbohydrate content in the plant material. Likewise, the Micro Kjeldahl method was used to determine the protein content (Alvarado-López *et al.*, 2019). Finally, determinations were also carried out in triplicate.

Statistical analysis

The ANOVA and Tukey's test ($P=0.05$) procedures from the SAS software were used for the statistical analysis of the data.

RESULTS AND DISCUSSION

Physico-chemical properties of the soil

Santa María Zacatepec has sandy loam soil (0-20 cm) and loamy sand (20-40 cm). The soil in Calpan is sandy loam (0-20 cm) and loamy clay sand (20-40 cm). Finally, most soils in Santa María Tianguistenco are sandy loams (0-20 cm) and loam (20-40 cm).

Table 1. Analysis of variance of the soil variables of three sites in three municipalities of the state of Puebla.

Source of variation	pH	CE	MOX	COT	NT	Ca	Mg
LOC	0.0665ns	1150.3889*	1.3102*	0.0046ns	0.00009ns	14590.1033*	49595.6228***
REP(LOC)	0.0262ns	98.7222ns	0.1345ns	0.0418ns	0.0001ns	6613.3144ns	549.2053ns
PROF	0.2964**	112.500ns	1.7797*	0.0103ns	0.0003ns	70205.0169*	150434.4843***
LOC*PROF	0.2815**	123.500ns	0.3567ns	0.0046ns	0.0006*	112222.288***	3694.3435*
CV	1.8669	16.5923	26.6777	16.6518	12.0658	15.76932	5.457948
Media	6.6028	48.2778	1.6133	1.8694	0.0851	323.7465	452.7427

ST (LOC): site; REP(ST) (REP(LOC)): repetition per site; DEP (PROF): depth; ST*DEP (LOC*FERT): site per depth; CV: coefficient of variation; EC (CE): electrical conductivity; OOM (MOX): oxidizable organic matter; TOC (COT): total organic carbon; TN (NT): total nitrogen; Ca: calcium; Mg: magnesium; ns: non-significant differences; and *, **, and ***: $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$ statistical significance, respectively.

Table 1 shows significant EC, OOM, Ca, and Mg differences per site. Significant differences were recorded in the pH, OOM, Ca, and Mg variables at the two soil sampling depths. Meanwhile, significant pH, Ca, and Mg differences were recorded, depending on the site-depth interaction. Both nutrients are available at both depths (0-20 and 20-40 cm) and in the three study sites. Ca and Mg influence crop growth and development. On the one hand, Ca helps to neutralize the soil, regulates the operation of cell membranes, reduces the phytotoxicity of B, and participates in the development of enzymes, among other effects. On the other hand, Mg improves cellular hydration and osmotic pressure, regulates acidity, is part of the reserve compound of seeds, and activates several enzyme systems involved in the metabolism of protein synthesis, among other functions (Urbano-Terrón, 2011; Millán-Martín, Abadía-Bayona and Heras-Cobo, 1981).

Characteristics of runner beans

Table 2 shows the amount of soluble carbohydrates and proteins in runner beans as a percentage of dry matter. Significant carbohydrate differences were recorded per site,

Table 2. Analysis of variance for the variables recorded in ayocote runner beans, resulting from application of six fertilizer formulas in three sites of three municipalities from the state of Puebla.

Source of variation	Soluble carbohydrates (%)	Proteins (%)
LOC	281.9709***	1.1880ns
REP(LOC)	0.0302ns	1.1664ns
FERT	56.9604***	2.8533*
LOC*FERT	199.9764***	3.2803***
CV	0.4164	4.3519
Media	40.4411	18.3520

ST (LOC): site; REP(ST) (REP(LOC)): repetition per site; FERT: fertilizer formula; ST*DEP (LOC*FERT): site per depth; CV: coefficient of variation; ns: non-significant differences; and *, **, and ***: $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$ statistical significance, respectively.

fertilization, and site per fertilization; meanwhile, significant differences in proteins can only be found in fertilization and site per fertilization. Differences in protein and carbohydrate content could be associated with the application of fertilizers in the soil, the environment, and even different cultivars (Alvarado-López *et al.*, 2019).

Figure 2 shows that the samples from site 1 recorded the lowest carbohydrate content, followed by site 3 and site 2 (highest value). Therefore, the soil fertility properties of Calpan, along with the nutrients supplied through chemical fertilizers, enable a higher accumulation of soluble carbohydrates (CAR). The carbohydrates levels of the samples from the three study sites are lower than the 64.41% results reported by Bernardino *et al.*, (2016); those carbohydrates mainly consisted of starch with various amylose and amylopectin concentrations.

Figure 3 shows that fertilizer formulas 4 and 5 (80-60 and 80-40 N-P, respectively) had a statistically higher carbohydrate content, while the best carbohydrate accumulation in the bean had been recorded with the 60-60 N-P fertilizer formula. The use of N in ayocote

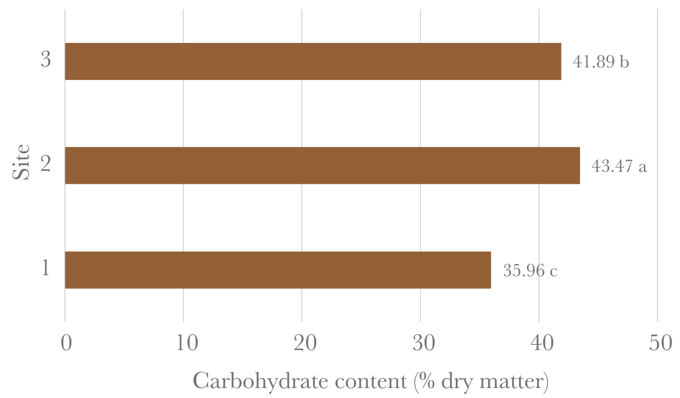

Figure 2. Dry soluble carbohydrate (CARB) content in *ayocote* runner bean samples, depending on the location of the crop. ST 1 (LOC 1): Santa María Zacatepec, municipality of Juan C. Bonilla; ST 2 (LOC 2): Calpan, municipality of San Andrés Calpan; ST 3 (LOC 3): Santa María Tienguistenco, municipality of San Miguel Huejotzingo. Values with the same letter are not statistically different (P≤0.05.)

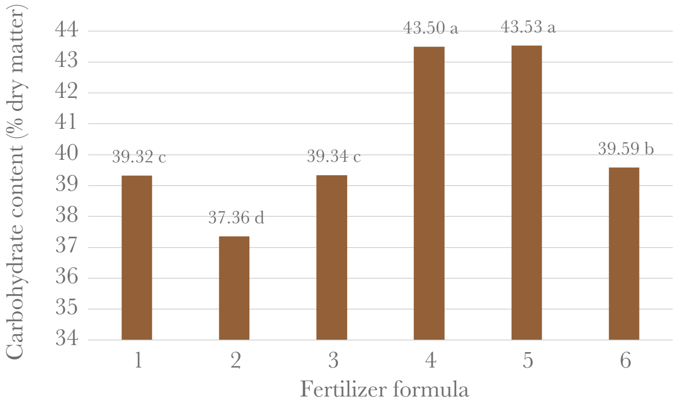

Figure 3. Carbohydrate content (CARB) of *ayocote* runner bean samples, depending on the fertilizer formula (N-P) applied during its cultivation: 1) 60-40; 2) 60-60; 3) 60-80; 4) 80-40; 5) 80-60; and 6) 80-80. Values with the same letter are not statistically different (P≤0.05.)

runner bean cultivation increases its carbohydrate and protein content, since the seeds are mainly composed of 40% carbohydrates, 25% proteins, and 15% other mineral substances and lipids (Rojas, Escalante, and Aguilar, 2023; Vargas-Vázquez et al., 2020). These results match the findings of this research: a fertilization doses with a higher N content resulted in higher carbohydrate levels.

Figure 4 shows that formula 6 (80-80 N-P) has a higher protein level (19.11%) than the other fertilization doses. The protein data obtained are higher than the 18.4 and 18.0% results reported by Pérez-Herrera *et al.* (2002) and Corzo-Ríos *et al.*, (2020), respectively. However, they are much lower than the 20.46, 21.93, and 21.7% reported by Osorio-Díaz *et al.* (2004), Bernardino *et al.* (2016), and Jacinto-Hernández *et al.* (2019), respectively.

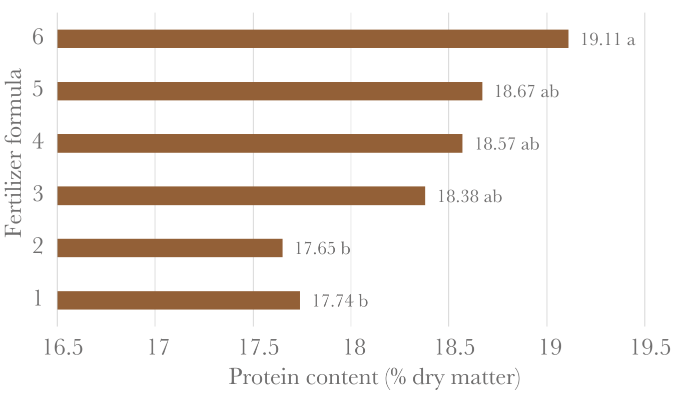

Figure 4. Protein content of *ayocote* runner bean samples, depending on the N-P formula applied during its cultivation: 1) 60-40; 2) 60-60; 3) 60-80; 4) 80-40; 5) 80-60; and 6) 80-80. Values with the same letter are not statistically different ($P \leq 0.05$.).

CONCLUSIONS

The statistical differences between the physical properties and fertility of the soils of the study sites depended on the type of soil and could be observed both in the variation of the soil texture and in the nutrient and organic matter content required for plant nutrition, among other variables.

Fertilizer formulas with high N and P content favor the protein and soluble carbohydrate content, consequently improving the nutritional quality of seeds.

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Effect of antifreeze action products used to prevent frost damage during the vegetative and reproductive stages of common bean

Calderón-Tomás, Celene[1]; Díaz-Ruiz, Ramón[1*]; Contreras-Ramos, Juan[1]; Pérez-Ramírez, Efraín[1]; Pérez-Armendáriz, Beatriz[2]; Álvarez-Gaxiola, Jesús F.[1]

[1] Colegio de Postgraduados, Campus Puebla. Boulevard Forjadores de Puebla núm. 205, Santiago Momoxpan, San Pedro Cholula, Puebla. México. C.P. 72760.

[2] Universidad Popular Autónoma del Estado de Puebla. Avenida 9 Poniente 1712, Barrio de Santiago, Puebla, México. C.P. 72090

* Correspondence: dramon@colpos.mx

ABSTRACT

Objective: To establish the frost damage to the stem and root nodules and protection degree of products with antifreeze potential, during the V2, V3, R6, and R7 phenological stages of bean.

Design/Methodology/Approach: Black beans with a type II indeterminate bushy habit were collected. Antifreeze (An), amino acids (Am), gibberellins (Gib) and their combinations were applied at 48-hour intervals. Subsequently, the plants were subjected to frost (0 °C) in a freezer for 1.5 h. Damage was evaluated in a 0 to 100% scale. The nodules were stained with 2,3,5-triphenyl tetrazolium chloride salt. Stained nodules were considered undamaged and non-stained nodules were considered damaged.

Results: Significant differences were found during the phenological stages and between the antifreeze action product treatments. Stage V3 was the most tolerant to frost, while stages R6 and R7 were the most susceptible. The number of undamaged and damaged nodules showed highly significant differences ($p \leq 0.01$) between phenological stages and between treatments, as well as in the total number of nodules. An and Ve+An recorded good effects, followed by Ve+Am. Gib was the least efficient product during the four stages.

Study Limitations/Implications: The increase of substances with antifreeze effect in different doses should be tested.

Findings/Conclusions: Frost caused different levels of damage in each phenological stage. V3 stood out as the most tolerant stage. All the products recorded different protection degrees during the phenological stages. Ve+An, An, and Ve+Am recorded the highest antifreeze action.

Keywords: *Phaseolus vulgaris* L., low temperatures, phenology, antifreeze products.

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INTRODUCTION

As a result of its protein content, bean (*Phaseolus vulgaris* L.) is a staple food worldwide. It helps soil fertilization (Maldonado *et al.*, 2015), through its atmospheric nitrogen fixation. Consequently, bean is grown in different areas, including humid tropics, semi-arid regions (Hernández-López *et al.*, 2013), and highlands, where low temperatures severely damage

production. Frost causes great damages to agriculture, because this weather phenomenon is very difficult to predict. Although implementing a system to protect crops from frost is very expensive, there are several alternatives, including a passive method to prevent the effect of frosts. This long-term method is particularly beneficial under frost conditions and is related to biological and environmental technologies used to reduce potential damage (Snyder and Melo-Abreu, 2010).

One of the passive methods used to prevent frost damages is the use of organic matter and the appropriate type of soil. This method highly improves soil characteristics, increasing heat capacity, maintaining a stable thermal regime, increasing and preserving structural soil stability, permeability, and water retention capacity, facilitating gas exchange, reducing erosion, and improving crop nutrition (Labrador, 2001; Fuentes-Yague, 2002). Another passive mechanism to prevent frost is a good soil nutrition. Consequently, the application of amino acids helps to mitigate wounds caused by abiotic stress. These biostimulants are known for their positive effects on growth and yield (Sadak *et al.*, 2015). Amino acids act when plants suffer physiological changes, playing a very important role in water balance (Espasa-Manresa, 1983). Stabilized vegetable oils can protect plants from temperature changes (extreme cold weather), preventing the formation of intracellular ice. Therefore, the objective of this study was to determine the frost damage in the stem and root nodules and the protection degree of potential antifreeze substances, during the V2, V3, R6, and R7 phenological stages of bean.

MATERIALS AND METHODS

Bean variety and sowing

Black beans with a type II indeterminate bushy habit were collected from the Tepeyahualco de Cuauhtémoc community in the State of Puebla. The seeds were sown in 21 cm wide × 30 cm tall plastic pots, with agricultural soil (As) and vermicomposting (Ve) prepared with cow manure mixed with agricultural soil (50:50 ratio). Seeds were placed at a depth of 2.5 cm and were fertilized that same day, with the ammonium nitrate and triple super phosphate and calcium sources for nitrogen and phosphorous, respectively, using the 40-40 formula.

Phenological stages

The vegetative stages were V2 and V3, while the reproduction stages were R6 and R7. The identification of the beginning of each phenological stage was based on the characteristics established by Escalante-Estrada and Kohashi-Shibata (1993).

Antifreeze action products

The following products were applied to the plant stems: antifreeze (An), amino acids (Am), and gibberellins (Gib). The An was made up of 95% stabilized vegetable oil (Grupo Ibarquim S. A. de C.V.). The thin biodegradable waxy layer produced by the oil acts as a physical barrier during extreme cold weather (≥0 °C), preventing the formation of intracellular ice (Table 1). The Am used in the experiment came from the Aminocel 500© commercial product. Amino acids enable the fast generation of proteins, but using less energy. They favor the balance between photosynthesis and respiration. This product was made up of 50% free amino acids, 10% nitrogen, 8% phosphorous, and 10% potassium. Finally, Gib were obtained from BioGib10PS, made up of 10% gibberellic acid and 90% diluents and conditioners. Gib stimulates plant growth, uniforms flowering, and improves fruit bearing and development.

Frost simulation

An, Am, and Gib were applied when the plants reached their vegetative and reproductive stages. Four plants were randomly chosen for the application of each treatment. The plants were subjected to two applications with 48 h intervals. The products were manually applied in the stems, using 900 ml atomizers. The doses applied were those recommended by the manufacturers of each product (Table 1). No products were applied to the AS and Ve control treatments. At 96 h after the application, plants were placed inside a Tor Rey Refrigeration CV-32 freezer and subjected to frost (0 °C) for 1.5 h.

Evaluation of frost damage in the stem

Plants were evaluated 48 h after they were taken out of the freezer. Damages produced to the plant organs were expressed in percentages from 0 to 100%, where 0 is an undamaged plant and 100% is a completely damaged plant.

Evaluation of frost damage in the root

Root damage was evaluated staining the roots with 2,3,5-triphenyl tetrazolium chloride salt. The seed feasibility test proposed by Moreno (1984) was used to stain and detect *Rhizobium* bacterial activity. The roots were placed in beakers and were completely immersed in a 0.1% tetrazolium salt solution for 60 minutes. Subsequently, the red-stained nodules were counted. These nodules were considered as undamaged. Meanwhile, the unstained nodules were considered as damaged.

Data analysis

An ANOVA was performed to detect statistical differences between treatments, while Tukey's Test ($\alpha=0.05$) was used to determine which treatments better mitigated frost damages. Both analyses were conducted with SAS v.9 statistical package for Windows.

Table 1. Antifreeze action products and doses used in the experiment.

Treatments	Dosage	Abbreviation
Agricultural soil	--	AS
Antifreeze	10 ml l^{-1}	An
Amino acids	1.5 g l^{-1}	Am
Gibberellins	0.05 g l^{-1}	Gib
Vermicompost*	50%	Ve
Vermicompost*+Antifreeze	50%+10 ml l^{-1}	Ve+An
Vermicompost*+Amino acids	50%+1.5 g l^{-1}	Ve+Am
Vermicompost*+Gibberellins	50%+0.05 g l^{-1}	Ve+Gib

RESULTS AND DISCUSSION

Stem damage caused by frost

The analysis of variance detected significant differences ($p \leq 0.01$) in the bean stem damage caused by frost, during the different phenological stages and between antifreeze action product treatments. Stage V3 (Figure 1) recorded the lowest frost damage (7.5%), while stages V2, R6, and R7 reached 22-31% damage to the stem. Consequently, V3 is the most tolerant stage to low temperatures. Meanwhile, the different damage level caused to other stages can be the result of the susceptibility of each stage to frost. Ambroise *et al.* (2020) mentioned that frost tolerance depends on the species, type of plant organ, and plant age; consequently, the earliest stages are more tolerant to frost. For their part, Calderón-Tomás *et al.* (2023) studied frost damage during the vegetative stage of bean and recorded that V3 was the most tolerant stage. Therefore, reproduction is the most vulnerable stage, given the susceptibility of reproductive organs to low temperatures.

The treatments showed a different protection degree in each stage (V2, V3, R6, and R7). During stage V2, damage was not detected with the Ve+An, Ve+Am, Am and An treatments (Figure 2), while the highest damage percentage was recorded with the Gib (71%) and Ve+Gib (83%) treatments. This situation can be the result of the exogenous application of gibberellins, which produces a wide variety of responses during the development of the plant, particularly at cellular level (Amador-Alférez *et al.*, 2013). Damage was lower (10%) during stage V3. However, the Ve+Gib treatment resulted in 50% stem damage. The significant damage suffered by Gib-treated plants during these stages can be the consequence of the impact of low temperatures on the synthesis and transport of hormones (Jones, 1985), which causes a physiological imbalance. The lowest frost damage was recorded during the reproductive stage of bean, with the Ve and Am treatments (Figure 2), while the highest damage was recorded with AS, followed by Gib. The Ve+An treatment applied in plants during stage R7 recorded a higher protection degree, followed by An. Meanwhile, the highest damage was recorded by the Ve+Gib treatment.

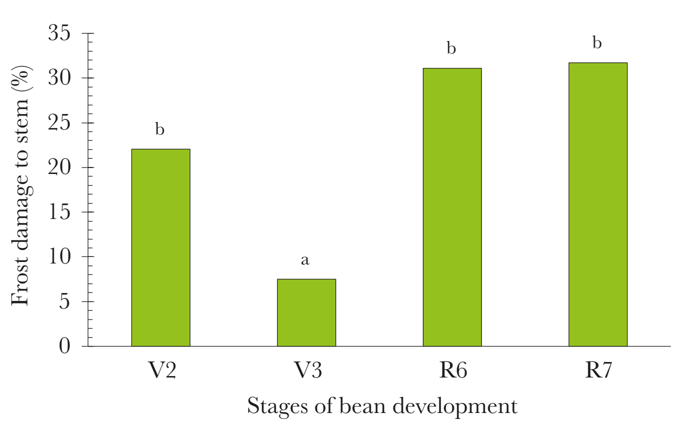

Figure 1. Frost damages in bean stems, during their phenological, vegetative, and reproductive stages.

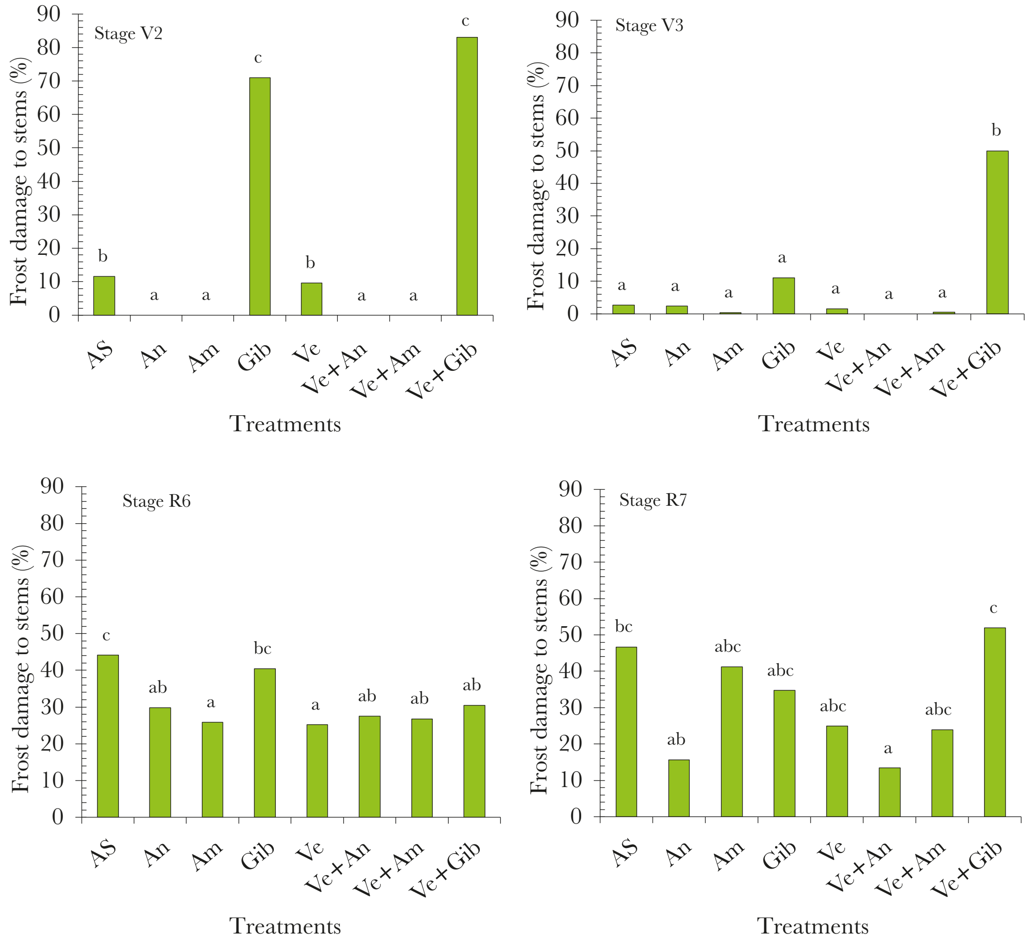

Figure 2. Frost damage to stems with the application of antifreeze products in the vegetative and reproductive stages of beans. AS: agricultural soil. An: antifreeze. Am: amino acids. Gib: gibberellins. Ve: vermicompost. Ve+An: vermicompost+antifreeze. Ve+Am: vermicompost+amino acids. Ve+Gib: vermicompost+gibberellins.

Each organ of the plant showed different sensitivity to the same frost conditions, but the leaves recorded most of the damage. This phenomenon could be related to the water percentage (90-94%) of pulses (Alcántar-González and Trejo-Téllez, 2009). Except for the Ve+Gib treatment, the lowest damage to the leaf structures in stages R6 and R7 was recorded in bean plants whose treatment included vermicompost. The water retention of vermicompost helped to alleviate the damage caused by low temperatures, because the roots were still able to provide water to the stem. Meanwhile, Badaruddin and Meyer (2001) worked with fields at full capacity and reported a lower damage to alfalfa and soybean seedlings caused by frost in soils with light texture than to seedlings that grew in soils with heavy texture. Therefore, the water content resulting from the moisture in the roots softens the impact of frosts. In conclusion, substrates with good water retention capacity (*e.g.*, compost or vermicompost) help to diminish the damages caused by low temperatures.

Undamaged leaves were protected by the antifreeze in the Ve+An treatment; meanwhile, the protection provided by the Ve+Am and Am treatments could be the result of an increase in the nutritional reserves of plant tissues, which lessen the effect of frosts. According to Chaar (2013), nutrient reserves influence the resistance to frosts, through the starch degradation in osmotically active compounds. This phenomenon increases the over-freezing capacity of the plant tissue and prevents or diminishes the risk of freezing.

Gibberellins are synthesized in different parts of the plants. This hormone is found in high levels on the leaves and buds of seedlings during their growing stages (Jordán and Casaretto, 2006). Therefore, the clear division and cell elongation of constantly growing tissues could favor the conditions under which frosts directly impact the tissues. Additionally, low temperatures determine the conversion of inactive gibberellins into active molecules in the other organs (Jordán and Casaretto, 2006).

Shafiq *et al.* (2012) reported that, during the flowering and pod development stages, the seed yield of peas sown on the field was negatively impacted by their exposition to −4.8 °C for 4 h. This phenomenon could be observed in pod, flower, and bud abortions and deaths, as well as the smaller seed size. The said research team concluded that genetic variation was reported in 83 accessions collected in 34 countries, 60 of which did not have buds, flowers, or pods after the frosts.

Root

Significantly high differences ($p \leq 0.01$) in the number of undamaged (NodU) and damaged (NodD) nodules were recorded between phenological stages and between treatments. The total number of nodules was highly significant between stages and treatments (Table 2).

More nodules were formed during stages R6 and R7 (Figure 3). Meanwhile, a lower number were recorded in stages V2 and V3, when a lower number of damaged nodules was also observed.

The highest number of nodules was developed in stage V2 with Ve+An (Figure 4). The AS treatment recorded the highest number of NodD. The Ve+An and Ve+Am treatments recorded the highest number of undamaged nodules in stage V3; the number of damaged nodules was not significantly different between treatments in this stage. Stage R6 recorded the highest number of undamaged nodules with the Am treatment, while the lowest quantity was obtained with the Ve+An treatment. For its part, the Gib treatment provided the highest number of NodD, while the Am, Ve, and Ve+An treatments recorded the lowest quantity. The highest number of damaged nodules was recorded in stage R7

Table 2. Mean squared error of the number of nodules developed by the roots of bean plants subjected to frost.

Source	NodU	NodD	NodTotal
Sta	2071202.642**	225.7862319**	2235285.961**
Tre	57929.212**	64.4558377*	49046.524**
Sta*Tre	58937.962**	41.4145223**	58704.060**

ns: non-significant. ** significantly statistical differences ($p \leq 0.01$). Sta: stage. Tre: treatments. NodU: number of undamaged nodules. NodD: number of damaged nodules. NodTotal: total number of nodules.

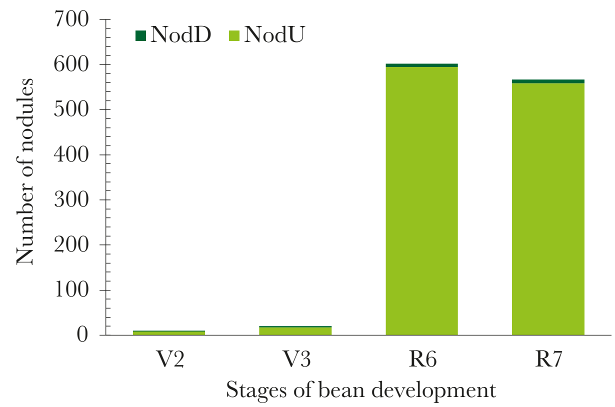

Figure 3. Number of undamaged and damaged nodules during four phenological stages of common bean. NodU: number of undamaged nodules. NodD: number of damaged nodules. Tukey (p≤0.05). Different letters represent a significant difference.

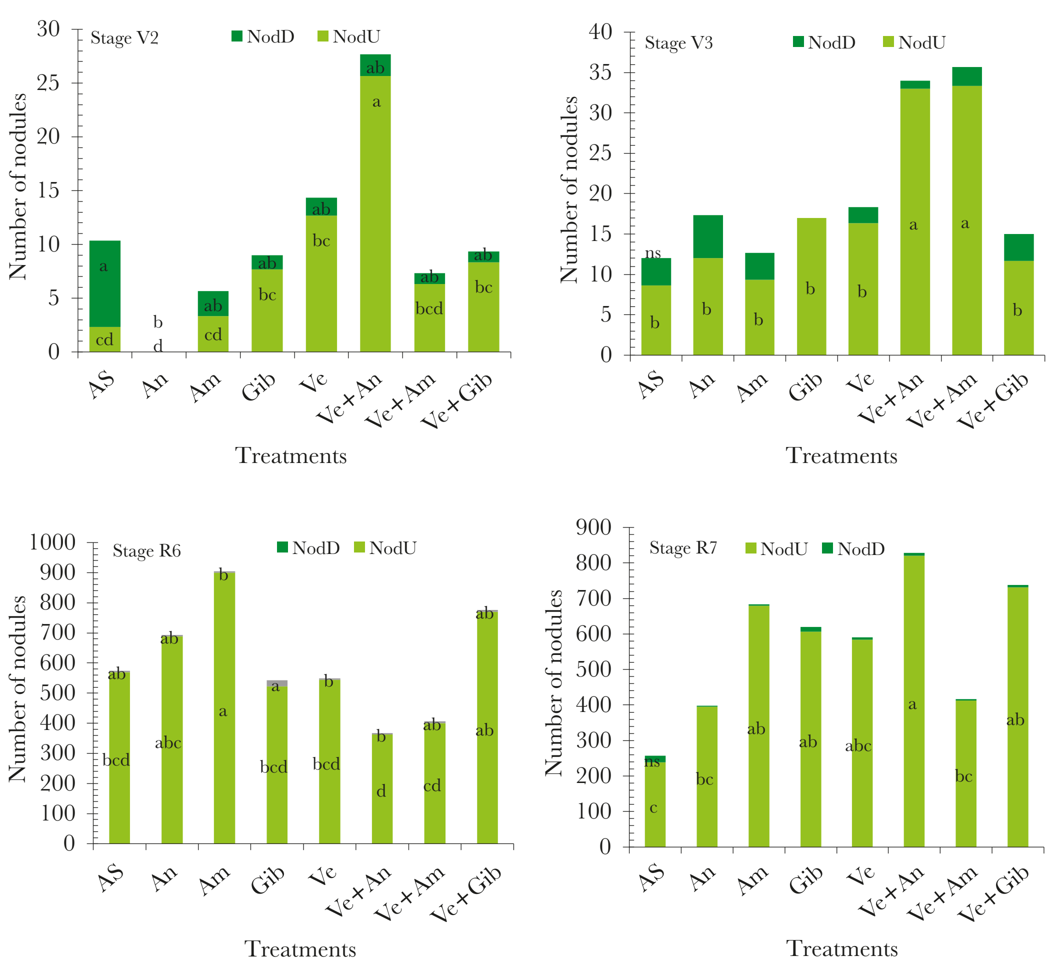

Figure 4. Number of root nodules damaged and undamaged by frosts, as a consequence of the application of antifreeze products, during four phenological stages of common bean. Tukey (p≤0.05). Different letters represent significant statistical differences. NodU: number of undamaged nodules. NodD: number of damaged nodules. AS: agricultural soil. An: antifreeze. Am: amino acids. Gib: gibberellins. Ve: vermicompost. Ve+An: vermicompost+antifreeze. Ve+Am: vermicompost+amino acids. Ve+Gib: vermicompost+gibberellins.

with the Ve+An treatment and the lowest number was reported with AS; meanwhile, the amount of NodD did not show a significant difference. A greater number of undamaged nodules and a lower number of damaged nodules mean that the root was not damaged by the frost; therefore, this organ of the bean plant can play an important role in the recovery of plants in which the treatments resulted in a lower damage to the stem. The final survival and the shoot production in *Vicia faba* grown in pots and exposed to freezing temperatures was related to the survival of the roots, rather than to the survival of the shoots (Sallam *et al.*, 2015). A similar phenomenon could happen with beans. Despite an increase in the global mean temperature, frost damage is likely to increase in the future, mainly because a greater climate variability would expose roots to lower temperatures and to more frequent freezing and unfreezing cycles, which could diminish agricultural productivity in temperate and colder climates (Ambroise *et al.*, 2020).

CONCLUSIONS

The impact of frosts on plant stems during the different evaluation stages caused damage of various magnitudes. Stage V3 was the most tolerant to frost. Antifreeze product treatments had a different effect in each stage: the Ve+An, Am, and Ve treatments provided greater protection during stage V2; the Ve+An treatment did not record damages in the stems as a consequence of the frost; the Ve+Gib treatment reported the highest damage; and the best treatments during stage R6 and R7 were the Ve and An treatments, respectively.

Frosts did not have a visible effect on the roots. However, the number of nodules was statistically different between treatments: the Ve+An treatment recorded the highest number of active nodules in stage V2, while the Ve+An and Ve+Am treatments had an equivalent effect in stage V3. For their part, the Am and Ve+An treatments reported the highest number of active nodules in R6 and R7, respectively.

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Social reproduction strategies and climate change in communal lands in the Sierra Nevada of Puebla, Mexico

Martínez-Corona, Beatriz[1*]; Méndez-Cadena, María Esther[1]

[1] Colegio de Postgraduados, Campus Puebla, Blvd. Forjadores de Puebla No. 205, Santiago Momoxpan, San Pedro Cholula, estado de Puebla, México. C.P. 72760.
* Correspondence: beatrizm@colpos.mx

ABSTRACT
Objectives: To understand the socio-demographics of *ejido* communities in the Sierra Nevada region of Puebla, Mexico, their social reproduction strategies within domestic units, their perception of climate change and its impact, and their interest in training on the subject.
Methodology: A questionnaire was administered to a probabilistic sample of 334 *ejidatarios* from ten *ejidos* in the municipalities of Calpan, Chiautzingo, San Nicolás de los Ranchos, and San Salvador El Verde; 16.2% of the *ejidatarios* in the sample were women and 83.8% were men.
Results: Of the 334 *ejidatarios* in the sample, 70% were between 46 and 75 years old and 97% declared they knew how to read and write. Their social reproduction strategies are agriculture (55.7%), selling labor force (23.7%), housewifery (9.3%), commerce (4.5%), and other activities (6.8%). Such diversification is associated with the impacts of climate change on agricultural production. In terms of land, 71% is owned by the *ejidatarios*, themselves, with 65% having a working area of 1-2 ha. A percentage as high as 89.8% of *ejidatarios* have heard about climate change, with 93.4% indicating personal and domestic unit affectations; 99.4% identified climate transformations, and 88.6% declared interest in training on the subject.
Study implications: Participants in the study showed motivation to learn about five thematic axes of climate change, fostering a commitment to continue producing collaborative knowledge and designing strategies to enhance the adaptation strategies of *ejidos* in the region.
Conclusions: There was consensus among participants on the perception of climate change and its effects. Climate change requires them to strengthen and develop adaptation strategies applicable to reproduction strategies. To do so, they need access to training and participation in the production of collaborative knowledge on the subject in the region.

Keywords: Climatic variability, Pluriactivity, Ejidos, Environmental training.

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INTRODUCTION

Global transformations linked to climate change have been widely recognized. Climate change is a deviation from historical climate patterns at different scales —global, regional, and local— due to natural and human causes, with activities in the agricultural sector being particularly significant. The increase in greenhouse gas emissions (GHG) has led to atmospheric alterations, affecting climate variability over time. Reports on the

impact of climate change on agriculture highlight the need to produce knowledge that aims at promoting adaptation strategies in rural environments. Mexican climate change legislation, the *Ley General de Cambio Climático* —enacted in 2012 and revised in November 2023— outlines its main objectives in Article 2: "... to guarantee the right to a healthy environment and to establish the concurrent jurisdiction of the Federation, federal entities, and municipalities in developing and implementing public policies to adapt to climate change and mitigate greenhouse gas emissions" (DOF 11-15-2023, p. 1).

This legislation emphasizes the shared responsibility of government and society in reducing greenhouse gas emissions and calls for continued research on how rural communities —such as the ejidos or communal lands in the municipalities of the Sierra Nevada region of Puebla, Mexico— perceive and experience climate change in the context of agricultural practices and social reproduction strategies (Batista-Fonseca, 2021). Studying social reproduction strategies helps us understand the everyday practices of social subjects in their environment. The concept, developed by De Oliveira *et al.* (1989) among others, provides a framework to analyze how farmer households adapt to socio-environmental challenges such as climate change and its effects on agricultural practices, as well as structural issues such as the endurance of poverty (Alcazar-Sánchez *et al.*, 2022). Understanding the characteristics of ejidal groups is critical to examining the socio-demographic factors that influence the creation of social reproduction strategies, particularly those aimed at adaptation to and mitigation of climate change.

Social context informs the configuration of reality among social groups. Thus, environmental perceptions are governed by culture and the socio-historical moment in which people live. Everything we think, believe, and build is part of such a construct. Gender, age, and education, among other socio-demographic factors, can influence how groups perceive specific environmental phenomena and their effects (Flores *et al.*, 2014). Hence the importance of understanding these perceptions to develop capacities and actions aimed at adapting to, mitigating, or remediating the causes and effects of climate change.

MATERIAL AND METHODS

This study used a descriptive-interpretive approach, employing quantitative tools to examine the socio-demographic characteristics of a representative sample of *ejido* members, their awareness of climate change, and the impacts they experience. According to Vizcaíno *et al.* (2023), this approach helps identify patterns and trends in data and explore causal relationships or correlations between variables. The data collection instrument was a questionnaire administered to a probabilistic sample defined through simple random sampling and including 334 *ejidatarios*, both men and women, from ten *ejidos*: Analco de Ponciano Arriaga, San Agustín Atzompa, San Andrés Calpan, San Gregorio Aztotoacan, San Lorenzo Chiautzingo, San Mateo Ozolco, San Nicolás de los Ranchos, San Pedro Yancuitlalpan, San Salvador El Verde, San Simón Atzizintla, y Tlatenco, located in the municipalities of Calpan, Chiautzingo, San Nicolás de los Ranchos and San Salvador El Verde.

RESULTS AND DISCUSSION

Participant characteristics

Of the 334 participants surveyed, 16.2% were women and 83.8% were men. Male predominance is due to the traditional allocation of *ejido* landownership to men, which limits access for women. In terms of age distribution, the 56-65-year-old group was the largest, with 86 people (25.7%), followed by the 46-55 group with 76 people (22.8%). The 66-75 group comprised 65 people (19.5%), while the 36-45 age group had 44 individuals (13.2%). At the extremes, 22 *ejidatarios* were aged 24-35 (6.6%), 31 were aged 76-85 (9.3%), and four were between 86 and 95 years old (1.2%). This distribution shows a higher concentration of people in the intermediate age range, in alignment with national trends, where most communal landowners are over 50 years old. Regarding literacy, 96.7% of participants reported being able to read and write, while 3.3% said they could not. As for educational levels, out of 45.5% who shared this information, 23.4% completed elementary school, 10.2% completed secondary school, 1.8% completed high school, 9% completed higher education, and 9.3% had incomplete elementary or secondary schooling.

In terms of marital status, we observed a remarkable diversity: 71.9% indicated they were married, 11.1% were widowed, and 8.4% lived with a partner. Moreover, 6.6% identified themselves as single, 1.2% as divorced, and 0.9% as separated. This variability reflects the heterogeneity of relationships and life experiences in these communities.

As regards the social reproduction strategies reported by *ejidatarios*, a notable 55.7% declared being occupied in agriculture, followed by 23.7% who also work in construction, 4.5% in commerce, and 9.3% in crucial activities such as the domestic and care work entailed in housewifery (9.3%). Another 4.2% performed other tasks, such as external domestic service. These figures show a variety of reproduction strategies in the respondents' domestic units and communities, highlighting the diversity of occupations and ways in which members of the *ejidos* contribute to the workforce (Hernández-Flores, 2021).

The difficulties in meeting basic needs and improving living conditions lead many residents of the region to consider migration. Indeed, 56.9% of participants reported having migrant relatives, while 42.5% denied having migrant family members. This finding underscores the importance of understanding migration dynamics. Migration is exacerbated by climate change (Baca *et al.*, 2022) and has various implications for local communities in the region, including structural issues that impact the endurance of poverty.

Information relative to landowning provided crucial findings on power dynamics, access to resources, and decision-making capacities within domestic units. Landownership impacts access to natural resources, property rights, decision-making, and the economic well-being of individuals and families. Moreover, this data allows us to identify gender, social, and economic inequalities that may exist within communities —point in case, the percentage of women included in the sample (16.2%), a trend confirmed by information in the Censo Nacional Agropecuario (INEGI, 2022), according to which 81% of agricultural producers are men and only 19% are women. Specifically, Puebla is the state with the highest percentage of women in charge of production units (12%). In the present study, 68.6% of the interviewees indicated that the ejidatarios are the landowners, 12.0% indicated that the land is owned by the parents, 3.6% said the land is owned by the children, and 15.9% did not share this information.

The area of land owned provides perspective on the distribution of natural resources in the *ejidos* of the region. To this effect, 41.0% of the respondents possess 1 hectare, 24.0% have 2 hectares, 18.9% have less than 1 hectare, 8.1% have more than 3 hectares, and 7.8% have 3 hectares. These data are crucial to understand how structural features favor the endurance of poverty in the region, prompt limitations in living conditions, and give rise to the diversification and multiplicity of reproduction strategies in the *ejido* domestic units.

Responsibility distribution within the household is also relevant to comprehending family dynamics. In this regard, 32.6% of the interviewees participate in household chores. Said chores are carried out by wives (46.4%), daughters or sons (9.0%), husbands (3.6%), and sisters, daughters or sisters-in-law (3.6%). In addition, 1.2% of participants indicated that household chores are performed by their grandchildren and only 0.3% said that they have the support of a domestic worker. These findings stress the importance of inquiring into the division of domestic labor and its implications in the configuration of gender equality and family well-being, since this type of work falls heavily on women.

Care and domestic work are relevant tasks within the *ejido* domestic units because they allow for workforce reproduction and favor its members' well-being. According to the results, 48.2% of the participants oversee seniors and children care. Moreover, 6.6% provide care to sick people and accompany them in medical care, while 4.5% are in charge of dropping children at school and maintaining communication with the educational institution. On the other hand, 39.2% of participants —mainly made up of men— indicated that they are not involved in any care activities. It is crucial to stress that, in rural areas, care activities are fundamental for the well-being and social reproduction of families. However, the unequal distribution of these tasks and responsibilities reveals gender inequalities, echoing the need to continue working towards a more equitable distribution of work among members of *ejido* domestic units, since work overload among women produces physical and emotional discomfort and limits women's options for development (Ramos-Cela *et al.*, 2021).

Climate change

When asked whether they had heard of climate change, 89.8% of respondents answered affirmatively. Those unaware of the term were aged 56 to 85. This age distribution suggests that older people are less prone to identify the concept, although not the phenomenon, since 98.8% of participants acknowledged changes in weather patterns, which they perceive as series of transformations, alterations, shifts, and modifications in temperature, seasonal patterns, and rainfall patterns. Figure 1 shows the most frequently mentioned trends in the perception of climatic alterations. Mentions to weather and temperature disruptions are numerous, with participants reporting increased heat and extreme weather events (frost, hail, droughts, storms, and wind). In short, respondents mentioned changes in seasonal patterns.

Figure 1. Weather variability, seasonal pattern shifts, and climate change perception. Source: Fieldwork, 2023.

Climate variability poses major challenges in terms of the stability and predictability necessary for agriculture, which in turn impacts various aspects of the lives of *ejidatarios* and their environment. In this regard, 93.4% reported being affected by climate change on both individual and family levels. Understanding the effects of climate change faced by interviewees is key for the development of effective responses that favor adaptation strategies, mitigate losses in food production, favor agricultural sustainability, and reduce risks in productivity, health, and well-being in rural communities. The *ejidatarios* surveyed pointed out that uncontrolled rainfall, lack of seasonal rain, heavy frosts, and droughts damage crops. They also noted that the degradation of natural environment harms everyone, drying out trees in the forest, affecting access to water, and damaging land, crops, and nature overall. These adverse effects impact the livelihood of *ejidatarios* in that they receive lower incomes (60.2%), are more prone to poverty (70.1%), are forced to rent their land (19.5%), and obtain lower yields (30%). Among this study's findings there is a series of concerns that participants associate with the impacts of climate change and the options they consider to mitigate them or adapt: 84.7% of participants consider migration as a possibility, reflecting the severe economic impacts they face; 82.3% indicated the need to find additional jobs, which suggests the precarity of the local economy and the need to resort to selling labor as a reproduction strategy. Another notable aspect was that many (80.8%) regard storing water as a key adaptation strategy due to scarcity. These data illustrate the climate-related challenges faced by agricultural communities, and the urgent need to implement measures addressing climate change impact through adaptation, mitigation, and restoration strategies.

In rural areas, temperature fluctuation and extreme hydro meteorological events have a direct impact on food production, bringing an increase in pests and diseases, and reducing surface area suitable for cultivation, among other effects (Gómez *et al.*, 2024). Considering the reality reported by informants, initiatives to understand, prevent, adapt to, and mitigate the effects of climate change are vital. In this context, training and knowledge exchange are necessary to enhance adaptation strategies based on local expertise and academic research with the aim to positively affect the community (Valdanha, 2024). Promoting collaborative processes to produce knowledge and alternative practices, with the participation of various social actors, is also key for addressing this global problem effectively and sustainably. As for training related to climate change, 88.3% of participants claimed to need it, outlining 295 topics of interest. Based on the latter, five main training areas were identified: 1) defining climate change (CC) and its causes; 2) understanding and analyzing the impact of CC, how it affects agriculture, how to address it, and its effects on the field and on everyday life; 3) holding back the problem and establishing measures conducive to reverse it, a topic that leads to identifying and strengthening adaptation and mitigation strategies based on local practices and knowledge; 4) demanding support to facilitate environmental awareness among younger generations, pinpointing what should be taught in schools and at home in the face of extreme phenomena associated to CC; and 5) requesting the exchange of knowledge on sustainable agricultural practices, organic alternatives in food production, efficient use of water, soil improvement, pollution reduction, use of organic fertilizers and pesticides, and conservation agriculture, among others.

CONCLUSIONS

By identifying the socio-demographic characteristics of the studied *ejidos*, as well as their social reproduction strategies and perception of climate change and its impact, we gained insight into the organization of domestic units in the face of the problems associated with this phenomenon and the training interests of *ejidatarios*. We found that agriculture remains their primary reproduction strategy. Nevertheless, adding other strategies that allow for the social and cultural reproduction of their way of life has been increasingly necessary. Selling labor —sometimes through migration— is one of their alternative strategies, although it entails the risk of identity shifts at the local level. Considering the difficulties women face in accessing land and their work overload, we found it crucial to address gender justice. The significance of agriculture requires implementing and strengthening adaptation strategies and even remediating agroecosystems in the face of climatic and socioeconomic factors. There was consensus among participants on the perception of climate change and its impacts. Interest in learning indicated a willingness to adopt new practices and develop alternatives that favor resilience in their communities.

Results underscore the urgency to address climate change through training, collective production of knowledge, and identification of adaptation, mitigation, and restoration strategies for agroecosystems. By identifying the topics of interest and grouping them into five axes, it is now possible to design educational and awareness-raising programs, as well as participatory processes for generating collective knowledge and identifying alternatives, as well as making decisions on specific adaptation and mitigation actions that may contribute to the conservation of agroecosystems through sustainable practices. This challenge, which begins on the local level and reaches the global, calls for the intervention of individuals, institutions, and policies alike.

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Colegio de Postgraduados

Regional hydro-climatic characterization for the efficient use and management of water Study case

Villarreal-Manzo, Luis Alberto

Colegio de Postgraduados, Campus Puebla. Boulevard Forjadores de Puebla 205 Santiago Momoxpan, Municipio de San Pedro Cholula, Pue., C.P. 72760
Correspondence: lavilla@colpos.mx

ABSTRACT

Objective: To analyze official information to project future groundwater availability and demand scenarios, based on the different consumptive uses of the Alto Atoyac aquifer, in Tlaxcala, Mexico.

Design/Methodology/Approach: The methodology used in this study included a bibliographic and documentary research. Likewise, based on the Penman-Monteith equation, quantitative research was used to calculate and estimate crop irrigation requirements.

Results: The results of the availability and demand of groundwater showed a surplus of ≈23.34% in 2020. This percentage will gradually decrease in the following years until it reaches a 24.71% deficit by 2070. Consequently, a groundwater deficit in the Alto Atoyac aquifer will take place throughout the whole period (2020-2070). From 2040 to 2050, this deficit will gradually increase.

Study Limitations/Implications: Measures for a sustainable use, exploitation, and conservation of the aquifer must be urgently implemented, as a regular and frequent measurements of aquifer depletion, through measures of phreatic and dynamic groundwater levels, also regular and frequent measures of groundwater extraction, water conduction through the conveyance and distribution system, and finally amounts of water applied to all crop pattern.

Findings/Conclusions: The integration of the consulted and generated data allowed the development of groundwater availability and demand scenarios in the aquifer. In addition, comparisons between the said scenarios were established and conclusions were drawn. The growing water demand in the region —required to meet the basic needs of the localities and inhabitants and to keep driving the economic activities in the region— would have negative effects on the environment and the inhabitants, due to the overexploitation of the aquifer groundwater.

Keywords: Consumptive use, groundwater, deficit, surplus, sustainable.

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INTRODUCTION

This study is based on the growing concern among the population, several government bodies, agricultural producers, industry members, and service providers regarding groundwater. All these sectors use groundwater from the aquifers that make up the basins and sub-basins of the hydrological regions managed by the Mexican government. The concerns include the current availability and demand of groundwater and the prospects for its future availability. The prevailing conditions of the study area show a precipitation deficit all year round. However, the development of agricultural and livestock activities requires water for irrigation and animal production supplementation. The surface water stored from the Manual Ávila Camacho "*Valsequillo*" dam and groundwater from the regional aquifer are the only source of water for these activities.

Based on the analysis and comparison of the bibliographical and field data, the objective of this study was to develop a 50-year projection regarding the demand and availability scenarios of groundwater from the Alto Atoyac aquifer, considering the different consumptive uses of groundwater (agricultural, urban, and industrial).

Agriculture is the activity with the highest consumptive use of water, sometimes using over 80% of the available and officially licensed water. The requirements and irrigation water volume of each crop —included in the established crop pattern— and their irrigation system were determined. A projection of water availability and demand was developed using these results, as well as the water consumption rates of both rural and urban populations and the industries of the municipalities and communities in the area of influence of the Alto Atoyac aquifer area. Finally, this projection established the moment when the first would be exceeded by the second, causing deficits in regional water availability.

MATERIALS AND METHODS

The Alto Atoyac is classified as aquifer 2901 in the Sistema de Información Geográfica para el Manejo del Agua Subterránea of the Comisión Nacional del Agua (SIGMAS-CONAGUA). The aquifer is located in the center of the State of Tlaxcala, at 19° 10' and 19° 35' N and 97° 58' and 98° 21' W, and has an area of 2,032 km^2 (CONAGUA, 2020).

The Alto Atoyac borders with the following aquifers: Tecolutla, Veracruz (N), Valle de Tecamachalco (SE) and Valley of Puebla (S), Puebla, Emiliano Zapata (NW), Huamantla (E), and Soltepec (NE). The last three aquifers are located in the State of Tlaxcala (CONAGUA, 2020) (Figure 1).

The Alto Atoyac aquifer totally or partially covers the following municipalities: Tlaxco, Atlangatepec, Tetla de La Solidaridad, Terrenate, Tocatlán, Xaloztoc, Muñoz de Domingo Arenas, San Lucas Tecopilco, Xaltocan, Hueyotlipan, Españita, Huamantla, Ixtacuixtla de Mariano Matamoros, Santa Ana Nopalucan, Santa Apolonia, Nativitas, Tetlatlahuca, San Jerónimo Zacualpan, San Damián Texoloc, Santa Catarina Ayometla, Santa Cruz Quilehtla, San Lorenzo Axocomanitla, Tepeyanco, San Juan Huactzingo, Santa Isabel Xiloxoxtla, Xicohtzinco, San Pablo del Monte, Tenancingo, Mazatecochco de José María M., Acuamanala de Miguel Hidalgo, Teolocholco, San Francisco Tetlanohcan, La Magdalena Tlaltelulco, Tlaxcala, Panotla, Papalotla de Xicohténcatl, Totolac, Amaxac de Guerrero, Santa Cruz Tlaxcala, Yauhquemecan, Apizaco, Coaxomulco, Tzompantepec, San José Teacalco, and Zacatelco.

No ban decree has been issued for most of the aquifer area. The Alto Atoyac aquifer is managed by the Organismo de Cuenca Balsas and falls under the territorial jurisdiction of the Dirección Local of Tlaxcala. The territory of the aquifer has a partial ban, subjected to the provisions of four decrees. In a small part of its west side, a decree establishes "a ban for an undefined period to supply groundwater to the closed basin (known as Oriental) of the States of Puebla and Tlaxcala" (Official Gazette of the Federation (DOF), August 19,

Figure 1. Location of the Alto Atoyac aquifer. Source: CONAGUA (2020).

1954). Another decree in force establishes "a ban to supply groundwater to the southern part of the State of Puebla" (DOF, November 15, 1967). Regarding the central-south region, a decree extends "for an undefined period the ban to supply groundwater to the southern part of the State of Puebla, established in the decree issued on June 12, 1967, for the municipalities of Amozoc, Calpa, Totimehuacán, and Puebla" (DOF, August 30, 1969). Based on the capacity of the aquifer, this type III ban allows a limited extraction from the water table for domestic, industrial, irrigation, and other uses. Finally, a decree establishes "a ban to supply groundwater of the basins of the Tochac and Tecocomulco lagoons, in the States of Hidalgo, Puebla, and Tlaxcala" (DOF, June 17, 1957) for a small part of the western side of the aquifer. Based on the capacity of the aquifers, this type II ban only allows a limited extraction from the water table for domestic use.

Weather and aridity index

Based on data from Station 000290 30 Tlaxcala de Xicoténcatl (DGE) of the Servicio Meteorológico Nacional (SMN), Table 1 shows the weather data for the 1991-2020 period. The difference between the average annual precipitation (866.00 mm) and the total evaporation (1,380.60 mm) resulted in a 514.60 mm deficit.

Figure 2 shows the water balance of the Tlaxcala de Xicoténcatl region, developed with the weather data from Table 1. The figure includes a hydrological deficit period from October to May (*i.e.*, ≈8-month crisis).

Meanwhile, Figure 3 shows the ombrothermic diagram of the same region, from March to November, a period during which environmental humidity prevails on mean monthly temperatures.

Table 1. Weather data from Station 000290 30 Tlaxcala de Xicoténcatl (DGE) for the 1991-2020 period (Servicio Meteorológico Nacional, 2024).

NATIONAL METEOROLOGICAL SERVICE

CLIMATOLOGICAL NORMALS

STATE:TLAXCALA PERIOD: 1991-2020

STATION: 00029030 TLAXCALA DE XICOTENCATL (DGE) LATITUDE: 19”19’26”N. LONGITUDE: 98”14’48”W. HEIGHT: 2230.0 MSNM.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DEC	SUMS AND MEDIUMS
NORMAL MAXIMUM TEMPERATURE	22.50	24.60	26.50	27.90	28.00	25.90	25.00	25.20	24.40	24.70	24.10	22.90	25.14
MEDIUM TEMPERATURE	13.30	14.90	16.60	18.50	19.10	18.80	17.90	18.20	18.00	17.10	15.40	13.80	16.80
MINIMUM TEMPERATURE	4.20	5.20	6.70	9.00	10.50	11.70	10.90	11.20	11.60	9.60	6.70	4.60	8.49
RAINFALL	8.00	8.10	15.50	35.20	75.40	159.10	159.50	154.70	153.20	71.60	19.20	6.50	866.00
TOTAL EVAPORATION	85.90	105.10	141.10	151.70	151.40	125.00	124.00	117.90	105.50	103.60	86.70	82.70	1380.60

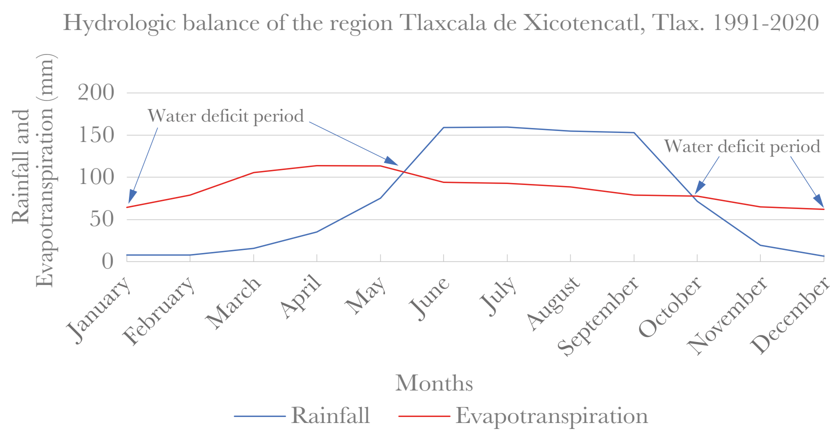

Figure 2. Water balance of the Tlaxcala de Xicotencatl region (1991-2020).

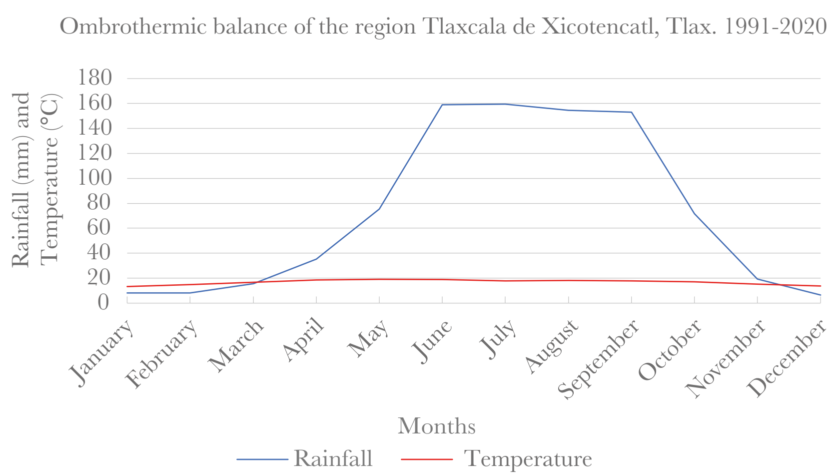

Figure 3. Ombrothermic diagram of the Tlaxcala de Xicotencatl region (1991-2020).

According to De Martonne aridity index, this is not an arid area (Table 2). Regarding the Dantín-Revenga index, the region has a lower humidity rate and, according to Gaussen, the driest months are December, January, and February (Figure 4).

Groundwater balance

The groundwater balance was established in 2,031 km^2 of the aquifer surface for which piezometric information is available. Most of the underground exploitations are located in this area (CONAGUA, 2020). Table 3 includes a groundwater balance summary of the Alto Atoyac aquifer.

Table 2. Aridity index of the Tlaxcala de Xicoténcatl region (1991-2020).

Aridity index's:		
Martonne:	More than 20: no arids.	32.31
	Between 5 and 20: arids.	
	Less than 5: more arids.	
Dantín-Revenga:	Less than 2: humid.	1.94
	Between 2 and 3: semiarid.	
	Betwen 3 and 6: arid.	
	More than 6: subdesertic.	
Gaussen:	Dry month when rainfalls are less than the double of the temperatures	

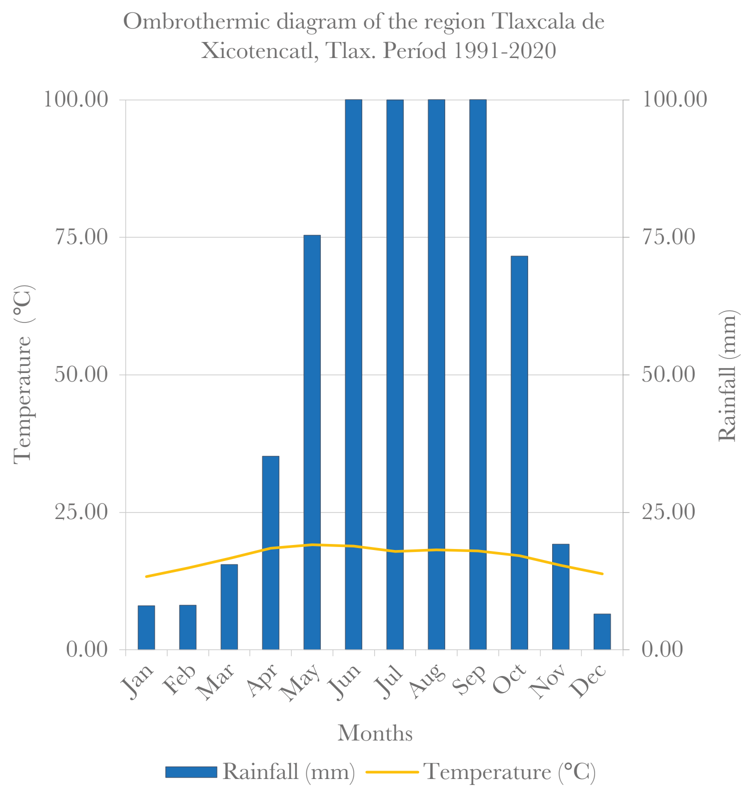

Figure 4. Ombrothermic diagram of the Tlaxcala de Xicotencatl region (1991-2020).

Table 3. Updating of the mean annual water availability in the Alto Atoyac aquifer. Figures are expressed in millions per m^3 and per year (December 30, 2020).

Code	AQUIFER	R	DNCOM	VCAS	VEAS	DAS
2901	ALTO ATOYAC	212.40	41.00	124.69	153.40	46.70

R: mean annual recharge; AND (DNCOM): allocated natural discharge; Ir (Ri): induced recharge; LGV (VCAS): licensed groundwater volume; GEVRTS (VEAS) groundwater extraction volume recorded in technical studies; MAGA (DAS): mean annual groundwater availability. These terms are defined in sections 3 and 4 of the NOM-011-CONAGUA-2015. Source: CONAGUA, 2020.

Analysis of the agricultural activity and its influence on the availability of water from the Alto Atoyac aquifer

This study required data about crop area and irrigation depths. Therefore, the analysis was partially focused on determining the water volume required for the crop pattern, established under irrigation systems, in the area of influence of the Alto Atoyac aquifer. This area was determined with data from the Servicio de Información Agroalimentaria y Pesquera (SIAP, 2022), which is a decentralized body of the Secretaría de Agricultura, Ganadería, Pesca y Alimentación (SAGARPA) of the Federal Government. The crop irrigation depths were used to calculate the said data.

Consequently, the irrigation requirements of the crop pattern were estimated in an *ex profeso* Excel spreadsheet (Villarreal, 2021), which included three estimation methods: the Blaney-Criddle method (Brouwer and Heibloem, 1986), the Penman-Monteith equation (Alle, 2020), and the Evaporimeter Tank Type A method.

Blaney and Criddle developed and improved their formula in Arizona (USA) and, consequently, it can be easily adapted to the arid and semiarid areas of Mexico, whose conditions are very similar to those of Arizona. In addition, the data used for the calculation of evapotranspiration (ET) or the consumptive use (CU) of irrigation water is easily obtained without special equipment. The factors used for this formula are mean monthly temperature, daylight hour percentages, and a coefficient that depends on the type of crop under study (López, 2016a).

The Penman-Monteith equation is the standard combined method used to estimate the evapotranspiration (ET) of a given crop. Most of the combined methods are similar, depending on the type of crop and the location of the weather instruments. This equation uses crop canopy and aerodynamic resistance to relate the height of weather instruments and the height of the crops, as well as the stomatal resistance of the minimum transpiration, which depends on crop type and height (López, 2016b).

Finally, López (2016c) pointed out that the Evaporimeter Tank Type A method has been widely used in irrigation areas with poor weather information. This author only recommends its use if the equipment is accurately calibrated.

The Penman-Monteith equation was used to estimate irrigation requirements. The total volume required by the established crop pattern had a 51.47% impact. This is the same percentage of mean efficiency of irrigation requirement established for the region by Villarreal (1994).

Building water availability and demand scenarios for the Alto Atoyac aquifer, based on agriculture, population, and industries water demand

Based on the water use of primary and secondary sectors and the water supply for the population of the localities and municipalities of the area of influence of the aquifer, a procedure was established to build the water availability and demand scenarios of the Alto Atoyac aquifer.

Population water demand

Using the *Panorama sociodemográfico de Tlaxcala, Tomo I* (2011), the population of each municipality in the area of influence of the aquifer was determined for 2010. Based on the data obtained from the Instituto Nacional de Geografía, Estadística e Informática (INEGI, 2011, 2012, 2013, 2014, and 2015), the population was also determined for the next five years (2011-2015). Finally, using information from the Consejo Nacional de Población (CONAPO, 2019), the birth rates of the municipalities under study, and lineal trends (the least square method), population growth projections were developed until 2070.

For the purposes of this analysis, the population was divided into urban (72%) and rural population (28%).

Considering that the urban population consumes 150 L of water per person and per day, the demand or consumptive use of the population was used to build the scenario. Meanwhile, the rural population consumes 75 L per person and per day. According to CONAGUA, both water consumptions are lower than the 320 L per person and per day, currently available for the Mexican population. However, these figures are closer to the 100-150 L per person and per day reported by the World Health Organization (WHO). This consumption is the minimum amount of water recommended to cover basic needs and prevent most health problems (ONU and OMS, 2011).

Industrial, public-urban, and agricultural demand

The demand or consumptive use of water for industrial and other activities accounted for 6.30% (9.68 million m^3) of the licensed groundwater volume (LGV) authorized by CONAGUA. Meanwhile, 52.80% (81.05 million m^3) and 40.90% (62.67 million m^3) of the LGV is used for public-urban consumption and agriculture, respectively.

Building water demand and availability scenarios depending on soil use (2020-2070)

The water demand and availability scenario depending on soil use (overall adujsted) for the 2020-2070 period was developed based on the hectares required for each substantive activity in the Alto Atoyac aquifer, including agricultural, public-urban, industrial, and other uses.

The consumptive use of water for substantive activities were obtained from the calculation of the water volume spreadsheets of the established crop pattern (agricultural use). These spreadsheets also include the consumptive use of the population and the industry.

The total water demand is made up of the sum of all the consumptive uses. The comparison between consumptive uses and groundwater availability —reported by CONAGUA in the *Actualización de la disponibilidad media anual de agua del acuífero Alto Atoyac, al 30 de diciembre de 2020* study— is included in the figures.

Finally, the different consumptive uses of water from the aquifer were weighted. The base line for the comparison included the sowing and harvested area, the water volume required by the established crop pattern, and the projected sowing area increases (21 and 50%) in the area of influence of the aquifer.

RESULTS AND DISCUSSION

Agricultural water demand

The 2022 crop pattern was made up of 46 annual and perennial crops, established under irrigation systems. Corn was the crop with the highest sowing area (13,934.50 ha), followed by green alfalfa (2,564.00 ha), forage oats (1,770.50 ha), green tomato (833.50 ha), and forage corn (827.00 ha). The total sowing area was 22,965.50 ha. This area produced a 16,620,562.34 t harvest, obtaining a total of MXN$909,395.99. Corn yielded MXN$365,316.96, which accounts for over 40% of the total production in the Alto Atoyac aquifer area.

The water volume was calculated for the building of the consumptive use scenarios, considering the sowing area and the water requirement of each established crop. Based on the sowing and harvesting area of each crop, the following crops and areas stood out as a result of their water volume requirement and consumptive use: corn grain, green alfalfa, forage oats, green tomato, grasslands, and prairies. Meanwhile, the rest of the crops had a similar water requirement trend. The crops grown in the area of influence of the Alto Atoyac aquifer consumed 120,290,077.00 m^3 of water in the 22,965.50 ha harvesting area. These figures account for 78.42% of the total groundwater volume extracted from this aquifer.

Public-urban water demand

The urban and rural populations consume 150 L and 75 L per person and per day, respectively. Therefore, the 973,288 inhabitants of the 45 municipalities of the Alto Atoyac aquifer required a total water volume of 45,827,265 m^3 during 2010. The population projection for 2020 recorded a local population of 1,077,134 inhabitants. This population required a total water volume of 50,716,835 m^3. Therefore, the area had 103,846 more inhabitants than in 2010 and required an additional water volume of 4,889,570 m^3. Based on the CONAPO data and the results obtained from the lineal trend (least square method), the total population of the area is projected to reach 1,409,318 inhabitants by 2070 and will require a total water volume of 66,357,742 m^3. Consequently, the area will have 332,184 more inhabitants than in 2020 and will require an additional water volume of 15,640,907 m^3.

The highest consumptive use of the total extracted groundwater (52.80%) was made by public and urban supply, followed by the agricultural and industrial sectors.

Regarding the consumptive use and soil use (adjusted) scenarios of each consumptive use of groundwater in the Alto Atoyac aquifer (2020, 2030, 2040, 2050, and 2070), the sowing area reached 22,970.50 ha in 2020. Out of this total, 3,054.00 ha belonged to urban and rural communities, while 500.00 ha were used for industrial parks and other purposes. Consequently, the consumptive use of water in the area reached 202,993,871.16 m^3. By 2070, the agricultural area, the urban and rural areas, and the industrial parks will reach 71,748.27 ha, 41,520.48 ha, and 620.00 ha, respectively. Therefore, the total consumptive use (250,673,196.55 m3) will be 47,679,325.00 m^3 higher than the total consumptive use of 2020.

The licensed volume (LGV) and the groundwater extraction volume allowed for technical studies (GEVRTS) and the mean annual groundwater availability (MAGA) will be impacted by a 0.96, 0.94, 0.92, and 0.90 factor in 2020, 2030, 2050, and 2070, respectively. The results indicated a total water volume of 200.10 million m^3 for 2020. This volume will decrease in the following years, until it reaches 149.51 million m^3 by 2070. Consequently, the groundwater surplus was 23.34% in 2020 and is projected to gradually decrease in the following years, until it reaches a 24.71% water deficit by 2070 (Table 2 and Figure 5).

Table 2. Groundwater availability and demand of the Alto Atoyac aquifer (2020-2070).

Year	Demand	Availability	%	Surplus/deficit
2020	153,400,000.00	200,100,000.00	76.66	23.34
2030	161,070,000.00	192,096,000.00	83.85	16.15
2040	169,123,500.00	180,570,240.00	93.66	6.34
2050	177,579,675.00	166,124,620.80	106.90	−6.90
2070	186,458,658.75	149,512,158.72	124.71	−24.71

Source: table developed by the authors.

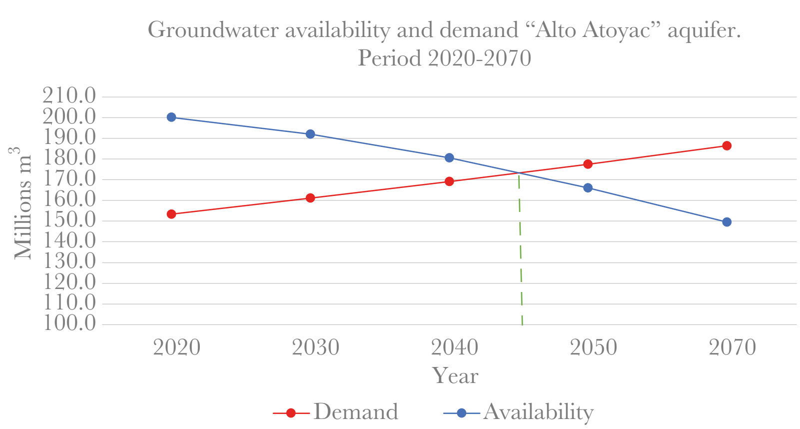

Figure 3. Groundwater availability and demand of the Alto Atoyac aquifer (2020-2070).
Source: figure developed by the authors.

CONCLUSIONS

The Alto Atoyac aquifer (number 2901) is located in an area that lacks natural water. This area has a mean annual precipitation of 866.0 mm and its potential mean annual evaporation reaches 1,380.6 mm. This situation indicates that most of the precipitation evaporates, resulting in a reduced infiltration and runoff. This situation and the growing water demand in the region —required to meet the basic needs of the localities and inhabitants and to keep driving the economic activities in the region— would have negative effects on the environment and the inhabitants, due to the overexploitation of groundwater. Therefore, the government and the population must control the extraction, use, and exploitation of groundwater. The groundwater surplus was 23.34% in 2020 and is projected to gradually decrease in the following years, until it reaches a 24.71% water deficit by 2070. By 2070, the agricultural area, the urban and rural areas, and the industrial parks will increase to 27,920.79 ha, 37,118.16 ha, and 607.75 ha, respectively, reaching a total area of 65,646.70 ha. The total consumptive use (186,458,658.75 m^3) will be 33,058,658.75 m^3 higher than the total consumptive use of 2020.

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Current status and socioeconomic importance of *capulín* (*Prunus serotina* Ehrh) in the Sierra Nevada of Puebla, Mexico

Díaz-Cervantes, Rufino[1*]; Gutiérrez-Rangel, Nicolas[1]

[1] Colegio de Postgraduados, Campus Puebla. Boulevard Forjadores de Puebla No. 205, Santiago Momoxpan, Municipio de San Pedro Cholula, C.P. 72760, Puebla, México. Tels. (222) 2850013, 2851442, 2851445 y 2851447, ext. 2223.

* Correspondence: rufinodc@colpos.mx

ABSTRACT

Objective: To determine the distribution, survival conditions, and socioeconomic and environmental importance of black cherry or *capulín* populations in the Sierra Nevada of Puebla, Mexico.

Methodology: Ethnographic and qualitative methods were used to estimate and describe *capulín* populations in transects, backyards, and orchards. Twenty-six informal interviews were conducted across 10 circuits covering 32 sites in the Sierra Nevada region.

Results: In three circuits, more than 3,600 trees were found to be well-managed. In the remaining circuits, there were between 16 and 74 neglected adult specimens.

Study limitations/implications: The cultivators' assessments of *capulín* populations differ from technical methods.

Findings/Conclusions: *capulín* populations are concentrated in three circuits where they hold notable socioeconomic and environmental importance.

Keywords: Ethnography, Populations, Traditional wisdom, Usage.

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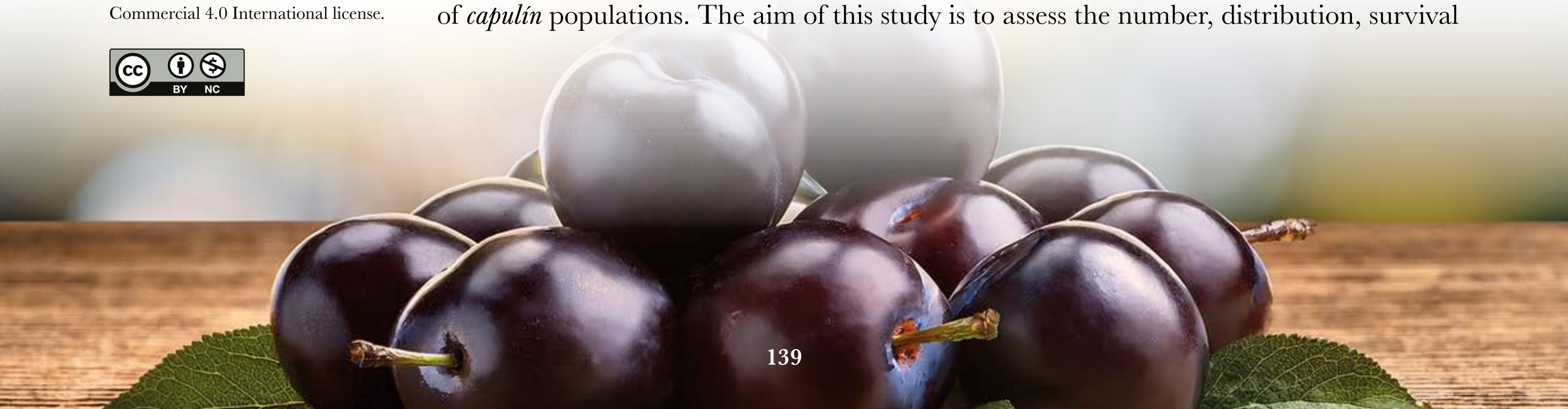
INTRODUCTION

The black cherry or *capulín* (*Prunus serotina* Ehrh) is a tree species native to North America (Guzmán *et al.*, 2020). In some regions of the Americas, it has been domesticated (Vázquez-Yanes *et al.*, 1999; Avendaño-Gómez *et al.*, 2015). In Mexico, *capulín* populations are found at elevations between 2,000 and 2,400 masl. In the state of Puebla, *capulín* trees are present in the Sierra Nevada, the Central Valleys, and the Sierra Norte. Similar to other regions, *capulín* is used by indigenous groups and cultivators for various purposes (SADER, 2017). Studies examining the distribution, environmental conditions, and socioeconomic significance of *capulín* in rural contexts are scarce and outdated. Gutiérrez (1993) researched grafting methods as part of the agronomic management of this species in the Tarascan Plateau in Michoacán. More recently, Guzmán et al. (2020) discussed the forestry potential of *capulín* populations. The aim of this study is to assess the number, distribution, survival



conditions, and socioeconomic and environmental importance of *capulín* trees in the Sierra Nevada of Puebla. The findings will contribute to update knowledge and, as suggested by Páez *et al*. (2013), support its promotion as a factor in rural development.

MATERIALS AND METHODS

This research was based on situated knowledge and therefore took into account local expertise (Cruz *et al*., 2012). We used ethnographic tools, including direct observation, qualitative techniques, and 26 informal interviews. Tree counts were conducted in 10 transects within 10 circuits, as per Mostacedo and Fredericksen (2000), along roads and highways that connect the 32 study sites in the Sierra Nevada of Puebla.

In each circuit, transects were defined along routes between two or more sites where *capulín* trees were known to be present. Each transect was approximately 3 km in length. For tree recording, we followed the ethnobotanical method proposed by Kvist *et al*. (2001), using a manual counter (M42).

Counts were conducted on both sides of the roads and highways, where the transects were located. Furthermore in backyards (spaces surrounding houses and housing units) and orchards (plots made up of a diversity of agricultural species where the *capulín* stands out). In addition to recording the number of *capulín* trees through direct observation, their physical and sanitary conditions were documented. Informal interviews were conducted with 20 men and six women across eight of the 10 circuits; 24 of these individuals were *capulín* tree owners, and two were traders.

RESULTS AND DISCUSSION

Capulín trees in the study region were primarily found along roadsides and land boundaries, followed by polyculture backyards and orchards (see Table 1).

Interviews estimated a total of 4,288 *capulín* trees, while transects revealed a count of 2,891 young (aged one to five years) and adult (over five years) trees. The majority of these trees were located in Circuit 2 (Huejotzingo-Domingo Arenas), particularly in the municipality of Domingo Arenas, which alone accounted for 2,600 trees. The next highest counts were observed in Circuit 5 (Huejotzingo-Atexcac-Buenavista) with 79 trees, and Circuit 3 (Huejotzingo-San Miguel Tianguizolco-Nepopoalco) with 45 trees.

The circuits with the lowest *capulín* populations were the following: Circuit 10 (San Nicolás de los Ranchos-San Pedro Yancuitlalpan-Teotón) had 34 trees; Circuit 4 (Huejotzingo-San Mateo Capultitlán-San Luis Coyotzingo-Xalmimilulco) had 29; Circuit

Table 1. *Capulín* populations in the Sierra Nevada of Puebla, Mexico

Number of observation units	Description of the site	Number of trees	
		Direct count	Peasant perception
10	Both site of the transect	2544	3936
5	Backyard	27	32
1	Orchard/ha	320	320
Total		2,891	4288

8 (Tochimilco-Tochimizolco-La Magdalena Yancuitlalpan) had 27; Circuits 7 (Atlixco-Axocopan-San Pedro Benito Juárez) and 9 (Calpan-Atzala-San Mateo Ozolco) had 21 trees each; Circuit 6 (Atlixco-Metepec-Tianguismanalco-San Pedro Atlixco-Atlimeyaya) had 19; and Circuit 1 (Cuautlancingo-Cholula-Juan C. Bonilla-Huejotzingo) had 16 trees.

The discrepancies between the estimates of *capulín* populations from direct counts and interviews suggest differing perspectives and methods of understanding the environment between cultivators and technicians (Gerritsen *et al*., 2003). To address this, Rangel-Ch. and Velázquez (1997), Mostacedo and Fredericksen (2000), and Kvist *et al*. (2001) propose methodologies that could improve these approaches.

General appearance of *capulín* populations

Ethnographic observations and informal interviews indicate that *capulín* tree populations exist in three distinct conditions: a) neglect and loss, b) maintenance, and c) appreciation (see Table 2).

Neglect. This condition refers to the absence of tree management or care, which includes practices such as pruning, fertilization, sanitary control, grafting, and other techniques. It suggests that the *capulín* populations are seen as having little value by their owners.

Maintenance. In this condition, the *capulín* trees appear to be in good health despite not receiving any specific attention. Although these trees may begin to be regarded as objects of management, this management is not systematic.

Appreciation. Trees in this condition receive focused attention aimed at improving yields, fruit quality, and overall income. This can be achieved through traditional methods or newly introduced management systems.

Circuits where conditions of neglect and loss were recorded include 1, 3, 4, 6, 7, and 8. Maintained *capulín* trees were observed in circuits 9 and 10, although some interviews revealed that these populations have diminished due to neglect.

In circuits 2 and 5, *capulín* management practices are implemented within polyculture orchards that engage in agroecological innovation and are clearly integrated into local markets. Here, the maintenance of *capulín* trees is part of their revaluation as significant socioeconomic and environmental resources.

In areas with severe neglect, many aging trees were found, along with partial or total felling, serious burn damage, significant parasitism from mistletoe, leaf damage caused by red spider mites, and trees that were partially or completely dead. Additionally, the fruits

Table 2. General appearance of capulín populations.

Circuit	Conditions of the capulín populations
1, 3, 4, 6, 7, 8	In abandonment and loss: trees in small proportion, scattered unattended, high risk of disappearing due to urban advance.
9 y 10	In maintenance and reduction: widely dispersed trees, arranged on roadsides and adges of plots.
2 y 5	In assessment: greater presence of trees in: a) orchards interspersed with annual crops, b) fences and roadsides, c) dispersed in agricultural, forestry and ravine areas.

exhibited severe damage from fruit flies (possibly *Anastrepha ludens* Low). These issues were also observed in transects 9 and 10, though with less severity.

In circuits where *capulín* populations are maintained or show slight increases, the value placed on these trees is evident. Here, despite certain challenges, selection practices are employed on specific types of *capulín* trees propagated through grafting, leading to the categorization of these trees as "grafted" *capulín* trees. These grafted trees differ significantly from "non-grafted" trees in various characteristics, including fruit size, color, consistency, pulp and cuticle thickness, seed size, flavor, and the timing of flowering and ripening. The condition of these trees reflects a wealth of traditional knowledge that is fortunately being preserved.

Socioeconomic and environmental importance of *capulín*

The socioeconomic and environmental importance of *capulín* trees was determined based on their various purposes, uses, and management practices, such as serving as a food source, providing economic income, contributing to cultural identity, and offering environmental services.

As a resource that supports the social reproduction strategies of domestic cultivator groups in the Sierra Nevada of Puebla, a loss or decrease in the numbers of *capulín* trees indicates a greater risk of biocultural fragility.

Interviews reveal that the importance of *capulín* trees can be categorized as: a) "none," b) "little," or c) "high" in the various circuits studied. This indicates a differentiated significance of these trees among the local population. The diverse levels of importance help distinguish at least two groups of circuits based on the size of *capulín* populations, the degree of management, consumption intensity, commercialization, and appraisal of environmental services.

We observed that the socioeconomic and environmental importance of *capulín* trees in the first group (A) is lower than in the second group (B). The towns of Huejotzingo, Nepopoalco, San Nicolás de los Ranchos, Xalmimilulco, San Pedro Benito Juárez, and La Magdalena Yancuitlalpan, located in circuits 1, 4, 6, 7, 8, 9, and 10, belong to group A. The communities of Domingo Arenas, Buena Vista, and Calpan, situated in circuits 2, 3, and 5, belong to group B (see Table 3).

In group A, *capulín* populations largely survive in the wild or with minimal care. The trees are small, scattered, and exhibit physical signs of neglect, such as infestations from mistletoe and fruit flies, which significantly reduce fruit quality. Nevertheless, the fruits are harvested mainly for fresh consumption by local groups known as "*capulineros*."

In contrast, group B has the highest number of polyculture orchards with clearly defined management processes that include pruning, grafting of outstanding local varieties, organic and conventional fertilization, and phytosanitary control (such as trapping and pesticide application). Notably, in the communities of Domingo Arenas, Buena Vista, and Calpan, *capulín* populations show a slight increase. This is largely due to the efforts of local leaders, organizations, and governments, alongside the promotion of strategies such as local fairs and agroecological innovation processes to enhance production and improve fruit and seed quality.

Table 3. Economic and environmental importance of *capulín*.

Community	Number of interviews	Socioeconomic and environmental importance (%)		
		Null	lttle	A lot
Huejotzingo	4		80	20
Nepopoalco	4		80	20
Domingo Arenas	2			100
Buena Vista	2			100
Calpan	4			100
San Nicolás de los Ranchos	2	10	80	10
Xalmimilulco	2	30	70	
San Pedro Benito Juárez	2	30	70	
La Magdalena Yancuitlalpan	2	40	60	
Weighted average		9.2	50	40.8

Fruits are harvested from April to June. In group B, the most notable yields range from 15 to 45 "buckets" per tree (equivalent to 255 to 765 kg/ha), with prices fluctuating between $250.00 at the beginning of the season and $400.00 at the end. These figures translate to an income ranging from $3,750.00 to $6,000.00 based on minimum production, or up to $18,000.00 at maximum production.

A press release indicates that Domingo Arenas is one of the municipalities in the Sierra Nevada of Puebla that produces around 600 tons of *capulín* fruits annually, which are intended for domestic consumption, the local market, and other regions within Puebla and Mexico. Approximately 1,200 families benefit from this activity (Corona, 2019).

In the circuits of Group B, *capulín* represents both a material and immaterial heritage, visibly exhibiting transgenerational cultural elements. It serves as a temporary source of significant economic contributions to the social reproduction strategies of farming communities at both domestic and communal levels.

CONCLUSIONS

The populations of *capulín* trees are primarily found in the circuits that comprise Group B, which includes Domingo Arenas, Buena Vista, and Calpan. In contrast, *capulín* populations are less dense and more dispersed in the other circuits. According to the interviewees, there has been a significant decline in *capulín* populations overall.

The socioeconomic and environmental significance of the *capulín* varies between the circuit groups. In Group B, the importance of the *capulín* is clear, whereas in Group A, it diminishes. This difference aligns with the number of trees, their management and care, and the conditions under which these populations are maintained. Additionally, the variety of uses for *capulín*, including food, medicine, and its role as a commodity in the value chain, is noteworthy. However, the environmental importance of *capulín* is less recognized by the interviewees. They tend to overlook its benefits as a source of food for wildlife, wood, firewood, shade, and as a windbreak barrier, among other uses.

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Agriculture and non-agricultural activities in the income strategies of family farming

Ramírez-Juárez, Javier

Colegio de Postgraduados-Campus Puebla, Programa en Estrategias para el Desarrollo Agrícola Regional, Boulevard Forjadores de Puebla No. 205, Santiago Momoxpan, Municipio de San Pedro Cholula, Puebla, México, C.P. 72760.
Correspondence: rjavier@colpos.mx

ABSTRACT
Objective: To identify agricultural and non-agricultural income strategies of family farming in the Puebla Valley.
Design/Methodology/Approach: A case study was conducted in the community of Tlaltenango, with family farming as the unit of study. A qualitative and quantitative approach was used, involving semi-structured interviews with farmers and an opinion-based survey of 72 family farming units. The resulting data were processed using the Statistical Package for the Social Sciences (SPSS v.23). A typology of family farming was determined based on the data, considering the percentage of agricultural and livestock income as a classification criterion to identify income strategies.
Results: Two categories of family farming were identified as income strategies. The first category includes 41.7% of family units, with an average agricultural income of 34%. The second category encompasses 58.3% of family units, where agricultural income accounts for 70.3%.
Study Limitations/Implications: Since this research is a case study, the results and conclusions are framed within a regional context, distinguishing themselves from the agricultural dynamics of other areas and regions.
Findings/Conclusions: The persistence and importance of agriculture and livestock as the main source of income in family farming is a significant proof, challenging the notion of the technical and economic unviability of small-scale production.

Keywords: Family farming, income strategies, typology.

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INTRODUCTION

The structural reforms and the 'outward-oriented' development model implemented in Mexico in the mid-1980s deeply transformed the economic and social conditions of family farming. The reforms were aimed at deregulating and privatizing the economy. In the agricultural sector, these measures eliminated instruments and support for farming. These reforms included the amendment of Article 27 of the Mexican Constitution in 1992, aimed at commercializing ejido and communal lands, and trade integration through the North American Free Trade Agreement (NAFTA) in 1994. This measure was justified by the stagnation, technical unviability, low productivity, and rural poverty generated by small-scale land ownership, known as *minifundio* (Presidencia de la República, 1992).

The consequences of the reforms included a decline in family farming incomes, along with an increase in migration, poverty, pluriactivity, and deagrarianization (Kay, 2007; Escalante *et al.*, 2007; Carton de Grammont, 2009; Pérez, 2001). However, according to the available statistical data, small productive units can still be found in Mexico, where family farming accounts for 81.3% of the approximately 5.3 5.4 million rural economic units (REU) (SAGARPA and FAO, 2012). The 2022 Agricultural Census (INEGI, 2022) revealed that 71.8% of production units have a surface area of up to five hectares.

Family farming is a persistent and socially heterogeneous phenomenon in various Latin American countries. It has social, economic, and environmental significance for food production, rural poverty alleviation, and the conservation of natural resources (Baquero *et al.*, 2007; World Bank, 2008; Salcedo and Guzmán, 2014; Schneider, 2014; Ramírez, 2016). A conceptual approach to family farming includes the family labor predominance, the production unit management led by the head of the household, and small-scale land ownership. For Chayanov (1974) and Shanin (1976), family labor defines farming units, as the basis for producing and generating output and income for its social reproduction. Additionally, it maintains ties to the market and non-agricultural economic activities and incomes. The social approach and characterization of family farming are associated with the typology system (Carmagnani, 2008).

In this context, the study addresses the persistence of agricultural and livestock activities and incomes in family farming in the Puebla Valley. Within the framework of the neoliberal model, the family farming that emerged in the region is characterized by a market-oriented and diversified agriculture, including higher profitability crops (*e.g.*, flowers, fodder, and vegetables) and livestock raising. Therefore, the objective of this research was to identify the agricultural and non-agricultural income strategies of family farming in the Puebla Valley. The income strategies of family farming are part of the reproduction strategies that rely on the assets and relationships available to households to maintain their social position (Bourdieu, 2016).

MATERIALS AND METHODS

A case study was conducted in the community of Tlaltenango, located in the upper basin of the Atoyac River, focusing on family farming as the unit of study. The Puebla Valley is situated at 2,200 m.a.s.l., with fertile soil and favorable conditions for agriculture. According to FAO, the local soils are classified as fluvisols with a sandy loam texture, with a 20 to 40 centimeters superficial layer (CIMMYT, 1974).

Small farms predominate in the region. They began transitioning towards more profitable crops by the late 1970s, when wells were drilled for irrigation units. This transformation included the production and expansion of the area destined to fodder, flowers, vegetables, and fruit trees, without abandoning maize (*Zea mays*) production. By 2018, 52,414 ha were sown in the municipalities of the upper basin of the Atoyac River; 17% of those ha was irrigated, contributing 35.8% of the agricultural production value. Fodder was grown on 5,347 hectares; 53.3% of that area was used for forage maize, 37.4% for alfalfa (*Medicago sativa*), and 9.3% for vetch (*Vicia sativa*) (SIAP, 2024). The dominant crop remains maize, covering 77.1% of the area cultivated in the region.

Semi-structured interviews were conducted from January to April 2019, using an opinion-based sampling method (Ruíz, 1999) that included farmers from the community of Tlaltenango. The survey obtained the percentage of economic income from agricultural, livestock, and non-agricultural activities, as well as other variables related to the family unit.

The resulting data were processed using the Statistical Package for the Social Sciences (SPSS v.23). A typology of family farming was determined, considering the percentage of agricultural and livestock income as the classification criterion. The classification of family farming was based on the theoretical model of Palerm (1980), which describes the relationship between family farming and capital based on the formation of economic income. Two types of family farming were determined: Category I, with incomes ranging from 1% to 49.9% of agriculture and livestock; and Category II, with incomes ranging from 50% to 100% of agriculture and livestock.

RESULTS AND DISCUSSION

Farmer families constitute the analytical instance for addressing the mechanisms of social reproduction, in which incomes stand for resources, activities, and relationships.

Land in the production unit

In the context of production units, the average size of family farming plots is 3.8 ± 1.6 ha. These small farms combine private property and ejidos. The average area of rainfed and irrigated plots is 2.5 ± 1.5 and 1.2 ± 0.70 ha, respectively. The typical agrarian structure of the country is determined by the size of the production units. Mexican agriculture is characterized by the predominance of small plots, since 67.9% of the rural production units (RPU) of the country have ≤ 5 ha (INEGI, 2012). This characteristic sets Mexico apart from other Latin American countries, such as Argentina, Chile, and Brazil, where the average size of the RPUs is 107.4, 46.0, and 24.1 ha, respectively. The Mexican situation is closer to the Andean countries, such as Colombia (4.5 ha) and Ecuador (3.5 ha). However, Mexican RPUs are larger than RPUs in Peru (1.3 ha) and Guatemala (1.2 ha) (Leporanti *et al.*, 2014). Land ownership is a fundamental asset in the reproduction strategies of family farming, both as heritage (Appendini, 2010) and as a source of employment, belonging, and holding for a community (Warman, 2001).

The farming family

The number of household members is one of the main assets that allows farming families to perform many activities and generate economic income. The average age of the head of the household is 48.8 ± 13.5 years, with an average education of 6.9 ± 2.2 years. The average number of family members is 4.6 ± 1.9 individuals. Family members establish solidarity and cooperation relationships, that maintain the household as a social and economic unit for agricultural work, contributing with economic resources through non-agricultural activities. Wives participate in agricultural production, harvest management, and surplus production marketing. Women, as resource providers, have become a part of the new configurations of family structures, leading families to move away from the more traditional nuclear family model, where women primarily engaged in domestic work.

Agricultural production

In the production units, various associated and intercropped crops are established. The total agricultural area cultivated across all production units was 287.0 ha, with maize, milpas, vegetables, and fodder accounting for 59.6, 6.8, 7.8, and 25.8% of the sowing area, respectively. Agricultural production was enhanced by the construction and expansion of irrigation units in the late 1970s, which enabled the production of fodder and vegetables.

The productive system of family farming relies on the development of local production capacities, the creation of irrigation units, and the integration of agriculture and livestock. Maize and fodder, in various proportions, are used to feed beef and dairy cattle, as well as sheep, goats, pigs, and poultry. Livestock farming is an alternative for improving income and retaining economic surplus within the production unit. This process is not imposed by agribusiness or capital, but rather allows the local RPUs to integrate into the regional market. Livestock farming, especially dairy cattle production, is the most significant activity, with an average of 6.0±5.4 heads of cattle per production unit. Livestock farming is not a recent development; it has always been a source of savings and labor for family farming. This remarkable process tends to strengthen through the production of fodder, facilitated by irrigation, as well as the increase in maize productivity and production. Livestock farming constitutes a strategic savings asset and a safety net (FAO, 2009) to face the demands of social reproduction. This condition is not exclusive to Mexico: in Latin America and the Caribbean, small-scale production contributes over 60% of the production of beef, poultry, and pork, as well as meat from other species and dairy products (Díaz and Valencia, 2014).

Income strategies and the typology of family farming

Total income is comprised of economic, agricultural, livestock, and non-agricultural activities. On average, agriculture accounts for 22.7% of the annual economic income, livestock 32.5%, and non-agricultural activities 44.8%. This composition of income reflects the assets and relationships of family farming: agricultural and non-agricultural activities are essential and complementary for the overall economic income. Consequently, two types of family farming were identified: Category I, multi-active farming, where income is primarily the result of non-agricultural activities; and Category II, family farming focused on agricultural activities. The typology is outlined in Table 1.

Category I

On average, agricultural and livestock income accounts for 34%, while income primarily comes from non-agricultural activities. This situation reflects a multi-active family farming system, with less irrigated land available than in Category II. Irrigated land is a fundamental asset for fodder production and livestock farming.

Category II

Family farming obtains 70.3% of its income from agricultural activities. Family farming is centered on agricultural activities and relies on irrigation and a productive system that integrates agriculture with livestock, establishing a pathway for agricultural development.

The comparison of the categories allows the identification of their distinguishing elements (resources, activities, and income). Both categories engage in non-agricultural activities. Limited productive resources and income from agricultural activities hinder the ability of the household unit to rely exclusively on agricultural activities for its reproduction.

Table 1. Typology of family farming. Source: Table developed by the authors based on field information.

Variable	Category I (41.7%)		Category II (58.3%)	
	Mean	Standard deviation	Mean	Standard deviation
Age of household head	48.0	14.6	49.4	13.9
Years of education	6.9	2.1	6.7	2.0
Number of persons in household	5.0	1.8	4.5	1.8
Area under irrigation (ha)	0.7	0.5	1.6	0.5
Rainfed land (ha)	2.2	1.4	2.7	1.5
Total land area (ha)	2.9	1.4	4.4	1.4
Agricultural income (%)	20.1	9.6	24.5	10.0
Livestock income (%)	13.9	13.6	45.8	17.9
Non-agricultural income (%)	66.0	11.2	29.7	12.8

This situation requires non-agricultural activities. Income is a core component of family farming reproduction, albeit with a differentiated relative importance.

The income strategies of family farming and the assets that support them, particularly for Category II, enable the social reproduction of agriculture. Gordillo (2004) classifies family farming into two main groups based on the level of their assets, which lay the foundations for the reproduction and income strategies developed according to the research findings. Therefore, the transformations in family farming are not only driven by neoliberalism, but also by the capacity for change within agrarian societies (González, 2007).

The persistence of family farming is significant proof against the assertion of the technical and economic unviability of small-scale production on which the structural adjustment reforms, particularly those made to Article 27 of the Constitution, were based and which claimed that poverty is linked to minifundios. The transformation of production units is taking place within the smallest production units, functioning as a model of multiple productive evolution and technological change, driven by the innovations of the Plan Puebla, under the auspices of CIMMYT and the Colegio de Postgraduados, which demonstrated the possibility and viability of technological changes in traditional agriculture (Díaz *et al.*, 1999).

Nevertheless, the agricultural pathway of family farming faces limitations, including restricted access to irrigation, land fragmentation due to inheritance or sale, and a lack of capital and financing that could strengthen available assets, including livestock. The family farming strategy is a response to an environment that offers limited productive and social options. This response allows farmer families to maintain and improve their social and economic conditions.

Meanwhile, the persistence of the agricultural activities identified in this study contrasts with findings reported in other regions of the country, where agricultural activities and income from family farming are marginal or nonexistent, due to the transition and diversification of the rural economy and labor markets (Appendini and Torres-Mazuera, 2008). This contrast highlights the diverse trends shown by changes to family farming and the rural economy. Agrarian transformations are heterogeneous and they vary depending on the territory, according to the strategies of family farming and their economic and social assets and relationships.

CONCLUSIONS

The family farming strategy is classified into two categories, which differ depending on the magnitude (%) of agricultural income: one category is centered on agricultural activities and income, while the other is characterized as pluriactive family farming. The persistence and importance of agriculture and livestock as the primary source of income in family farming provide relevant proof for the reassessment of its social and economic viability. The income strategy was developed based on irrigation units and the selection of crop systems integrated with livestock. The strategy for non-agricultural income in family farming highlights the limitations of small-scale agricultural production, which lacks the necessary assets, particularly land and irrigation, for an income strategy centered on agriculture.

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Colegio de Postgraduados

Pests and diseases in coffee (*Coffea arabica* L.) production in two municipalities of the State of Puebla

Ramírez-Valverde, Benito[1]; Ramírez-Suárez, José Gustavo[1]; Juárez-Sánchez, José Pedro[1*]

[1] Colegio de Postgraduados Campus Puebla. Santiago Momoxpan, Municipio de San Pedro Cholula, Puebla, México. C. P. 72760.

* Correspondence: pjuarez@colpos.mx

ABSTRACT

Objective: To analyze the presence and impact of pests and diseases on coffee production in two indigenous communities in the state of Puebla.

Design/Methodology/Approach: Information was collected through interviews with 57 growers in Huehuetla and 52 in Cuetzalan.

Results: The coffee area sown in the region is made up of very small *minifundios* (very small plots, not big enough to produce profits), which reflects the challenging living conditions of coffee farming families. A statistically significant difference in yield was recorded between municipalities ($t=2.348$; $p=0.021$). The coffee varieties grown in the region include: Typica, Caturra, Mundo Novo, Garnica, and Bourbon. Pests and diseases were found in the plots of the farmers. The most prevalent pests and diseases were the coffee berry borer and the coffee leaf rust, found in 57 and 42.9% of the farms. In the case of coffee leaf rust, statistically significant differences were recorded ($\chi^2=3.906$; $p=0.048$) between the two municipalities, with a higher prevalence in Cuetzalan (53.1%) than in Huehuetla (33.9%). Additional pests and diseases were identified, including American leaf spot (24.8%), pellicularia koleroga (7.9%), cercospora leaf spot (6.9%), coffee white stem borer (6.1%), root rot (6%), and coffee leaf miner (3%). Chemical treatments are used to control most of these pests and diseases.

Study Limitations/Implications: The detection of pests and diseases depended on the perception of the grower.

Findings/Conclusions: Coffee growers in these municipalities are among the poorest of the region. Furthermore, their crops are impacted by pests and diseases, which increase their already challenging living conditions.

Keywords: living conditions, chemical control, poverty.

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INTRODUCTION

Coffee plays a key role in Mexican economy, society, culture, and environment. It is cultivated in twelve states across an area of approximately 800,000 hectares (Aguirre-Cadena *et al.*, 2012). Most coffee growers in Mexico are poor and live in indigenous regions. In addition, they operate under extreme *minifundio* conditions.

Coffee production in Mexico has declined in recent years. This situation is attributable to several factors, mainly pests and diseases. As a result of the coffee price crisis and off-farm employment increase, growers have reduced the time and attention they dedicate to coffee plantations, making them more vulnerable to pest and disease infestations, such as coffee leaf rust (Henderson, 2019). The objective of this research was to analyze the presence and impact of pests and diseases in the coffee cultivation areas of two municipalities in the state of Puebla.

MATERIALS AND METHODS

Study area

The two municipalities selected for this research were Cuetzalan del Progreso and Huehuetla. Both are located in northern Puebla.

Cuetzalan has 51,823 inhabitants, 33,308 out of which are Nahuatl. The area is highly marginalized and a large part of its population lives in extreme poverty (Secretaría del Bienestar, 2024a). It is located between 20° 02' and 20° 10' N and 97° 35' and 97° 40' W. Cuetzalan is located at an altitude ranging from 200 to 1,100 m.a.s.l. and has a temperature of 18-24 °C, with a precipitation of 2,900-3,600 mm. Its climate is semi-warm and humid with rainfall all year round (100%). Fifty-two-point-six percent of its soil is used for agriculture (INEGI, 2024a).

Huehuetla has 22,122 inhabitants, 13,755 out of which are Totonac. The area is highly marginalized and 83.62% of the population lives in poverty (Secretaría del Bienestar, 2024b). Huehuetla is located between 19° 57' and 20° 06' N and 97° 23' and 97° 35' W, at 180-1,600 m.a.s.l. The temperature of the area ranges between 18 and 25 °C, with a 1,900-4,100 mm precipitation. Huehuetla has a semi-warm humid climate with rainfall all year round (99.12%). Sixty-four percent of the land is used for agriculture (INEGI, 2024b).

Statistical analysis

A survey was conducted among coffee growers in the municipalities of Huehuetla ($n=57$) and Cuetzalan ($n=52$). Parametric and non-parametric tests were used for the statistical analysis, according to the scale of measurement of the variable.

RESULTS AND DISCUSSION

Coffee growers were 56.9 years old in Huehuetla and 55.1 years old in Cuetzalan. These results match those reported by Alvarado-Méndez *et al.* (2006).

Like most coffee growers in the country, the farmers of these municipalities grow coffee in small plots. In Huehuetla, most growers (84.2%) cultivate coffee in a single plot, with an average area of 1.32 ha ($s=1.86$). Meanwhile, coffee growers (67.3%) in Cuetzalan grow coffee in a single plot, with an average area of 1.56 ha ($s=1.86$). This result is consistent with the findings of Benítez-García *et al.* (2015), who reported that plots in Cuetzalan had a 1.57 ha average area. No statistically significant differences were identified between the area owned by growers in the two municipalities ($t=-0.679$; $p=0.499$). Coffee is the main crop of the region and the *minifundio* systems contributes to the poverty of the families that grow coffee as their main income.

Regarding tenure, all the growers in Huehuetla and 96.2% in Cuetzalan own their lands (private property), while the remaining 3.8% of the producers from Cuetzalan rent land to grow coffee.

Producers grow one, two, or three coffee varieties, accounting for 66.1%, 22.9%, and 9.2%, respectively. A comparison of the two municipalities reveals a high similarity between them. In Huehuetla, 70.2% of producers grow one variety, while 22.8% grow two varieties. Meanwhile, in Cuetzalan, 61.5% of producers grow one coffee variety and 23.1% grow two varieties.

Typica is the most popular variety (34.5% of the growers) in the two municipalities. Nearly a quarter (24.1%) of the farmers grow Caturra, while Mundo Novo accounts for a slight lower percentage (22.1%). The remaining percentage is covered by other coffee varieties grown in the area. In Cuetzalan, Typica and Caturra are the most cultivated varieties. In contrast, the interviewees from Huehuetla mainly mentioned Mundo Novo and Typica. In face of the emergence of coffee leaf rust, new varieties resistant to this fungal disease are being promoted in the area.

Agricultural practices

The prevalence of pests and diseases in the Sierra Norte de Puebla has prompted alterations in coffee production technology (Barrera *et al.*, 2021). In the study area, coffee is intercropped with seasonal and perennial crops, which are used as shade trees. An additional crop is grown on 28% of the plots. Two and three crops are grown along with coffee on 19.6 and 30.8% of the plots, respectively. Other polycultures include four (8.4%) and five (9.4%) additional crops. Finally, six different crops are grown on 3.7% of the plots. Some farmers grow staple food crops, including corn, beans, and chili. Regarding shade trees, chalahuite (*Inga spuria*) can be found in 31% of the plots, orange (*Citrus* spp.) in 19%, pepper (*Pimenta dioca*) in 15.7%, and banana (*Musa paradisiaca*) in 14.8%. Meanwhile, species such as bamboo (*Bambusa* spp.), mamey (*Pouteria sapota*), and red cedar (*Cedrela odorata*) can be found in the rest of the plots.

Only one-third of the surveyed growers applied fertilizers and 46.5% of them used chemical fertilizers. Most coffee growers (94.7%) used manual weed control methods, while 5.4% used herbicides.

Pests and diseases

The presence of pests and diseases is evident in the plots of the farmers. In a study conducted in the Sierra Norte de Puebla, Lugo-Morín *et al.* (2018) established that two pests (coffee berry borer and leaf miner) and three diseases (coffee leaf rust, cercospora leaf spot, and American leaf spot) cause the greatest economic losses.

Coffee berry borers were found in 57% of the farms (Table 1) and, according to Leyva (2010), they cause the greatest damage to the crop. This insect was found in 49.1% and 66% of the plots in Huehuetla and Cuetzalan, respectively. No statistically significant differences were found between the two municipalities ($\chi^2=3.096$; $p=0.059$).

A total of 80.3% growers were able to control the pest (89.3% in Huehuetla and 72.7% in Cuetzalan). Regarding control methods, 14.3% of coffee farmers used

Table 1. Pests and diseases of coffee crops in the municipalities of Huehuetla and Cuetzalan.

Pests / diseases	Huehuetla		Cuetzalan		Total		p
	F	%	F	%	F	%	
Broca del café (*Hypothenemus hampei*)	28	49.1	33	66	61	57	0.059$^{\chi}$
Minador de la hoja (*Leucoptera coffeella*)	1	2	2	4.2	3	3	
Arañero (*Oligonychus coffeae*)	1	2	0	0	1	1	
Barrenador de tallo (*Xylosandrus compactus*)	1	2	5	10.4	6	6.1	
Roya del café (*Hemileia vastatrix*)	19	33.9	26	53.1	45	42.9	0.048$^{\chi}$
Ojo de gallo (*Mycena citricolor*)	17	30.9	9	18	26	24.8	0.096$^{\chi}$
Mancha de hierro (*Cercospora coffeicola*)	5	9.4	5	4.1	7	6.9	0.252^{F}
Mal de hilachas (*Pellicularia koleroga*)	4	7.7	4	8.2	8	7.9	0.608^{F}
Pudrición de la raíz (*Fusarium* spp.)	2	3.9	4	6.2	6	6	
Mal Rosado (*Corticium salmonicolor*)	1	1.9	1	2.1	2	2	

Note: Significance obtained by Chi-square test (χ) or Fisher's Exact Test (F). Source: field work.

traditional methods, 40.8% applied biological methods, and 44.9% implemented chemical procedures. The distribution of control methods across municipalities had a similar pattern. In Huehuetla, 16.7, 41.7, and 41.7% of growers used traditional control methods, chemical products, and biological control, respectively. In Cuetzalan, 12, 48, and 40% of growers used traditional control, chemical products, and biological control, respectively.

Most growers (82.3%) indicated that this insect causes minimal or regular damage to their crops. In contrast, the rest (17.7%) considered this pest a serious problem that causes substantial or severe damage to their coffee plots. The Mann-Whitney test ($U=327.00$; $p=0.804$) showed highly similar percentages in both municipalities, with no statistically significant differences between them. Furthermore, a lower incidence of other pests was reported in the municipalities under study, including the red spider mite (1%), the coffee leaf miner (3%), and the coffee white stem borer (6%).

Regarding diseases, coffee leaf rust has spread throughout the coffee producing states, impacting ≈256,973 ha. Coffee leaf rust is the most important disease, because it drastically reduces crop yield (Leyva, 2010).

Coffee leaf rust was found in 42.9% of the farms. A statistically significant difference ($\chi^2=3.906$; $p=0.048$) was established between the two municipalities. This disease was found in 33.9% and in 53.1% of the plots in Huehuetla and Cuetzalan, respectively. The coffee leaf rust infestation was higher in Cuetzalan; however, this percentage was lower than the percentage reported (92.5%) by Cardeña-Basilio *et al.* (2023) for the municipality of Hueytamalco, located in the Sierra Nororiental de Puebla.

A total of 69.6% of growers use some type of control against coffee leaf rust; no statistically significant differences were found between the two regions (68.4% in Huehuetla and 70.4% in Cuetzalan). Cardeña-Basilio *et al.* (2023) obtained similar results (71%) in Hueytamalco. Meanwhile, 14.7% of the producers interviewed for this research implemented traditional control measures to manage the disease (21.4% in Huehuetla and 10% in Cuetzalan). For their part, 17.6% of the growers mentioned that they use biological control measures (21.4% in Huehuetla and 10% in Cuetzalan), while 67.7% reported the use of chemical fungicides (64% in Huehuetla and 70% in Cuetzalan). Escamilla (2016) pointed out that the use of fungicides is one of the strategies employed by governments and some growers as a short-term solution for the problem. However, the inappropriate application of fungicides may contribute to the increase of coffee leaf rust. This opinion is also shared by Cardeña-Basilio *et al.* (2019), who mentioned that chemical application is often haphazard and lacks the required technical support.

In terms of the impact of this disease on coffee plantations, 50% of growers indicated that the damage was still slight, 27.8% stated that it was regular, 16.7% reported that the damage was severe, and 5.6% mentioned that the impact on their coffee plantation was very severe. The Mann-Whitney test found no statistically significant differences between the two municipalities ($U=122.5$; $p=0.335$).

Additionally, other diseases were detected, including American leaf spot (24.8%), cercospora leaf spot (6.9%), pellicularia koleroga (7.9%), and root rot (6%). According to the information collected, most growers whose crops were infested faced diseases such as American leaf spot (57.7%), cercospora leaf spot (71.4%), and pellicularia koleroga (62.5%). Despite the relatively low incidence of root rot, 66.7% of the producers with infested crops said they made efforts to control it. Chemical control was the most frequently used method against the American leaf spot, accounting for 64.7% of the total cases. Nevertheless, 80% of growers implemented chemical control measures to control cercospora leaf spot, while 71.4% used fungicides to tackle pellicularia koleroga. Despite the limited number of plots impacted by these diseases, the use of chemicals increases the production costs of the crop. Additionally, the yield damage caused by these diseases in most cases ranged from minimal to regular (68.8% American leaf spot, 66% cercospora leaf spot, and 75% pellicularia koleroga).

Although the damage was relatively minor, diseases and pests had a significant impact on both production costs and yields. Consequently, implementing plans to increase productivity through the use of agrochemicals would offer short-term advantages. However, the economic cost and ecological damage of such plans would also be considerable (Aguirre-Cadena *et al.*, 2012). According to the survey, 14% of growers reported lack of increase in production during the last few years, while 2.8, 12.1, and 29.9% reported a notable, modest, and slight increase, respectively. Meanwhile, 29.9% of growers pointed out that coffee yields have suffered a slight decline and 41.1% believe that there has been a considerable decrease in coffee yields. The larger group of producers in the area live under the same challenging circumstances than other coffee farmers. No statistically significant yield differences were reported by the producers from the two municipalities (Mann Whitney $U=1{,}665.5$; $p=0.118$).

The yield obtained in Huehuetla and Cuetzalan was 1,473.75 and 742.94 kg/ha of cherry coffee, respectively. Statistically significant yield differences ($t=2.348$; $p=0.021$) were found between the municipalities. However, Jaramillo *et al.* (2022) had recorded annual variations that show yield changes: a 1.47 t/ha yield of cherry coffee in Cuetzalan. For their part, Benítez-García *et al.* (2015) recorded 2.06 kg/ha. Meanwhile, Ramírez and Juárez (2008) reported yields of 1,178.64 kg/ha in Cuetzalan and 1,502.3 kg/ha in Huehuetla.

According to Alvarado-Méndez *et al.* (2006), coffee berry borer and coffee leaf rust impact a significant number of plots, consequently reducing yields. This situation is one of the factors that contributes to the reduction of the income of the growers. The annual income sometimes does not even cover production costs. In addition, the persistence of the crop can be attributed to the overexploitation of the family labor force. Likewise, Rivadeneyra and Ramírez (2006) highlighted that, some years, the costs of cultivation are not covered due to the low coffee prices. Consequently, pests and diseases increase in the abandoned plots. Ramírez and Juárez (2008) also pointed out that, as a consequence of the recurrent coffee crisis, pests and diseases have reappeared in coffee plantations, impacting the quality and income of coffee growers.

CONCLUSIONS

Coffee growers live under poverty conditions and practice agriculture under extreme minifundio conditions. These difficulties are exacerbated by the recurrent coffee price crises and the presence of pests and diseases that reduce production, perpetuating the difficult living conditions of farming families.

A multitude of pests and diseases impact crops. Chemical products increase production costs and have a negative impact on the environment. In addition, the lack of technical guidance hinders the appropriate use of these products. In conclusion, developing strategies for farmers to minimize the damage and to encourage a greater government support —including technical assistance and adequate resources— is fundamental for the effective control of pests and diseases in coffee plantations.

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Colegio de Postgraduados

Agronomic and morphological evaluation of six genotypes and two hybrids of Poblano peppers in field conditions

Jiménez-Hernández, Leticia[1]; **Camposeco-Montejo, Neymar**[2*]; **Sandoval-Rangel, Alberto**[1]; **Robledo-Torres, Valentín**[1]; **Alcalá-Rico Juan Samuel Guadalupe**[3]; **Antonio Flores Naveda**[1]

[1] Universidad Autónoma Agraria Antonio Narro, Departamento de Horticultura, Calzada Antonio Narro 1923, Col. Buenavista, Saltillo, Coahuila, México. C.P. 25315.
[2] Universidad Autónoma Agraria Antonio Narro, Departamento de Fitomejoramiento, Calzada Antonio Narro 1923, Col. Buenavista, Saltillo, Coahuila, México. C.P. 25315.
[3] Campo Experimental Las Huastecas-INIFAP. Carretera Tampico-Mante km 55, Villa Cuauhtémoc, Tamaulipas, México. C.P. 89610.
* Correspondence: neym_33k@hotmail.com

ABSTRACT

Objective: to evaluate agronomic and morphological traits of six Poblano-type pepper genotypes, compared to a commercial hybrid and an experimental hybrid, in order to select genotypes with potential to continue with a plant breeding program.

Design/Methodology/Approach: treatments and statistical model were arranged in randomized complete blocks, with eight treatments (six F_2 genotypes, and two hybrids Carranza (commercial F_1) and F402 (experimental F_1). Treatments were analyzed with analysis of variance ($p \leq 0.05$); then tested with Multiple Mean Comparison (Tukey, $p \leq 0.05$) and Pearson Correlation Analysis.

Results: no statistical differences were found in yield per plant, number of fruits per plant, average weight per fruit, plant height, stem thickness, leaf length and leaf width. Regarding width at the base of the fruit the hybrids were superior; in average width of the fruit the genotypes G4, G6 and the hybrids were better; in fruit length G2, G5 and G6 stood out; in calyx depth G1, G3 and G4; in length of the peduncle G4 was different from the others; and in thickness of the mesocarp the genotypes G2, G4, G6 and hybrids were superior. According to Pearson's correlation, the yield depended on NFP (0.66), MT (0.46), FBW (0.38), as it is shown by their coefficients.

Limitations/Implications of the study: F_1 hybrids do include market features preferred by consumers and producers, since those hybrids were created to favor those traits; for this reason, those hybrids were compared to second generation (F_2) genotypes obtained by directed manual pollination.

Findings/Conclusions: The evaluated G2, G4 and G6 second generation (F_2) genotypes are highlighted for their agronomic potential compared even to the tested hybrids. So, their genetic potential is inferred and could be useful to continue selecting them within a plant breeding program.

Keywords: *Capsicum annuum*, F_2, agronomic behavior, correlation analysis.

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INTRODUCTION

The cultivation of chili peppers in Mexico is of great importance due to its origin and domestication. There is archaeological evidence which suggests that peppers were

cultivated from 7000 to 2555 B.C. in regions as the Coaxtlán Cave, Tehuacán Valley, Puebla, Ocampo, Tamaulipas and Mitla, Oaxaca (Perry & Flannery, 2007; Kraft *et al*., 2014). Within the genus *Capsicum* 43 species and five varieties are recognized; among them there are five taxa of economic importance which are *Capsicum annuum* L. var. *annuum*, *C. baccatum* L. var. *pendulum* (Willd.) Eshbaugh, *C. baccatum* L. var. *umbilicatum* (Vell.) Hunz. & Barboza, *C. chinense* Jacq. and *C. frutescens* L. (Purkayastha *et al*., 2012; Barboza *et al*., 2022).

Mexico ranks second worldwide in green production with 3 113 244 tons and fourteenth place in dry or dehydrated with a production of 60 987 tons (FAOSTAT, 2022). Those varieties with the highest production are Jalapeño, Poblano and Serrano peppers. In the case of Poblano pepper, it is grown in 16 696.88 hectares, with a production of 414 656 tons, with an average yield of 25 tons per hectare. The five states that lead production are Zacatecas, Guanajuato, Jalisco, Baja California Sur and Sinaloa. For this type of pepper, but dried, that after dehydration is known as "Ancho pepper", 15 247 hectares are used with a production of 151 270 tons and yield of 9.9 tons per hectare. There are five states of the Mexican republic that lead the production of this Poblano pepper dehydrated, which are Zacatecas, San Luis Potosí, Durango, Puebla and Oaxaca (SIAP, 2022).

Poblano-type pepper is appreciated for its gastronomic, economic, social, and cultural importance (Rodríguez *et al*., 2007; Toledo *et al*., 2011). This crop is adapted to diverse environmental conditions in various producing regions of the country; where there are native varieties with morphological diversity of interest to be integrated into conservation and genetic improvement projects (Rodríguez *et al*., 2007; Toledo-Aguilar *et al*., 2011; Tripodi & Kumar, 2019). However, these native varieties are highly susceptible to pests and diseases; environmental consequences derived of climate change further limit their productivity (Rodríguez *et al*., 2007; Herrera-Fuentes *et al*., 2023). In addition, the seed for pepper production is generally imported by foreign companies, which generates high costs for small producers before starting cultivation (Toledo-Aguilar *et al*., 2011).

Hence the importance of genetic improvement of crops, since it allows the creation of new variants from plant materials with genetic diversity, promoting the combination of traits conferred by the original selections, inducing mutations or retro-crossing wild varieties with commercial ones (Duvick, 2007). In the improvement of chili pepper, several objectives are pursued such as high yield, resistance to pests and diseases or to abiotic stress, to create ornamental plants, and even to increased pungency, meeting market demands (Padilha & Barbieri, 2016). Therefore, several techniques have been applied in chili peppers to improve the crop, such as mass selection, pedigree or genealogical technique, single-seed offspring, recurrent selection, retro-crossing and hybridization (Srivas-tava & Mangal, 2019; Karim *et al*., 2021).

For these reasons, a genetic improvement program using native or creole genotypes will increase yield, productivity, tolerance to adverse abiotic and biotic agents, increasing the quality and range of adaptation in the different producing areas in medium and long terms (Bailey-Serres *et al*., 2019). However, in any plant breeding program, it is necessary to evaluate the genotypes for their agronomic and morphological traits, to identify their actual genetic potential. Therefore, the objective of this study was to evaluate genotypes of second generation of selection (F_2) Poblano peppers, compared to two hybrids for selecting the best genotypes. Once selected, those shall continue in the breeding program, which would eventually allow generating hybrids or outstanding varieties in medium and long terms.

MATERIALS AND METHODS

Location

This research was established in field conditions at the experimental area of the Department of Horticulture at the Universidad Autónoma Agraria Antonio Narro, Saltillo (Coahuila) Mexico, located at coordinates 25° 21' 23.44" N and 101° 2' 5.18" W, with an average annual temperature of 24 °C, and average annual rainfall of 400 mm; However, during the cultivation period 22 °C was the average temperature, 6.7 °C as minimum and 36.93 °C as maximum temperatures, according to the local University Network of Atmospheric Observatories.

Genetic material

Six genotypes generated from directed manual pollination were used between a genotype that served as a female parent, with the pollen bulk of three genotypes that served as a male. As a result of this recombination, from plants that were cultured in 2022, F_1 was obtained out of which six genotypes were selected for their distinctive and outstanding phenotypic characteristics. This research was the subsequent evaluation of those F_2 genotypes, the stage that was evaluated in 2023. Likewise, it was compared with two hybrids, one of them was the commercial breed from SEMINIS, the Carranza® (F_1) Ancho pepper that ripens from green to red, suitable for fresh and dry markets, with high yield potential and excellent quality of green fruit, good fresh/dried fruit ratio. The other was the experimental hybrid F402 (F_1) generated at the Center for Training and Development in Seed Technology of the "Antonio Narro" Autonomous Agrarian University (Table 1). Both types of genotypes were considered as treatments.

Table 1. Identification of the genetic material used to evaluate agronomic and morphological behavior in field conditions in Saltillo (Coahuila), Mexico.

Key	Description
G1	Genotype1
G2	Genotype 2
G3	Genotype 3
G4	Genotype 4
G5	Genotype 5
G6	Genotype 6
F402	UAAAN Experimental Hybrid F_1
CARR	Carranza F_1-Seminis

Plant production

The genetic material was sown on February 18, 2023, in 200-cavity polystyrene germination trays, with substrate for germination of peat-moss and perlite at a 70:30 (%) ratio. Seeds were sown at a 0.5 cm depth, covered with a thin layer of the same substrate mixture. To induce germination, they were covered with black plastic for 72 h, then left in the greenhouse for the emergence and growth of the plants. In order to have good quality plants, fertilization was supplied after six days of emergence with soluble Triple 20 (20-20-20), added with microelements at a dose 1 g L^{-1}.

Establishing the crop

Transplant was done 60 days after planting, the genotypes were distributed in four culture beds raised to 30 cm in height, by 40 cm in width and 15 m in length, plastic mulch was used to prevent weed abundance. Distance between beds was 1.8 m; distance between plants was 30 cm in double rows, with a separation of 25 cm between rows. Planting density calculated under that configuration was 37 000 plants per hectare.

Crop nutrition and crop management

Crop nutrition was supplied by irrigated fertilization (fertigation). After 5 days from transplantation, a modified Steiner-type solution was used in ascending concentrations, according to the stage in crop phenology, 50% (at transplanting), 75% (during vegetative stage) and 100% (at fruiting). As it is shown in Table 2, these occurred at 5, 21 and 50 days after transplantation respectively. It was intended to maintain pH ranging 5.9 to 6.1, electrical conductivity from1.5 to 2.7 dS m^{-1} depending on the stage.

Weed elimination between beds and in the holes of the mulch was made every 15 days to prevent their spread. Tutors for plants were placed according to plant growth by the trellis method; it began when the plants had an average height of 25 cm, in order to keep the plant upright throughout the crop cycle. To prevent the proliferation of pests such as whiteflies, thrips (order Thysanoptera) and spider mites, Spirotetramat at 15.3%, Spiromesifen at 23.1% and Imidacloprid 17% + betacylfutrin 12% at a rate of 1 mL L^{-1} were applied. And

Table 2. Nutrient chemical composition of the nutrient solution used in the nutritional management of Poblano-type peppers.

Macroelements (mEq L^{-1})										
SN (%)	Cl^-	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	HCO_3^- & CO_3^{2-}	K^{+1}	Mg^{+2}	Ca^{+2}	NH_4^+	Na^+
50	3.26	6	0.5	3.5	1	3.5	2	5.5	1	3
75	3.26	8.6	0.75	5.25	1	5.25	3	8.25	1.5	3
100	3.26	12	1	7	1	7	4	11	2	3
Microelements (ppm)										
SN (%)	Fe^{+3}	Mn^{+2}	H_3BO_3	Zn^{+2}	Cu^{+2}	MoO_4^{2-}	EC(dS/m)		pH	
50	1.5	0.74	0.14	0.12	0.06	0.04	1.5		5.9-6.1	
75	2.25	1.1	0.21	0.18	0.09	0.06	2.1		5.9-6.2	
100	3	1.48	0.28	0.24	0.12	0.08	12.7		5.9-6.3	

for diseases such as Damping-off and mildew (*Laveillula taurica*), Metalaxil-M 45.28%, and Azoxistrobin 50% were used, both in a dose of 0.5 mL L^{-1}.

Harvest

The harvest was made when the fruits presented the external coloration characteristic of the genotype; this occurred 90 days after transplantation. Bags were separated and marked for the subsequent evaluation of each genotype. Two harvests were accomplished during the experiment.

Determination of yield variables and Agronomic behavior

To determine total yield in grams per plant, the yields obtained from both harvests per plant of each genotype were added. This sum was made using a digital scale OHAUS® Scout-Pro®. On each time, the number of fruits per plant (NFP) also was recorded. To calculate the average fruit weight (AFW), the total yield per plant was divided by the total number of fruits collected from that plant. The fruit length (FL) in centimeters was determined using a Vernier caliper (Steren® Her-411, Mexico). This same instrument was used to measure the width at the base, the mean width, the thickness of the mesocarp and the depth of the calyx, all expressed in millimeters. The number of locules was also counted when sectioning the fruits in half.

To quantify the total soluble solids in the fruit, four fruits were randomly selected by replicate, which presented harvest maturity and green color. This measurement was made using a digital refractometer (SOONDA® TD6010, China) and was expressed in °Brix.

With a measuring tape in centimeters (Truper® FH-5M, Mexico), morphological and agronomic behavior variables were measured. Total plant height was measured from the ground to the apical part, as well as leaf length, leaf width and peduncle length. In addition, stem thickness was measured using a Vernier caliper (Steren®, Her-411, Mexico).

Data analysis

The design of treatments was in complete randomized blocks with four replicates. An analysis of variance was performed ($p \leq 0.05$) with the general linear model for a factorial arrangement with six treatments and four replicates. Significant variables were tested with the multiple means comparison of Tukey ($p \leq 0.05$). To analyze interaction and relationship among variables, in order to guide genotype selection, a Pearson correlation analysis was performed (Shumbulo *et al.*, 2017). All these analyses were run in R-Studio (2023 version).

RESULTS AND DISCUSSION

Agronomic variables

The analysis of variance performed for genotypes and hybrids in Poblano-type peppers, in the variables of yield (YPP; kg per plant), number of fruits per plant (NFP), average fruit weight (AFW) did not detect significant differences as observed in Table 3. However, at comparing percentages, hybrids F402, CARR, and genotypes G3 and G6 outperformed G1 and G2 by more than 20%. This statistically insignificant response is probably due to the genotypes are of a second filial generation (F2); therefore, it is an expected response in individuals. In terms of number of fruits per plant, G6 was 24% higher than the Carranza hybrid (CARR), which means that G2 shows genetic potential in this trait; a similar response was observed in the average fruit weight (AFW). Number of fruits per plant is an attribute directly related to yield; it is also a determining variable for recurrent selection in breeding programs (Monge-Pérez *et al.*, 2022).

In the case of the variable number of locules (NL), there was a significant difference; G3, G4, G5 and G6 were statistically equal to hybrids with two locules on average (Table 3), whereas G2 and G1 had 2.5 and 2.2 locules. In Poblano-type peppers, it is known they have two locules. Since most consumers prefer Poblano peppers with fewer veins and seeds, this can make them easier to clean and prepare for cooking. However, some farmers reported that for dried Poblano peepers (then called "Ancho" peppers) they prefer three veins.

Although the variable of total soluble solids (°Brix) did not show significant differences between genotypes and hybrids as observed in Table 3, in a selection and breeding program it is important to consider the total soluble solids content of the Poblano pepper genotypes, especially if the aim is to increase their sweetness, when dried. Therefore, even if there were no statistical differences between genotypes and hybrids, their inclusion in the analysis is still important to assess the sweetness potential of Poblano peppers, for selecting those which best align with market preferences.

Regarding the fruit quality variables, as observed in Figure 1A, there was a significant difference between genotypes and hybrids in the variable of fruit base width, the hybrids CARR and F402 were statistically equals, but superior to the genotypes. A similar trend was observed in average fruit width (Figure 1B), although in this variable G4 and G6 were also similar to hybrids.

Table 3. Analysis of variance and comparison of means for yield and its components; number of locules and total soluble solids of six genotypes and two hybrids of Poblano peppers, evaluated in field conditions, in Saltillo (Coahuila), Mexico.

Genotype	YPP ($Kg\ plant^{-1}$)	NFP	AFW (g)	NL (mm)	TSS (°Brix)
CARR	0.80 a	14.86 a	53.62 a	2.11 b*	8.71 a
F402	0.69 a	15.16 a	67.87 a	2.03 b	8.89 a
G1	0.55 a	11.91 a	49.59 a	2.28 ab	10.43 a
G2	0.53 a	9.93 a	54.09 a	2.53 a	8.60 a
G3	0.69 a	15.81 a	44.61 a	2.22 b	8.70 a
G4	0.61 a	12.71 a	49.15 a	2.17 b	8.75 a
G5	0.66 a	13.74 a	47.11 a	2.17 b	8.68 a
G6	0.78 a	15.11 a	55.82 a	2.08 b	8.95 a
ANVA P≤	0.0515	0.3361	0.7911	0.0008	0.6674
LSD	0.29	8.94	48.84	0.28	3.58
CV %	15.61	22.73	32.15	4.48	13.85

*Different letters in the same column indicate statistically significant differences (Tukey $p \leq 0.05$). LSD=Least Significant Difference, CV=Coefficient of Variation, YPP=Yield per plant, NFP=Number of fruits per plant, AFW=Weight per fruit, NL=Number of locules, TSS=Total soluble solids.

In fruit length at Figure 1C, it is observed that G2, G5 and G6 were statistically equal to the CARR hybrid, whereas the rest of the genotypes and the F402 hybrid showed lower results. Regarding the calyx depth variable (Figure 1D), genotypes G1, G3 and G4 were statistically equal to the CARR hybrid, whereas the rest of the genotypes and F402 showed minor calyx depth.

In the variable of peduncle length (Figure 1E), it was observed that, with the exception of G4, the rest of the genotypes showed a statistical response similar to each other. In terms of mesocarp thickness, the best genotypes were G2, G4, G6 since they showed a statistical response similar to the hybrids (Figure 1F). These variables are of great importance because they are indicators of fruit quality, according to the Mexican Standard (NMX-FF-025-SCFI-2014).

Morphological variables

In the plant height variable, no statistically significant difference was found between the genotypes and hybrids evaluated, as observed in Table 4. However, the height of the evaluated genotypes ranged from 110.48 to 121.46 cm, which is higher than that found

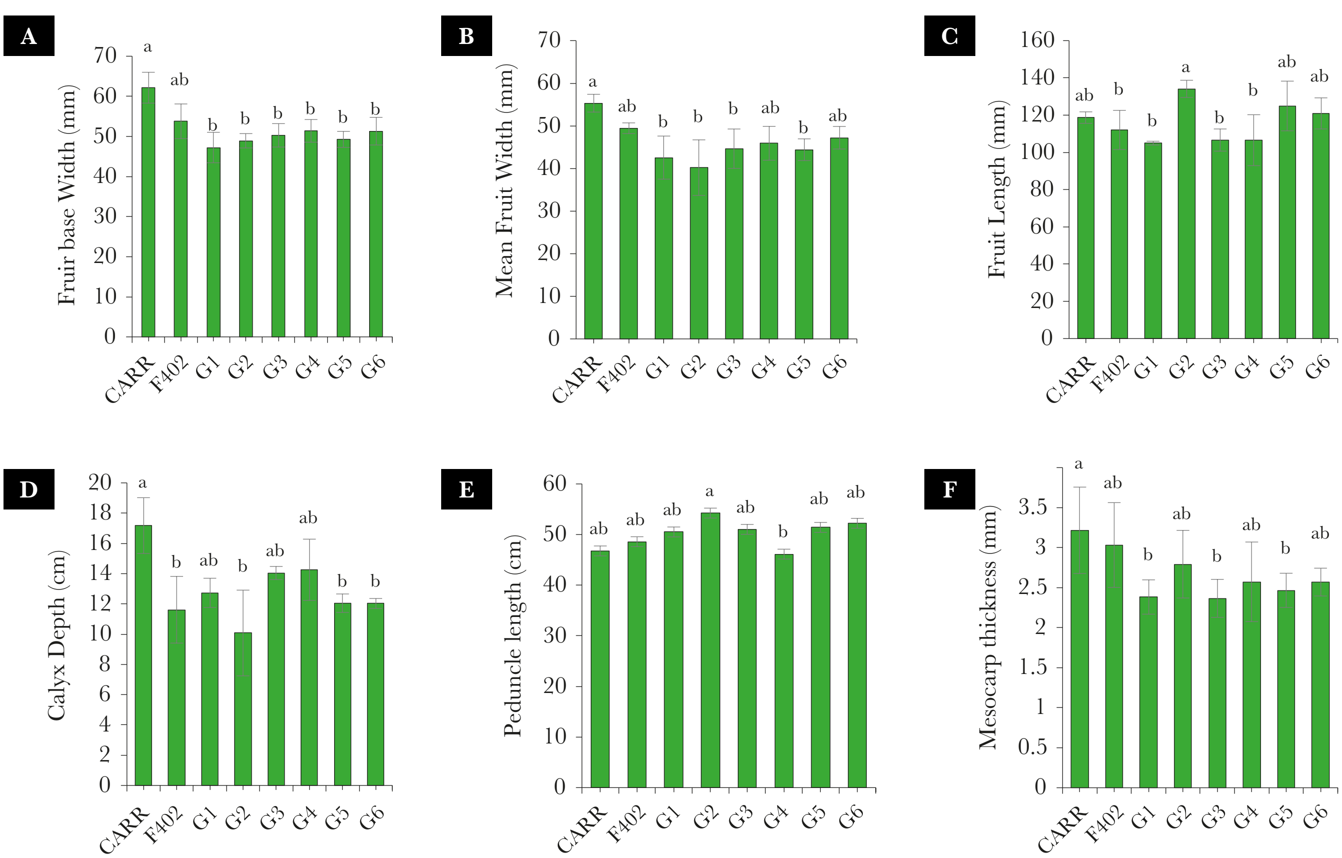

Figure 1. Multiple means comparison (Tukey, p≤0.05). A: fruit base width; B: mean fruit width; C: fruit length; D: calyx depth; E: peduncle length; and F: mesocarp thickness of six genotypes and two hybrids of Poblano pepper evaluated in field conditions in Saltillo (Coahuila) Mexico. Vertical bars correspond to the standard deviation.

Table 4. Analysis of variance and multiple comparison of means (Tukey, p≤0.05) of morphological variables of six genotypes and two hybrids of Poblano peppers evaluated in field conditions, in Saltillo (Coahuila), México.

Genotype	TPH(cm)	SD (mm)	LL (mm)	PL (mm)	LW (mm)
CARR	110.49 a	16.26 a	94.60 a	75.07 a*	42.03 a
F402	99.79 a	15.17 a	96.37 a	69.78 ab	42.36 a
G1	121.46 a	15.23 a	91.93 a	64.93 ab	44.33 a
G2	132.15 a	16.03 a	93.38 a	59.62 b	46.43 a
G3	120.63 a	14.94 a	90.16 a	66.59 ab	42.47 a
G4	127.98 a	14.85 a	89.23 a	67.25 ab	43.48 a
G5	122.40 a	15.38 a	92.09 a	64.98 ab	39.03 a
G6	110.48 a	15.53 a	83.40 a	59.89 a	39.41 a
ANVA P≤0.05	0.07160	0.36015	0.40200	0.01423	0.09446
LSD	33.62	2.27	18.65	12.73	8.12
CV %	9.87	5.11	7.08	6.70	6.64

Different letters in the same column indicate statistical differences (Tukey p≤0.05), LSD=Least Significant Difference, CV=Coefficient of Variation, TPH=Total plant height, SD=Stem diameter, LL=Leaf length, PL=Petiole length, LW=Leaf width.

by Toledo-Aguilar *et al.* (2011) who reported 37.9 to 56.8 cm. Morphological variables are indicatives of crop production, since they represent vigor linked to physiological processes. Stem thickness is a clear example of this, where no statistical difference was detected and measurements ranged 14.9-16.3 mm; stem thickness is one of the morpho-physiological parameters used to evaluate the genetic diversity and heritability of chili pepper genotypes (Pandiyaraj *et al.*, 2017). It is a trait that can contribute to the selection of genetically superior parents and inbred lines for reproduction due to vigor (Vinodhini *et al.*, 2019). In addition, it is a horticultural trait that can be associated with other important characteristics, such as plant height, number of branches, and yield (Karim & Nesa, 2021).

The length of the leaf petiole can be used as a parameter to evaluate the health and plant growth, since it is related to the response of the plant to light intensity (Tsukaya *et al.*, 2002). The results obtained in this variable indicate that except for G2, all obtained the same statistical result with values 59.89-75.07 mm. This indicates that there is potential of the genetic material evaluated, compared with the commercial one, and it is feasible to continue with the plant breeding program.

Correlation coefficients

Pearson correlation coefficients of the evaluated variables were determined (Figure 2), such correlations constitute a measure of the magnitude of the linear association between two variables, without considering cause and effect between them, regardless of the units of measurement. Among the variables of the yield components, the highest correlation corresponded to the YPP with NFP (r=0.88**), followed by YPP with MT (0.46**) and with FBW (0.38*) in Figure 2. The results are similar to those reported by Monge-Pérez *et al.* (2022), where they obtained a positive and highly significant correlation between

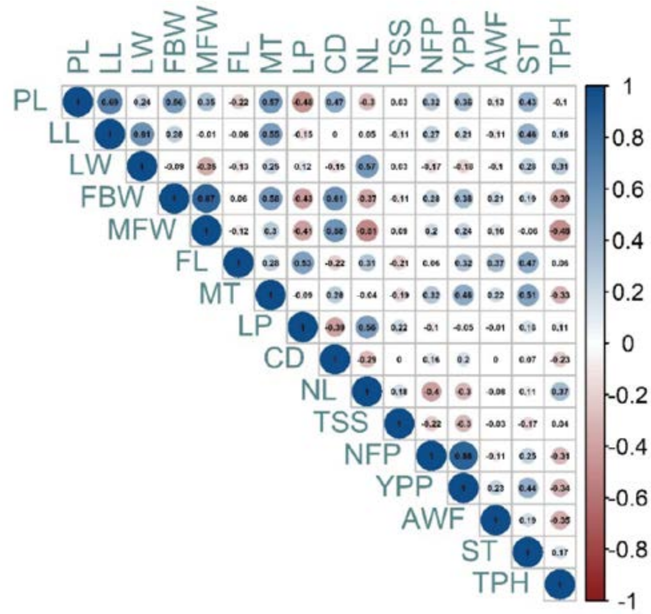

Figure 2. Pearson correlation diagram. PL: petiole length, LL: leaf length, LW: leaf width, FBW: fruit base width, MFW: mean fruit width, FL: fruit length, MT: mesocarp thickness, LP: peduncle length, CD: calyx depth, NL: number of locules, TSS: total soluble solids, NFP: number of fruits per plant, YPP: yield per plant, AWF: average weight per fruit, ST: stem thickness, and TPH: total plant height.

commercial yield and number of fruits per plant (r=0.51**), which means that yield is correlated in the selection of these variables.

Genetic improvement of chili peppers also involves using correlation analysis to understand the relationships between different traits for effective selection and generational advancement. Several studies have shown positive correlations between traits such as yield, fruit length, and the number of seeds per fruit (Islam *et al.*, 2023; Karim & Nesa, 2021). In addition, genotypic and phenotypic correlations have been observed between traits such as plant height, fruit weight, and various biochemical contents such as ascorbic acid and capsaicin (Rahevar *et al.*, 2019). By analyzing the interrelationships between different phenotypic traits, plant breeders can make informed decisions to improve attributes, especially yields and fruit quality.

CONCLUSIONS

The agronomic response of the genotypes and hybrids was similar in some of the response variables, but different in others. In the morphological variables they also showed a similar response; therefore, it is inferred that the G2, G4 and G6 genotypes have genetic potential that may be useful to continue with the plant breeding program. The similarity in agronomic and morphological response between the commercial and experimental hybrid is similar, indicating the genetic potential of the experimental hybrid.

The correlation between the variables evaluated revealed that the number of fruits per plant, fruit length, mesocarp thickness, and width of the fruit base are variables that contribute to a greater extent to crop yield. These findings provide valuable information for the breeding program, highlighting those promising genotypes and key variables to consider in future evaluations in order to clearly understand their behavior.

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Colegio de Postgraduados

Effect of the Application Timing of VIUSID Agro® on the Growth of *Coffea arabica* L. Seedlings

Bustamante-González, Carlos A.[1*]; **Vázquez-Osorio, Yudmila**[1]; **Álvarez-Morales, Roxana**[1]

[1] Instituto de Investigaciones Agro-Forestales. Unidad de Ciencia y Tecnología de Base Tercer Frente. Cruce de los Baños, Tercer Frente, Santiago de Cuba. Cuba. C.P. 92700.
* Correspondence: marlonalejandro2012@gmail.com; sanvegetal3@tercerfrente.inaf.co.cu

ABSTRACT

Objective: VIUSDI Agro® is a biostimulant that contains amino acids, vitamins and minerals. In Cuba, its beneficial effects have been primarily demonstrated in vegetables, sugarcane and tobacco. However, there is limited information regarding its use in coffee. Therefore, this study was conducted to evaluate the effect of application timing on the growth of coffee seedlings.
Design/methodology/approach: The experiments were conducted at nursery of the Agro-Forest Research Institute in Tercer Frente, from December 2019 to July 2020 and from October 2020 to June 2021, under saran mesh shade. Using a completely randomized design, four treatments were evaluated: without VIUSID Agro® (Control); monthly applications from the second to the fifth leaf pairs; application on the second, fourth and sixth leaf pairs; and applications on the third and fifth leaf pairs. Height, stem diameter, dry mass, leaf area, seedlings quality index, as well as agronomic efficiency were assessed. Data were analyzed using a one-way analysis of variance, and Tukey test was applied to compare the means.
Results: The coffee seedlings responded positively and significantly to the biostimulant. The applications enhanced the morphological variables and improved the application efficiency.
Findings/conclusions: Foliar applications of VIUSID Agro® on the third and fifth pair of leaves were the most efficient, reducing the production costs of coffee plants.

Keywords: biostimulant, coffee seedlings, growth, efficiency, promoter.

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INTRODUCTION

It is well known that splitting fertilizer applications in crops is a strategy to increase their efficiency (Mattson and van Iersel, 2011). Fertilizers can be applied either through the soil or via foliar application. The effectiveness of foliar application depends on several factors, including the fertilizer source, the application method, the timing (Salamanca and González-Osorio, 2020), and the nutrients applied (Fageria *et al.*, 2009).

In Colombia, it is recommended to apply phosphate fertilizer to the soil at the time of transplanting seedlings, with additional applications one month and three months after transplanting (Sadeghian and Ospina, 2021). On the other hand, it has been suggested that foliar applications do not affect the dry matter of seedlings (Sadeghian, 2022), may lead to additional costs, and can cause plant toxicity (National Coffee Research Center, 2021).

Furthermore, foliar fertilization applied at different doses, timings, and fertilizer sources did not significantly improve coffee cherry production or the physical quality of the beans (Salamanca and González-Osorio, 2020).

The effect of biostimulants and biofertilizers has been positive in coffee seedlings (Silva *et al.*, 2020; Canseco Martínez *et al.*, 2020; Ferrás *et al.*, 2021) as well as in coffee crops under production (Chacón-Villalobos *et al.*, 2021), with yield increases of up to 74% following two or three foliar applications. The application of *Azolla filiculoides* as a biofertilizer every 15 days for five months improved the physico-chemical properties of the soil, as well as coffee bean production and quality in Ecuador (Vásquez and Espinosa-Palacios, 2023). In India, soil and foliar applications of humic acid increased coffee yield, quality, and profitability (Kishor *et al.*, 2020).

In Cuba, VIUSID Agro® is registered as one of the formulations used as a plant growth stimulant. In *Coffea arabica* under production, doses of 2.0 and 4.0 mL of VIUSID Agro® dissolved in 5 L of water increased the number of fruits per plant, the equatorial and longitudinal diameters of the fruits, yield per plant, and yield per hectare of coffee (Maldonado, 2016). However, when applied to coffee in Ecuador, it was concluded that higher doses and application frequencies must be explored to achieve conclusive results (Cargua Chávez *et al.*, 2022). Recent information on the use of VIUSID Agro® in producing coffee seedlings is available (Bustamante *et al.*, 2023); however, alternatives must be sought to improve its efficiency. Therefore, this study was conducted to evaluate the effect of application timing on the growth of coffee seedlings.

MATERIALS AND METHODS

Study Site

The experiment was conducted at the nursery of the Agroforestry Research Institute (UCTB Tercer Frente) (20° 08’ 11.06” N, 76° 16’ 22.27” W), located in the Consejo Popular Cruce de Los Baños, Tercer Frente municipality, during two periods: the first from December 2019 to July 2020 and the second from October 2020 to June 2021.

During the experimental period, the average temperature for both years was approximately 24 °C. The total rainfall accumulation was 626 mm in 2020 and 1221 mm in 2021.

Treatments

The following treatments were studied:

- No application (control).
- Monthly application from the second to the fifth leaf pair.
- Application on the second, fourth, and sixth leaf pairs.
- Application on the third and fifth leaf pairs.

Each treatment consisted of 28 plants, of which 10 were evaluated per treatment. Black polypropylene bags with dimensions of 12.5 cm in width and 25 cm in length were used.

Two seeds of *Coffea arabica* L., variety "Isla 6-14", were planted in each polyethylene bag, which were filled with a substrate of Pardo soil / filter cake in a 3:1 (volume/volume) ratio.

The shading used was a saran mesh, which provided 60% shade to the plants.

Application of VIUSID Agro®

VIUSID Agro® was applied at a concentration of 0.6 mL L^{-1} using a 16-liter Matabi backpack sprayer, during the early morning hours, when the dew had already evaporated, but there was still no strong sunlight.

Recorded Variables

Plant height (cm): Measured from the base of the stem to the apical meristem using a graduated ruler.

Stem diameter (mm): Measured with a Dijite digital caliper, 1 cm above the base of the stem.

Leaf area (cm^2): Estimated by measuring the linear dimensions of the leaves (Soto, 1980) using the formula: $AF = \text{length} \times \text{width} \times 0.64$

Dry mass (g): The plants were separated by organs (leaves, stems, and roots), washed with water, blotted with paper, and then dried in a forced-air oven at 70 °C until a constant weight was reached.

Quality index based on the dry mass values, height, and stem diameter.

Efficiency index (E.I.): This was calculated for the variables evaluated in the experiment using the following formula:

$$E.I.\% = \left(\frac{\textit{Value of the variable in the treatment} - \textit{Value of the control}}{\textit{Value of the control}} \right) \times 100$$

Statistical Analysis

The analysis of variance was performed using a completely randomized design according to the linear model of fixed effects. The data were processed using the Statistica software for Windows. The normality of the data was tested using the Kolmogorov-Smirnov test, and the homogeneity of variance was assessed using Levene's test. Tukey's test ($p \leq 0.05$) was used to determine the differences between the treatments.

RESULTS AND DISCUSSION

The coffee seedlings responded positively in both experimental years to the application of the biostimulant, with an increase in the evaluated variables, regardless of the application timing. In 2020, the monthly application of the biostimulant significantly increased all the evaluated variables, with the maximum values for each treatment showing a 7% increase in height and total dry mass, a 23% increase in the quality index, and a 12% increase in the leaf area of the coffee seedlings compared to the control (Table 1).

Table 1. Effect of the moment of application of the biostimulant on morphological variables of coffee seedlings. 2020.

Moments	Heigth, cm	Stem diameter, mm	Dry mass, g	Quality index	Leaf area, cm^2
Control	19.45 b	2.92 ab	3.30 b	0.30 b	383.06 b
Monthly	20.84 a	3.21 a	3.54 a	0.37 a	431.51 a
2^{nd}, 4^{th} y 6^{th} pair of leaves	20.01 b	2.89 b	3.35 b	0.31 b	386.40 b
3^{rd}, and 6^{th} pair of leaves	20.93 a	3.17 ab	3.38 b	0.32 ab	409.16 ab
E. E., $\bar{x}$	0.323*	0.054*	0.08*	0.01*	12.46*

* Means with different letters indicate significant differences (Tukey, $p \leq 0.05$).

Among the treatments studied, the monthly applications of VIUSID Agro showed a more pronounced and significant effect ($p \leq 0.05$) on the evaluated variables (Table 1). The applications of the biostimulant when the seedlings reached the third and fifth pairs of leaves resulted in an effect statistically similar to that of the monthly applications for height, stem diameter, quality index, and leaf area. In contrast, the applications on the second, fourth, and sixth pairs of leaves showed statistically similar values to the control, except for the height of the seedlings.

In 2021, the highest significant values for height, leaf dry mass, stem dry mass, and total dry mass were found when applying VIUSID Agro® to the third and fifth pairs of leaves, which were statistically different from the other treatments (Table 2). This situation represented an increase of 25% for height, 7% for stem diameter, 48% for dry mass, 11% for quality index, and 30% for leaf area.

The application of VIUSID Agro® to the second, fourth, and sixth pairs of leaves had a similar effect on stem diameter as the application to the third and fifth pairs of leaves, but both values were statistically higher than the treatment without biostimulant application.

VIUSID Agro® increased the quality index of coffee seedlings (Table 2). Statistically similar increases, all higher than the control, were achieved with monthly applications (23%), every two months (19%), and with applications to the third and fifth pairs of leaves (11%).

Table 2. Effect of the moment of application of the biostimulant on morphological variables of coffee seedlings. 2021.

Moments	Heigth, cm	Stem diameter, mm	Dry mass, g	Quality index	Leaf area, cm^2
Control	21.07 c	3.37 b	2.75 d	0.26 c	402.74 c
Monthly	24.18 b	3.49 b	3.87 b	0.32 a	464.11 b
2^{nd}. 4^{th} y 6^{th} pair of leaves	24.47 b	3.58 a	3.59 c	0.31 ab	504.92 a
3^{rd}. and 6^{th} pair of leaves	26.41 a	3.63 a	4.09 a	0.29 b	523.33 a
E. E., $\bar{x}$	0.33*	0.07*	0.068*	0.007*	7.72*

*Means with different letters indicate significant differences (Tukey, $p \leq 0.05$).

The monthly application of the bioproduct increased the leaf area by 15% compared to the control (Table 2), while applications to the second, fourth, and sixth pairs of leaves resulted in a 25% increase, a value lower than the 30% increase observed when the VIUSID was applied to the third and fifth pairs of leaves. These leaf area increases were lower than those achieved by applying Azotobacter monthly after the seedlings reached the third pair of leaves (49%) (Pérez *et al.*, 2002) and those found when applying FitoMas E (between 9% and 56%) after a second application 150 days after seed sowing (Díaz-Medina *et al.*, 2016).

VIUSID Agro® is one of the formulations used as a plant growth stimulant (Pérez *et al.*, 2020) and acts as a biostimulant due to its composition of amino acids, vitamins, and minerals (Catalysis, 2016). The amino acids catalyze the synthesis of sugars, starch, and other components of leaves, flowers, and fruits. They contribute to the increase in leaf chlorophyll, thus intensifying the performance of photosynthesis (Maldonado, 2016).

It has been reported that the greatest increase in coffee seedling growth rate and net assimilation rate when applying biofertilizers occurred between 60 and 90 days in the nursery phase. This is related to the fact that during this period, the roots increase their growth and explore a larger volume of soil, thus obtaining greater nutritional resources that promote seedling growth (Cargua-Chávez *et al.*, 2022).

The variation in the response of the seedlings to the timing of bioestimulant application between years could reflect an effect caused by climatic conditions and the duration of the experiment. It was established that this different management of the seedlings resulted in a differentiated response, and that perhaps the key factor to consider when selecting a variant could be the economic analysis.

The efficiency index (E.I.) exhibited different behavior depending on the evaluated variable, the treatment studied, and the year of experimentation. It is known that the ideal balance for the growth of different plant organs is variable, with a certain endogenous concentration potentially promoting the growth of one organ while inhibiting the growth of another (Taiz and Zeiger, 2010). In 2020 (Figure 1), the monthly application was characterized by the highest increase in all evaluated indicators except for height. The application of the bioestimulant at the second, fourth, and sixth leaf pairs showed the lowest efficiency values, while the application at the third and fifth leaf pairs only had a slight superiority in seedling height.

In 2021, the treatment that received the bioproduct at the third and fifth leaf pairs showed the highest I.E. values for all indicators except for the quality index (Figure 2). The treatment with monthly applications was characterized by the lowest efficiency values for height, stem diameter, and leaf area. This situation could be related to the higher level of rainfall during this experimental period, which was double that of the previous experiment, potentially causing the washout of the product from the leaf surface. At the same time, it is known that applying bioproducts at doses higher than the plants' requirements can have a depressive effect on morphological variables. Bustamante *et al.* (2022) found this situation when studying Enerplant concentrations in cacao seedlings.

This difference in the efficiency index response of the coffee plants could also be related to the higher values of leaf area in the seedlings in 2021. By increasing the leaf

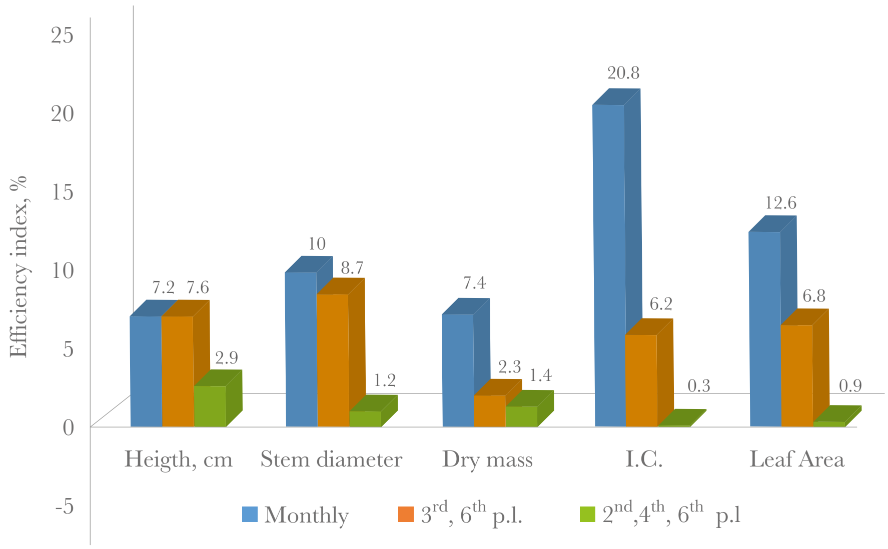

Figure 1. Efficiency index of the VIUSID application timings. 2020. IC: quality index.

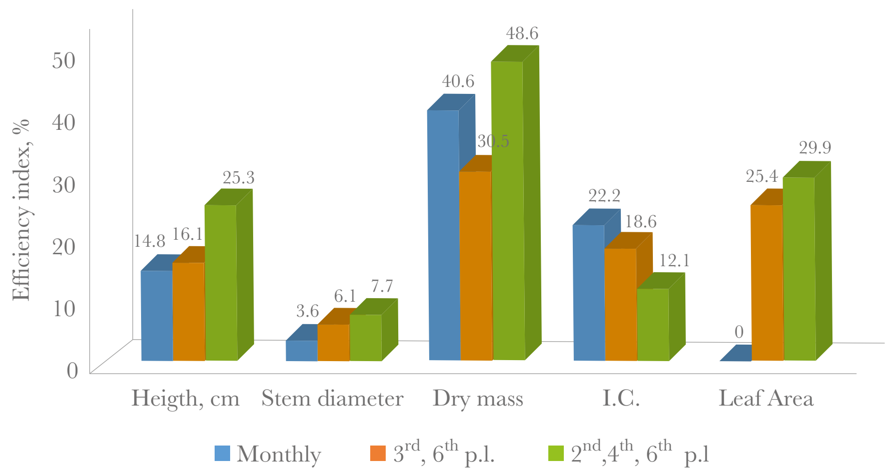

Figure 2. Efficiency Index of the timing of VIUSID application. 2021. IC: quality index.

area, conditions are created that enhance nutrient absorption from the solution (Fageria *et al.*, 2009).

When the product is applied at the third and fifth leaf pairs, production costs are reduced by 67% compared to its monthly application. This economic assessment aligns with the higher efficiency achieved with this timing of application, which supports its recommendation for use under the country's productive conditions.

CONCLUSIONS

The application of VIUSID Agro® at the third and fifth leaf pairs resulted in the highest morpho-agronomic values for coffee seedlings on average over the two years, increased the product's efficiency, and reduced production costs by 67% compared to its monthly application.

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Areas with agroecological potential for *Agave cupreata* (Trel. & Berger) plantations in Guerrero, Mexico

Huerta-Zavala, Jorge[1]; Espinosa-Rodríguez, Mariana[2]; Sarmiento-Villagrana, Alicia[1]; Ochoa-Miranda, Rafael[3]; Segura-Pacheco, Héctor R.[2]; Hernández-Castro, Elías[1*]

[1] Universidad Autónoma de Guerrero, Facultad de Ciencias Agropecuarias y ambientales, Doctorado en Sostenibilidad de los recursos Agropecuarios, Campus Tuxpan. Carretera Iguala-Tuxpan km 2.5, Iguala de la Independencia, Guerrero, México C.P. 40101.

[2] Universidad Autónoma de Guerrero, Facultad de Ciencias Agropecuarias y ambientales, Maestría en Ciencias Agropecuarias y Gestión Local, Campus Tuxpan. Carretera Iguala-Tuxpan km 2.5, Iguala de la Independencia, Guerrero, México, C.P. 40101.

[3] Innovaciones El Cedral S. C. Edificio A8, Paseos del Valle, Iguala de la Independencia, Guerrero, México, C.P. 40010.

* Correspondence: ehernandez@uagro.mx

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ABSTRACT

Objective: to determine areas with agroecological potential for *Agave cupreata* (Trel. & Berger) plantations in the state of Guerrero, Mexico.

Design/Methodology/Approach: fifty-four specimens of *A. cupreata* were characterized. For each specimen, phenotypical, agroclimatic and agroecological data were recorded. Information from 123 herbarium specimens and information available in the literature were consulted. In addition, representatives of the State Council of Mezcal in Guerrero and other companies were interviewed, in order to identify possible areas excluded in the field. As well as in the specimens reviewed at the herbarium, which were validated with field observations. This information was processed in ArcGIS© version 10.3.1 (Esri Inc., 1999-2015, United States), with which a geographic information system was built and the distribution map was obtained, as well as the soil and climate and agroecological requirements of *A. cupreata* in the state of Guerrero. This information allowed the delimitation of the optimal, suboptimal and marginal areas for establishing agave plants. The validation of the information was made through field trips to specific areas to validate the agroecological variables of the potential areas defined in this study.

Results: areas comprising 673 084.16 ha with optimal agroecological potential, and 1 942 072.86 ha with suboptimal potential were determined.

Limitations/Implications of the study: it is suggested to complement with studies on productivity, population ecology, intra- and inter population genetic variability, in plantations and natural population (called in Mexico 'magueyeras') of *A. cupreata*.

Findings/Conclusions: in the state of Guerrero (Mexico), North, Central and Mountain regions were those with the highest number of optimal areas, which coincides with the areas where *mezcal* (a strong and dry alcoholic beverage distilled from the sap of *Agave* plants) production is concentrated.

Keywords: broad-leaf maguey, *mezcal*, ecological distribution analysis, geographic information system.

INTRODUCTION

In Mexico, the high demand for agave species for mezcal production has led to the degradation or loss of numerous *Agave* populations, so sustainable management is required to avoid extinction risk (Torres *et al.*, 2015). The broad-leaf (Ancho, Papalome or Chino) maguey (*Agave cupreata* Trel. & Berger) is endemic to the Mexican states of Guerrero, Michoacán, and Oaxaca. The International Union for Conservation of Nature (IUCN) has placed this species in the "endangered" category because its population rates have decreased by 50% in the last 30 years. This situation may increase as the demand for mezcal of this species increases (Torres-García *et al.*, 2020).

Guerrero is, by tradition, a mezcal producing Mexican state; mainly from species, *Agave angustifolia* Haw and *Agave cupreata* Trel. *et* Berger (Barrientos Rivera *et al.*, 2020). Mexico's Agri-Food and Fisheries Information Service–SIAP reported that Guerrero produced 39 033.81 tons (Megagrams, Mg) of maguey, with a production value of $ 202 771 000 Mexican pesos ($ MXN) (SIAP, 2022). However, the lack of information related to standards that define the optimal places for the establishment of these plantations, and the environmental impacts associated with the lack of planning in crops can generate problems of oversupply of this resource in the medium term (Lucio-López, 2022).

Due to the economic and cultural importance, and commercial pressures to which wild populations of *A. cupreata* are subjected, the objective of this study was to determine the ideal sites in the state of Guerrero for establishing plantations of this species; in order to avoid the deforestation of tropical forests in those unsuitable sites for agave establishment.

MATERIALS AND METHODS

Study, sampling and distribution area of *Agave cupreata*

The study area is located in southern Mexico, in the state of Guerrero, which has an area of 63 564.87 km^2 (INEGI, 2022). Twenty-two field trips were made in the North and Central regions of Guerrero between March 2021 and May 2023. A total of 54 specimens were characterized according to the methodology of Huerta-Zavala *et al.* (2019), of which 26 were deposited in the UAGC and MEXU herbariums. The analysis was complemented with information from 123 specimens of *A. cupreata* found in the collections of MEXU, ENCB, and UAGC herbariums, whose information is available in the literature. In addition, nine interviews were conducted with representatives of the Mezcal Council in the state of Guerrero and with members of the companies Mezcalli del Sur, Mezcal Al Centavo and Sanzekan Tinemi, in order to identify possible areas excluded in the field visits and those mentioned in the herbarium reviews. This information was processed in ArcGIS© ver. 10.3.1 (Esri Inc., 1999-2015, United States) for integrating the distribution map of *Agave cupreata* in Guerrero.

Determination of potential areas

The determination of the potential areas for the cultivation of *A. cupreata* was first done by obtaining information from the different field specimens described and published in the National Commission for the Knowledge and Use of Biodiversity digital catalog (CONABIO, 2016; 2020), coupled with the cartography of the National Institute of Statistics and Geography (INEGI, 2016, 2020, 2021, 2024). Then, the geospatial information of each specimen was organized in a database with Microsoft Excel®; among them, agronomic factors (size of the specimens, weight, cultural works for crops or those in natural populations, the "magueyeras"); soil and climate factors (altitude, climate, rainfall, types and texture of soils); and agroecological factors (current land use, potential use of land and vegetation).

The database was integrated into a geographic information system (GIS) with ArcMap© 10.8, with which 12 thematic maps were generated and the soil and climatic and agroecological variables for this species were defined; with this, the categorization of three types of areas was obtained (optimal, suboptimal and marginal), according to the habit of the species (Huerta-Zavala *et al.*, 2019) (Table 1). The maps of the areas with soil and agroecological potential of *A. cupreata* were generated with the methodology proposed by Huerta-Zavala *et al.* (2019). The validation of the information was done through field visits to the sites that the cartographic system created categorized as optimal and suboptimal, in order to corroborate on site that these areas met the soil and climate and agroecological requirements for the good development of *A. cupreata*.

RESULTS AND DISCUSSION

Through the collection of specimens, field observations, and review of herbarium specimens, the presence of *Agave cupreata* was identified in 21 municipalities and 111 localities of Guerrero (Figure 1A). Table 1 presents the soil and climate and agroecological

Table 1. Soil and agroecological requirements of *Agave cupreata* in the state of Guerrero, Mexico.

Variable	Optimal	Suboptimal	Marginal
Altitude (m)	1300-1800	900-<1300 y >1800-2200	<900 y >2200
Slope (%)	5-15	3-<5 y >15-45	0-<3 y >45-90
Soil groups	Leptosol, Regosol and Phaeozem	Phaeozem, Luvisol and Calcisol	Cambisol, Fluvisol and vertizol
Soil texture	Loams, sandy loams or clay loams	Clay	Silty clay
pH	6.5-7.5	5.5-<6.5 y >7.5-8.0	<5.5 y >8
Climate Type	Warm subhumid and Semiwarm subhumid	Very warm semi-dry and Semi-warm humid and temperate humid	Very warm semi-dry, humid semi-warm and humid temperate
Temperature (°C)	20-28	13-<20 y >28-36	<13 y >36
Annual precipitation (mm)	900-1400	700-<900 y >1400-2000	<700 y >2000
Rainy days per year	80-105	55-<80 y >105-130	<55 y >130
Actual evapotranspiration (mm)	700-900	600-<700 y >900-1000	<600 y >1000
Days with hail per year	0	1-2	>3
Frost probability	<0.10	>0.10-0.15	>0.15
Land and vegetation uses	Annual, semi-permanent and permanent seasonal agriculture; palm grove and induced grassland; Sv low deciduous shrub forest; Sv oak forest weeds; Sv oak forest shrubs.	Sv arboreal and shrubby oak-pine forest; Sv tree of medium and low deciduous forest; Sv arboreal oak forest.	Sv herbaceous, shrubby and arboreal pine-oak forest; pine; pine-oak; Vs thorny semi-evergreen lowland forest shrub.

Sv: Secondary vegetation.

requirements identified for this species in the state of Guerrero. Altitude is one of the main variables that defines regional climatic conditions, whose optimal range for *A. cupreata* is between 1300 and 1800 m, where warm sub-humid and semi-warm sub-humid climates are found, with an annual rainfall between 900 and 1400 mm. The orography present in Guerrero favors a large number of areas with soil and climatic characteristics rated as optimal (18.20%, of the total state territory) and suboptimal (43.37%). In addition, there are those areas where the species grows under adverse or marginal conditions (Figure 1B).

Agroecological areas for *Agave cupreata*

We determined 673 084.16 ha (10.59% of the state territory) as of optimal agroecological potential; plus 1 942 072.86 ha (30.55% of the territory) with suboptimal potential; and other 24 019.63 ha (0.38% of the territory) with marginal potential (Figure 1C) for the establishment of *A. cupreata* plantations. The North, Central and Mountain regions were those with the highest number of optimal areas, while the North, Tierra Caliente and Central regions ranked second, and presented areas with suboptimal characteristics. Marginal areas were not accounted because in those sites the species does not express its whole productive potential (Figure 1D).

When grouping the optimal and suboptimal areas, the North, Central and Tierra Caliente regions presented the areas with the largest surface area, more than 71% of the

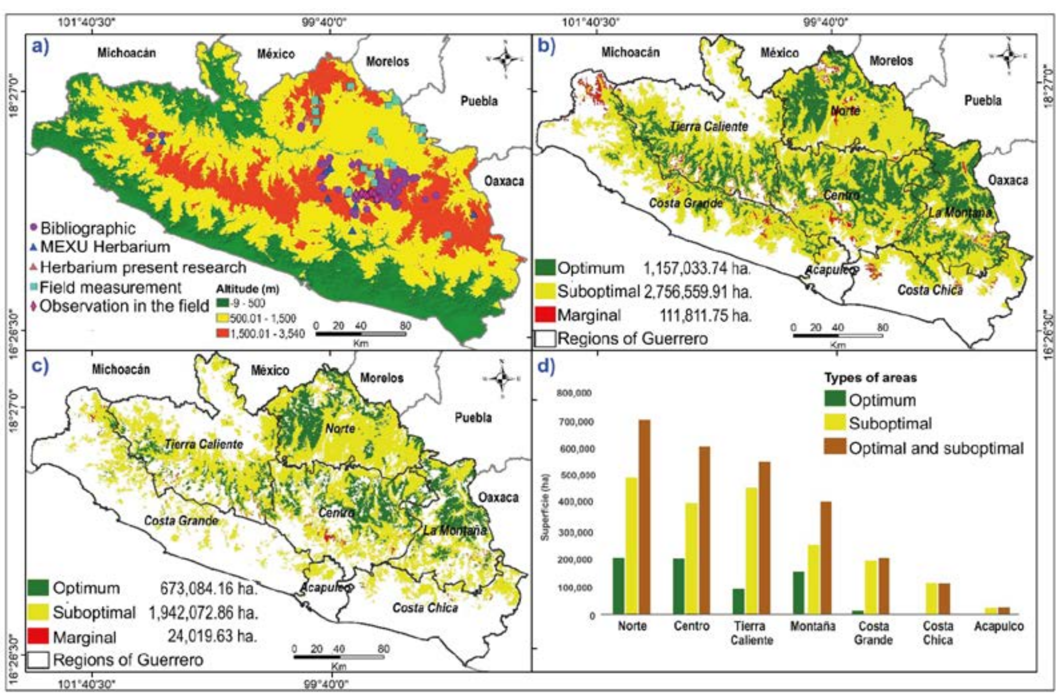

Figure 1. *Agave cupreata* in Guerrero (Mexico). A: natural distribution, according to data from the authors, complemented by Avendaño-Arrazate *et al.* (2015); Barrientos-Rivera *et al.* (2020); IIlsley Granich (2008); López-Serrano *et al.* (2021); Martínez-Palacios *et al.* (2011); Sáenz-Romero *et al.* (2012). B: soil and climate potential; C: agroecological potential, and D: areas defined as optimal, suboptimal and total agroecological potential by regions. Coordinate system: GCS, geographical. *Datum*: WGS 1984. Units: degrees.

suitable areas. The municipalities with the largest optimal areas are Teloloapan (58,024.89 ha), Tlapa de Comonfort (35,883.54 ha), San Miguel Totolapan (33,196.62 ha), General Heliodoro Castillo (30,170.43 ha) and Chilapa de Álvarez (28,917.61 ha). Those with the largest suboptimal areas are San Miguel Totolapan (146 819.25 ha), Coyuca de Catalán (136 094.06 ha), Huitzuco de los Figueroa (118 580.55 ha), General Heliodoro Castillo (104 976.08 ha) and Teloloapan (90 255.16 ha). These are also the municipalities where mezcal production exists and thrives.

In the municipalities of Teloloapan, Tlapa de Comonfort, Heliodoro Castillo and Chilapa de Álvarez there are areas with large natural populations of *A. cupreata*, since in these sites there are optimal soil and climatic characteristics (altitude, soil types, climate and annual rainfall). Our soil and climate results are consistent with those obtained by other authors for this species (Martínez-Palacios *et al.*, 2011; Avendaño-Arrazate *et al.*, 2015; López-Serrano *et al.*, 2021). However, the optimal potential area calculated for the North and Central regions in this research (407 857.46 ha) differs from the results obtained by Olvera-Vargas *et al.* (2022) who calculated a potential area of 7800 ha for *A. cupreata* in these two regions using geomatic techniques.

Such a difference in total area may be due to the methodologies used, since these authors used field spectral radiometry signatures for the analysis of satellite photographs; these authors identified as potential, those areas where *A. cupreata* is present. On the other hand, in this research we determined the optimal areas through the analysis of the soil and climate and agroecological requirements of the species, which were verified in field observations and complemented with studies by Martín *et al.* (2011) and Barrientos-Rivera *et al.* (2020).

In regard to suboptimal areas, several authors have mentioned that in suboptimal areas for other agave species, there are edaphoclimatic limitations of some kind, such as water content, nutrients, or soil texture, which can be compensated by providing irrigation, organic or mineral fertilization (Reynoso-Santos *et al.*, 2016; Huerta-Zavala *et al.*, 2019). These principles are also applicable for the establishment of *A. cupreata* plantations in the suboptimal areas we determined in this study.

In determinig appropriate areas for the establishment of *A. cupreata* plantations, it is essential to care for and protect areas with native vegetation and to propose those spaces, that have already been negatively impacted by human activities (such as eroded areas, agricultural, livestock or with secondary vegetation), as suitable areas to implement productive reconversion strategies such as agroforestry models with maguey (Simonit *et al.*, 2020; Guzmán *et al.*, 2021; Olvera-Vargas *et al.*, 2022).

This would allow local producer families to diversify their productive areas, in which yields of up to 75 Mg ha^{-1} of agave could be achieved, depending on the species used (Simonit *et al.*, 2020). In addition to obtaining firewood and wood from various species such as white cedar (*Cupressus* sp.), juniper (*Juniperus* sp.), oak (*Quercus* sp.), guaje (*Leucaena* sp.), guamúchil (*Phytecellobium dulce* (Roxb.) Benth), mesquite (*Prosopis laevigata* Humb. & Bonpl. ex Willd.), and pine (*Pinus* sp.), in order to diversify and increase the economic income of families (Simonit *et al.*, 2020; Barrera-Cobos *et al.*, 2023). On the other hand, the use of other perennial and annual species contributes to improve the characteristics of the soils with the increase of organic matter content, nitrogen fixation, and the improvement of the texture, porosity, bulk density and water content of the soils (Simonit *et al.*, 2020).

CONCLUSIONS

A total of 673 084.16 ha were determined with optimal agroecological potential for the establishment of *Agave cupreata* plantations, which represent 10.59% of the state territory. This finding is relevant for the design of public policies related to the delimitation of specific areas for the establishment of *A. cupreata* plantations under less extensive agroecological models, which contribute to the conservation of natural areas with a different land use vocation in the state. Likewise, other areas that safeguard the genetic and phenotypic variability of the broad-leaf agave populations in Guerrero.

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Colegio de Postgraduados

Inclusion of Hydroponic Green Forage in Rabbit Feeding

Sifuentes-Saucedo, Diana M.[1]; **Vargas-Monter Jorge**[1*]; **Noguez-Estrada, Juan**[1]; **Vargas-López, Samuel**[2]; **Rodríguez-Ortega Leodan T.**[1]; **Nieto-Aquino Rafael**[3]

[1] Universidad Politécnica de Francisco I. Madero. Tepatepec, Francisco I. Madero, Hidalgo, México C.P. 42660.

[2] Colegio de Postgraduados Campus Puebla. Km. 125.5 carretera federal México-Puebla (Blvd. Forjadores de Puebla 205). C.P. 72760, Puebla, Pue.

[3] Tecnológico Nacional de México. Campus Ciudad Valles. Carr. al Ingenio Plan de Ayala Km.2, Col. Vista Hermosa. Cd. Valles, S.L.P. C.P. 79010.

* Correspondence: jvargas@upfim.edu.mx

ABSTRACT

Objective: The study aimed to evaluate the inclusion level of hydroponic corn green forage (HCGF) in rabbit diets and its effect on growth and carcass conformation characteristics.

Design/methodology/approach: Five inclusion treatments were established, in the daily diet of Tepexpan® brand commercial balanced feed (CBF) and hydroponic corn green forage (HCGF), in the following proportions (CBF:HGCF): T1:100:00, T2: 75:25, T3:50:50, T4: 25:75, and T5: 00:100. The HCGF was harvested and used 10 days after planting. The treatments were evaluated in 45 weaned rabbits, in a completely randomized design for 30 days. The productive performance variables were daily weight gain, live weight, carcass weight and carcass yield. Additionally, measurements of digestive tract organs were recorded.

Results: Higher productive performance and better carcass conformation were found in the rabbits from T1, fed with concentrate, followed by T2 and T3 in a 75:25 and 50:50 ratios, repectively. Rabbits in T3 exhibited lower productive performance during growth and carcass yield.

Limitations on study/implications: Further research is recommended on the the inclusion of HCGF at levels below 50% in rabbit diets.

Findings/conclusions: The inclusion of hydroponic corn green forage at levels of 25 to 50% maintains the productive performance of rabbits, while higher inclusion levels negatively impact feeding efficiency.

Keywords: feeding, rabbits, hydroponic corn green forage.

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INTRODUCTION

Hydroponic green forage (HGF) is a type of forage obtained from the germination and early growth of grass seeds (Cisneros *et al.*, 2023). It represents an alternative in forage production for animal feeding due to its high digestibility and nutritional quality (Chavarria *et al.*, 2018; Bouadila *et al.*, 2022). The production of hydroponic green forage in short production cycles (6-10 days), with efficient use of land, water, and labor under

controlled conditions, offers an alternative for feeding poultry and rabbits in production units with limited land availability (Birgi *et al.*, 2018; Arif *et al.*, 2023). The use of HGF in rabbits proportionally replaces commercial balanced feed, aiming to reduce feeding costs during the growth and fattening phases without affecting productive performance (Miah *et al.*, 2020; Mohamed *et al.*, 2021).

Rabbit meat production is important globally due to its high protein content and low fat content. However, feeding costs account for 60-70% of total production costs. Therefore, alternative and cost-effective feed sources are being evaluated to meet nutritional needs for optimal production (Abdel *et al.*, 2023). However, the peculiarities of the digestive process in rabbits must be considered. Their voluntary intake is 5% of their body weight, and they require cellulose to regulate the movement of food during digestion. They also frequently need to eat and perform cecotrophy as a necessary physiological process (Gidenne *et al.*, 2004). Taking into account the digestive characteristics of rabbits, it is possible to partially replace the supply of balanced feed with hydroponic forages, thereby improving profitability. Reports on the use of sprouted grains in rabbit feeding are diverse and are influenced by the level of replacement in the diet, the type of sprout, and the duration of the evaluation periods (Fuentes *et al.*, 2011; Miah *et al.*, 2020; Mohamed *et al.*, 2021).

The use of hydroponic corn green forage during the fattening phase of rabbits affects productive performance. Therefore, this study aimed to evaluate the inclusion level of hydroponic corn green forage (HCGF) in rabbit diets and its effect on growth and the morphology of the digestive tract.

MATERIALS AND METHODS

Study Area Location

The study was conducted at the livestock unit of the Francisco I. Madero Polytechnic University in the state of Hidalgo. The location is situated at an altitude of 1,995 meters above sea level, with geographic coordinates of 20° 15’ 20” North latitude and 99° 00’ 10” West longitude. It has a temperate cold climate, with an average annual temperature of 17 °C and annual precipitation of 540 mm.

Production of Hydroponic Green Forage

It was carried out in an automated tray system, where disinfected and soaked seeds were germinated. Irrigation was applied until the fourth day, when the first uniform sprouts appeared, and the forage was harvested after 10 days for use in rabbit feeding.

Experimental Design for Rabbit Fattening

Forty-five F1 rabbits (New Zealand×California) at 30 days of age with an average weight of 948.3±92 grams were used. Five treatments were established based on inclusion levels: commercial balanced feed (CBF) Tepexpan® brand and hydroponic corn green forage (HCGF) in the following proportions: T1: 100:00, T2: 75:25, T3: 50:50, T4: 25:75, and T5: 00:100. The treatments were evaluated in three replications, each consisting of 3 rabbits, using a completely randomized design.

Study Variables

The difference between the offered amount and the leftover feed in the feeders determined daily consumption of hydroponic corn green forage and balanced feed. Initial live weight, final live weight, daily weight gain, feed conversion, and feed efficiency were determined. Rabbits were sacrificed 30 days after the experiment to determine carcass weight, carcass yield, and the weight of kidneys, stomach, intestines, cecum, as well as the length of the small and large intestines (Cantarero *et al.*, 2022).

Statistical Analysis

To determine the behavior of the evaluated productive parameters, a completely randomized design was used, as described below:

$$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$$

Where: Y_{ij}=Observed Value of the Variable; μ=Population Mean; i=5 Experimental Treatments; j=3 Replicates; α_i=Effect of the i-th Treatment; ε_{ij}=Experimental Error.

The data were subjected to Shapiro-Wilk normality tests, followed by analysis of variance (ANOVA) using the GLM (General Linear Models) procedure. Mean comparisons between treatments were performed using Tukey's test with SAS version 9.4 (2015).

RESULTS AND DISCUSSION

The rabbits in the experimental groups were homogeneous (Table 1), so the initial weight did not show statistically significant differences ($P \geq 0.05$). The final live weight showed differences between treatments ($P \leq 0.05$), with the highest value observed in treatment T1, which consisted of 100% commercial balanced feed (2112.4 g), followed by the treatments with 25% (1861.40 g), 50% (1743.3 g), and 75% (1355.0 g) inclusion of hydroponic green forage.

The daily weight gain and carcass weight showed statistically significant differences between treatments ($P \leq 0.05$), with the highest values observed in treatment T1, which consisted of 100% commercial balanced feed, followed by the treatments with 25%, 50%, 75%, and 100% inclusion of hydroponic corn green forage, respectively. Higher carcass yield was found in the treatments with 25%, 50%, and 75% inclusion, followed by the commercial balanced feed treatment, and finally, the 100% hydroponic green forage inclusion treatment ($P \leq 0.05$).

Consumption decreased with the increase in the level of hydroponic green forage inclusion and the reduction of commercial balanced feed. The highest consumption was 129.53 g/rabbit/day for the 100% commercial balanced feed treatment, decreasing to 94.2 g/rabbit/day in the 25% HGCF treatment, then increasing to 115.6 g/rabbit/day at the 50% HGCF inclusion level, and showing declines at the 75% and 100% HGCF inclusion levels ($P \leq 0.05$). The results found in this study are similar to those reported in the literature. The inclusion of GCF at 50% has an effect on feed consumption, time to live weight at slaughter, final live weight, and carcass yield (Fuentes *et al.*, 2011). Cisneros *et al.* (2023)

Table 1. Effect of hydroponic corn green forage (HCGF) inclusion on the productive performance of F1 rabbits (New Zealand × California).

Variable	**100:00 M±S.D.**	**75:25 M±S.D.**	**50:50 M±S.D.**	**25:75 M±S.D.**	**00:100 M±S.D.**	**Valor de F**	**N**
Initial weight (g)	1020.01[a] ±322.5	1048.78[a] ±108.4	986.11[a] ±209.6	896.11[a] ±199.9	790.52[a] ±152.0	0.09	>0.1
Final weight (g)	2112.44[a] ±186.9	1861.40[ab] ±165.5	1743.33[b] ±254.9	1355.0[c] ±201.5	991.5[d] ±167.0	0.0001	>0.1
Daily weight gain (g)	39.03[a] ±10.3	27.10[b] ±2.3	27.04[b] ±11.6	16.38[c] ±3.8	6.81[c] ±3.0	0.0001	>0.1
Carcass weight (g)	1054.12[a] ±93.30	987.24[ab] ±152.0	913.85[b] ±133.6	711.37[c] ±105.81	419.33[d] ±88.33	0.0001	>0.1
Carcass yield (%)	50.32[a] ±3.53	53.01[a] ±0.01	52.42[a] ±0.09	53.0[a] ±1.3	42.2[b] ±3.6	0.0001	>0.1
Feed intake (g/day)	129.53[a] ±3.5	94.23[c] ±1.7	115.63[b] ±0.62	93.77[c] ±1.6	85.19[d] ±3.5	0.0001	>0.1
Feed conversion (kg/Kg)	3.5[b] ±0.8	3.50[b] ±0.2	5.25[b] ±3.0	6.11[b] ±1.9	14.5[a] ±5.8	0.0001	>0.1
Feed efficiency (g/g)	0.30[a] ±0.07	0.28[b] ±0.02	0.23[ab] ±0.1	0.17[b] ±0.04	0.08[c] ±0.03	0.0001	>0.1

Mean (M), Standard Deviation (S.D.), Normality (N). Means with different letters in the same row indicate significant differences according to Tukey (P≤0.05).

report that replacing concentrated feed with 30% barley CGF had a negative effect on feed consumption and growth, but no effect on feed conversion and carcass yield. The feed conversion ratio was 3.5, 3.5, 5.25, and 6.11 for the treatments with 100% commercial balanced feed, 25%, 50%, and 75% inclusion of hydroponic corn green forage (HCGF) (P≥0.05), while for the 100% HCGF treatment it was 14.50, which was statistically different (P≤0.05). Feed efficiency is significantly affected by the increase in the percentages of HGCF inclusion (P≤0.05). Monjica (2021) found that the inclusion of hydroponic corn green forage as a progressive substitute for commercial concentrate negatively affects weight gain, feed conversion, and feed efficiency, but does not affect carcass yield. In a diet based on hydroponic green oat forage, a daily weight gain of 35.09 g, a feed conversion ratio of 5.5, and an average market weight of 3136.6 g were obtained (Núñez *et al.*, 2017).

Figure 1 shows the effect of the treatments on the weight of the stomach, intestines, and cecum (P≤0.05). It was observed that as the proportional level of hydroponic corn green forage (HCGF) increased, the weight of the kidneys, stomach, and large intestine decreased.

The increase in the inclusion level of HCGF affects the morphometry of kidneys, stomach, cecum, and intestines (P≤0.05). The values found differ from those reported by Giusti *et al.* (2012), where the weight of viscera, intestines, head, skin, and legs showed no statistical differences in treatments with the supplementation of any alternative ingredient in the diet. They mention that replacing 30% and 50% of concentrated feed with hydroponic barley forage does not affect intestinal morphology. Dihigo *et al.* (2001) mentions that feeding rabbits 100% with hydroponic forage decreases the height and width of the intestinal villi, affecting digestion and the productive performance of the rabbits.

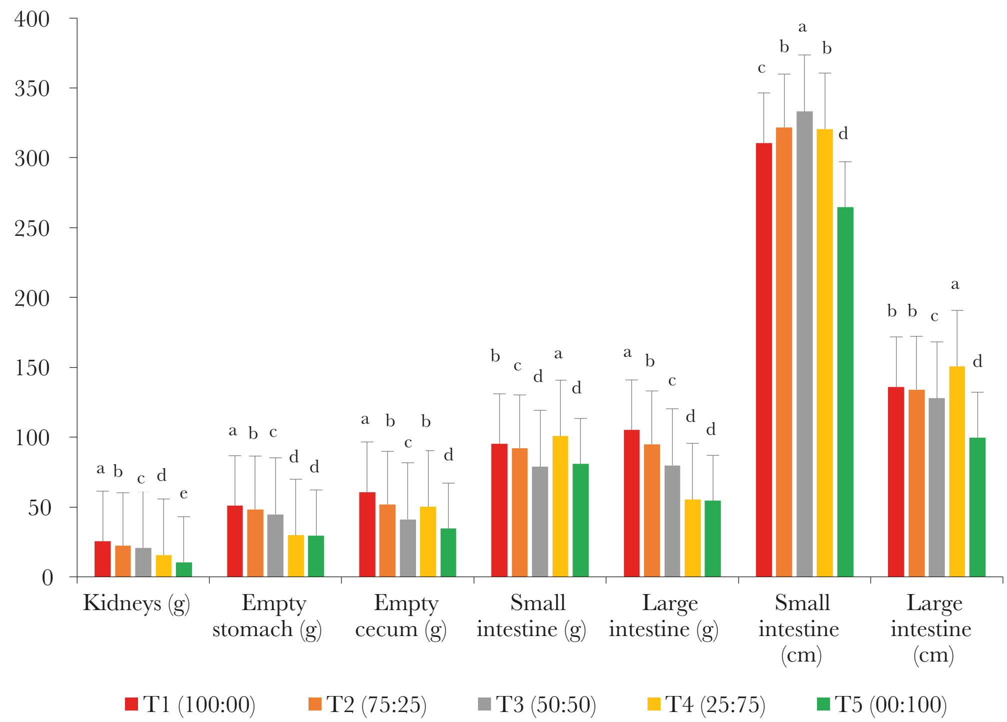

Figure 1. Effect of proportions (commercial balanced feed: hydroponic corn green forage) on the gastrointestinal tract morphometry and internal organs of F1 rabbits (New Zealand × California). Means with different letters in each structure indicate significant statistical differences (Tukey, P≤0.05).

They report changes in the length of the intestine, as fibers regulate the transit speed and the entry of chyme into the cecum.

This study found better productive performance in rabbits fed with commercial balanced feed (T1), followed by T2 and T3, with inclusion levels of 25% and 50%. Using HCGF at levels above 50% as a substitute for commercial feed implies negative effects on productive variables and digestive tract structures, likely due to the lack of digestive balance between fiber, starch, and protein. The inclusion levels of HCGF in the diet could be altering the fiber-starch ratio, affecting intestinal transit, fiber fermentation in the cecum, daily weight gain, and feed conversion (Zhu *et al.*, 2015 and Carabaño *et al.*, 2020). The increase in indigestible fiber contributes to lower nutrient digestibility and increased fecal excretion of endogenous protein (Cisneros *et al.*, 2023). Replacing the commercial diet with HCGF should take into account changes in digestion and nutrient utilization to optimize its use as an alternative forage in the feeding of rabbits during the fattening phase (Mohsen *et al.*, 2015).

CONCLUSIONS

Hydroponic corn forage has an effect on the productive variables of rabbits. The progressive substitution of commercial concentrate with hydroponic corn forage negatively affects weight gain, feed conversion, and feed efficiency. It is suggested to continue investigating the inclusion range of 25% to 50% and its effect on the productive performance of rabbits, considering factors that affect the nutritional quality of hydroponic forage, which may be associated with changes in the morphology of the digestive tract.

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Detection of *Bruggmanniella perseae* in Hass avocado (*Persea americana* cv. Hass) in Morelos, Mexico

García-Escamilla, Paul[1]; Hernández-Castro, Elías[1]; Mora-Aguilera, José Antonio[2]; Durán-Trujillo, Yuridia[1*]; Monteón-Ojeda, Abraham[1]

[1] Universidad Autónoma de Guerrero, Facultad de Ciencias Agropecuarias y Ambientales, Maestría en Ciencias Agropecuarias y Gestión Local. Periférico poniente s/n, Iguala de la Independencia, Carretera Iguala-Tuxpan km 2.5. Iguala de la Independencia, Guerrero, México. C.P. 40101.

[2] Colegio de Postgraduados en Ciencias Agrícolas, Carretera Federal México-Texcoco km 36.5, Montecillo, Texcoco, Estado de México, México. C.P. 56264.

* Correspondence: 18479@uagro.mx; duty_1@hotmail.com

ABSTRACT

Objective: to determine the presence of *Bruggmanniella perseae* in commercial Hass avocado orchards in Tetela del Volcán, Morelos (Mexico).

Design/Methodology/Approach: sampling was carried out in three Hass avocado orchards during October-December 2020. Adults of *B. perseae* were collected by direct collections of small fruits in the form of a spinning top, with symptoms of *B. perseae* infestation inside. The adults thus collected were observed under a stereo microscope and a scanning electron microscope to confirm their identity.

Results: adult specimens of *B. perseae* were captured and analyzed in the laboratory and their presence at the sampling site was confirmed. Avocado fruits with typical symptoms of avocado ovary fly larva infestation were collected. If not controlled at the beginning of fruit tying, it can be a threat to avocado production (yield) in the region. These results are the basis for generating knowledge about this pest, regarding its biology, distribution and control methods.

Results: adult specimens of *B. perseae* were captured and analyzed in the laboratory and their presence at the sampling site was confirmed. Avocado fruits with typical symptoms of avocado ovary fly larva infestation were collected. If not controlled at the start of the fruiting larvae can be a threat to avocado production (yield) in the region. These results are the basis for generating knowledge about biology, distribution and control methods for this pest.

Limitations/Implications of the study: capturing adults of *B. perseae* in the field is difficult, requiring the use of sticky colored traps, or other effective alternatives.

Findings/Conclusions: the presence of *B. perseae* was confirmed in avocado cv. Hass in Tetela del Volcán, Morelos. The information generated can help avocado growers implement management measures and reduce losses from this pest.

Keywords: avocado ovary fly, *Bruggmanniella perseae*, *Persea americana*, Cecidomyiidae.

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INTRODUCTION

Morelos is positioned as the sixth largest avocado producer nationwide, and has the first place in terms of quality (SENASICA, 2024; SIAP, 2024). Avocado is the main income for families in the region that today faces a serious threat, the avocado ovary fly

Bruggmanniella perseae (Gagné *et al.*, 2004). This insect was discovered in 2004, it represents a significant danger to production, as it attacks immature fruits smaller than 2 cm and causes deformations, abortion, and premature fall (Gagné *et al.*, 2004; Sheng-Feng *et al.*, 2020).

In Mexico, the presence of *B. perseae* has already been documented in Michoacán, where damage of up to 17% has been recorded in the affected plots (Delgado-Ortiz *et al.*, 2015; García-Bonilla *et al.*, 2015). In the State of Mexico, the pest has caused damage of up to 90% to the fruits (Laureano-Ahuelicán *et al.*, 2022). In Morelos, this study verifies its presence in avocado crops cv. Hass. Safeguarding avocado production in Morelos requires more in-depth research to better understand the biology and behavior of the pest, as well as to develop effective strategies for the monitoring and control of *B. perseae*.

MATERIALS AND METHODS

Study Site

The study was implemented during the season from October to December 2020, in Hass avocado orchards in the municipality of Tetela del Volcán, Morelos. Presence of *Bruggmanniella perseae* was detected by capturing adults which were preserved in 70% alcohol. The identification of the specimens was done in the laboratory of the master program on Local Agricultural and Environmental Management at the Faculty of Agricultural and Environmental Sciences under the Autonomous University of Guerrero. To do this, a Carl Zeiss West Germany stereo microscope was used, following the description detailed by Gagné *et al.* (2004) and Sheng-Feng *et al.* (2020).

Presence confirmed of *Bruggmanniella perseae*

Presence of *B. perseae* in Tetela del Volcán was confirmed with the collection and preservation of adults, as well as identification with scanning electron microscopy by comparison with the taxonomic description of Gagné *et al.* (2004) and Sheng-Feng *et al.* (2020), which ensures the reliability of this finding.

RESULTS AND DISCUSSION

Bruggmanniella perseae, the pest that threatens avocado

The avocado ovary fly, *Bruggmanniella perseae*, is a species of Diptera belonging to the family Cecidomyiidae that poses a threat to avocado production. This pest specifically attacks small fruits and deforms them as the larva feeds (Gagné *et al.*, 2004; Maia *et al.*, 2010; Londoño-Zuluaga *et al.*, 2020).

Distinctive features of *Bruggmanniella perseae*

Connate eyes: the eyes of *B. perseae* are fused together, forming a single structure in the head. **Wings with reduced venation**: the wings of this pest have a simplified vein network, which differentiates it from other species of Diptera. **Thread-like antennae**: the antennae of *B. perseae* are long and thin, with a thread-like appearance. **Uneven legs**: the first and third pairs of legs are longer than the second pair, that is a distinctive feature of the species. **Claw-shaped tarsal nails**: toenails are small and curved, resembling claws. **Elongated empodia**: the empodia, located between the tarsal nails, are as long as the claws in *B. perseae*. **Abdomen with eight divisions**: the abdomen is divided into eight segments, the first seven are rectangular-shaped, but the eighth is smaller. **Reduced VIII-sternum in the male**: in the male of *B. perseae*, the eighth sternum is significantly smaller than the others; it is twice as wide as it is long, and lacks hairs. **Pin nail-shaped edeagus**: the edeagus, or male reproductive system of *B. perseae* has the shape of a pin nail (Gagné *et al.*, 2004; Delgado-Ortiz *et al.*, 2015; Rodrigues *et al.*, 2020; Laureano-Ahuelicán *et al.*, 2022) (Figures 1, 2, and 3).

The presence of *B. perseae* in avocado orchards can have a significant impact on production, as the deformation of small fruits by larval feeding leads to their abortion and premature fall. This represents a considerable economic loss for producers.

The detailed description of the morphological characteristics of *B. perseae*, as presented in this report, is essential for its correct identification and differentiation from other species of Diptera. This is crucial to implement adequate control and management strategies to combat this pest effectively.

Evidence of *Bruggmanniella perseae* infestation in avocado cv. Hass fruits

In avocado cv. Hass orchards, it is observed the presence of fruits with characteristic damage signs that coincide with the descriptions of Gagné *et al.* (2004). These fruits show significant deformations that are far from the typical oval shape of the avocado. In some cases, they take on a shape similar to a spinning top, with a wider base that tapers toward the tip. In addition, its size does not exceed 2 cm, as García-Bonilla *et al.* (2015) indicated (Figure 4).

The signature of the pest (clearer signs of infection) includes irregular shapes, the fruits affected by *Bruggmanniella perseae* lose their characteristic oval shape, and present deformations that vary in intensity. Spinning top appearance, in some cases the deformation is so severe that the fruits acquire a shape similar to a spinning top, with a wide base and a narrow tip. Small size, the affected fruits do not reach their normal size, but remain less than 2 cm long (Figure 4).

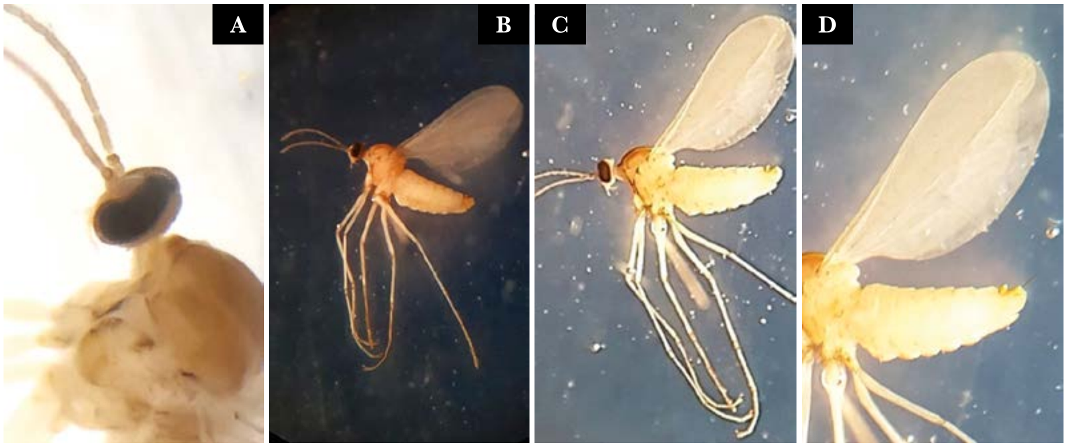

Figure 1. Specimens of *Bruggmanniella perseae* (Diptera: Cecidomyiidae) harvested in avocado orchards cv. Hass in Tetela del Volcán (Morelos) Mexico. A: connate eyes, B: body shape, C: yellow coloration of the body, and D: wings with reduced venation and abdomen with eight segments. Source: photographs by the author, taken with a stereo microscope (Carl Zeiss™, Germany).

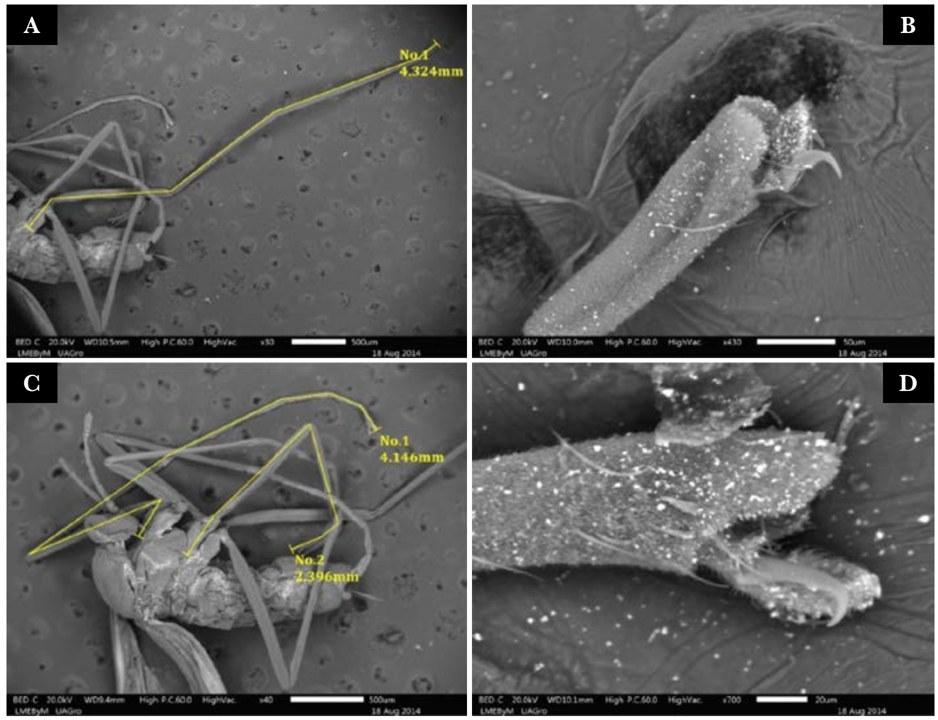

Figure 2. Specimens of *Bruggmanniella perseae* (Diptera: Cecidomyiidae). A: size of a male wings and abdomen; B: connate eyes and thread-like antennae; C: pin-nail-shaped edeagus, and D: size of antennae, head, thorax and abdomen of a male. Source: photographs by the author, with a scanning electron microscope (JEOL™, modelo IT-300LV, USA).

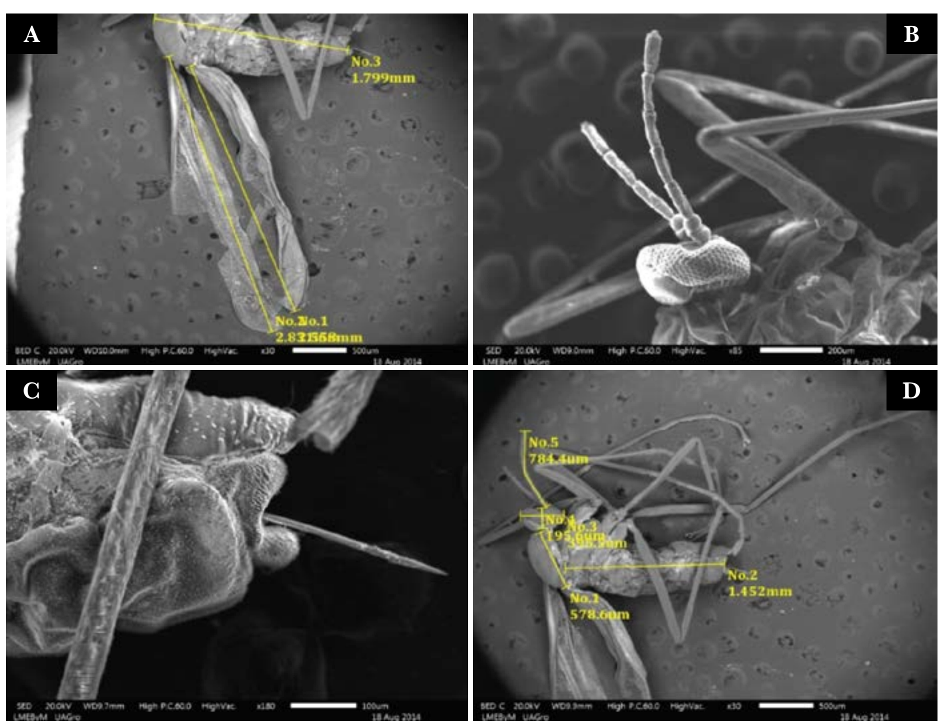

Figure 3. Specimens of *Bruggmanniella perseae* (Diptera: Cecidomyiidae). A: III leg size; B: claw-like nails; C: size of legs I and II; and D: empodium with the same size of the tarsal nails. Source: photographs by the author, with a scanning electron microscope (JEOL™, modelo IT-300LV, USA).

Figure 4. Fruits selected for (A, B): showing signs of the presence of *Bruggmanniella perseae*, collected in cv. Hass avocado orchards in Tetela del Volcán (Morelos) Mexico; which presented (C, D): deformities and did not exceed 2 cm in length. Source: photographs by the author.

These deformations are a clear indication of the attack of *Bruggmanniella perseae*, a pest that mainly affects the young fruits of the avocado. The feeding of the larvae inside the fruit causes its deformation and stunted growth, which in the end leads to abortion or premature fall of the fruit.

This study confirms for the first time the presence of the pest known as avocado ovary fly (*Bruggmanniella perseae*) in cv. Hass avocado plantations in the state of Morelos. This finding represents a fact of great relevance, because it expands the known distribution of the pest in Mexico. Until now, cases of *B. perseae* had been reported in Hass avocados in the State of Mexico (Laureano-Ahuelicán *et al.*, 2022), and in Michoacán (Delgado-Ortiz *et al.*, 2015). Presence confirmed of this pest in Morelos expands the scope of this pest and highlights the need to take measures for its monitoring and control.

The presence of *B. perseae* in cv. Hass avocado orchards in Morelos raises concerns about its potential impact on production. The pest attacks young fruits, because the insect lays its eggs in them. When hatching, the larvae feed on the embryo of the fruit, causing it to deform and fall prematurely, with a size similar to that of a marble. This situation can confuse producers, who could attribute the fall of the fruits to nutritional deficiencies or strong winds, thus underestimating the presence of the pest due to misdiagnosis.

The finding of *B. perseae* in Morelos drives the need to intensify research on this pest of economic importance. Greater knowledge about their biology, behavior, and life cycle is required to develop effective management strategies. Integrated pest management (IPM) is presented as a fundamental tool to combat *B. perseae* in a sustainable way, and to minimize its impact on the environment in order to protect avocado cultivation in Morelos, thus ensuring their future permanence.

CONCLUSIONS

This study marks a milestone by confirming for the first time the presence of *Bruggmanniella perseae*, the avocado ovary fly, in Morelos, Mexico. The detection of this pest in cv. Hass avocado orchards, during the October-December 2020 season, opens a new chapter in the fight to protect this crop, that is vital for producer families in Morelos.

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Colegio de Postgraduados

Identification of the Morphology of *Tamarix* spp. in the Mexicali Valley, Baja California, Mexico

Rodríguez-González, Rosario E.[1*]; Sánchez-Castillo, Marisol[1]; Iñiguez-Monroy, César G.[2]; Soto-Ortíz, Roberto[1]; Rueda Puente, Edgar O.[2]; Brigido-Morales Juan G.[1]

[1] Universidad Autónoma de Baja California, Instituto de Ciencias Agrícolas. Carretera a Delta s/n. Ejido Nuevo León, Mexicali, Baja California, México. C.P. 21705.
[2] Universidad Autónoma de Baja California, Facultad de Ingeniería. Bulevar Benito Juárez s/n, Mexicali, Baja California, México. C.P. 21280.
[3] Universidad de Sonora. Departamento de Agricultura y Ganadería. Carretera 100 a Bahía de Kino km 21.5, Hermosillo, Sonora, México. C.P. 83000.
* Corresponding author: esmeralda.rodríguez@uabc.edu.mx

ABSTRACT

Objective: The predominant species of *Tamarix* spp. in the Mexicali Valley is unknown, and due to the scarce information available, this study aims to expand the knowledge of the morphology of *Tamarix* spp. in the Mexicali Valley, Baja California, Mexico.
Design/methodology/approach: For this research, five branches with inflorescences and roots of *Tamarix* spp. trees were collected from four selected locations in the Mexicali Valley. The collection was carried out during the flowering season from March to August, considering branches between 2.50 and 3.50 cm in height. The morphological descriptions were based on fresh plants using an Olympia optical microscope.
Results: After the morphological analysis was carried out at the different sampling sites, the predominant salt cedar genotype found in the Mexicali Valley corresponded to *Tamarix chinensis*. In addition, it was found high electrical conductivity measured in the upper soil layer (20 cm depth) was found to be caused by the excretion of salts through the glands of the leaves of this species. Consequently, salt cedar species can inhibit other vegetation types, although it can benefit honey bee production.
Findings/conclusions: *Tamarix chinensis* was the predominant salt cedar species throughout the sampling sites under the conditions of this study. The high electrical conductivity measured in the upper soil layer (20 cm depth) shows that salt cedar species can inhibit the growth of other vegetation types, although it can be beneficial for honey bee production.

Keywords: Varietal description, pollen, soil, salinity, pH.

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INTRODUCTION

The Salt Cedar known as *Tamarix* spp. originates from Eurasia, specifically from southern Europe and some areas of Africa. It appears along the banks of arid and semi-arid regions in northern Mexico and the southern part of the American continent, such as Argentina and the western United States [1, 2] and Australia [3, 4]. During the years 1830 to 1920, eight species of the genus *Tamarix* were introduced into the United States,

such as *Tamarix ramosissima* and *Tamarix parviflora* [5], occupying around 650,000 ha in 23 states of the United States and becoming the most abundant genus in the riparian areas of the southwest, thus creating a significant factor of environmental alteration and economic impact [6, 7]. The two species with the broadestdistribution, from the northern plains of the United States to northern Mexico, are *Tamarix ramosissima* Ledebour and *Tamarix chinensis* Loureiro, which often hybridize among each other, and two other species, *Tamarix canariensis* Willdenow and *Tamarix gallica* Linneo [8], are found on the Gulf Coast of Mexico. A fifth species, *Tamarix parviflora* de Candolle, is more commonly found in the Pacific's coastal channels. In Argentina, Dimitri *et al.* [9] cite five species that have been cultivated, *Tamarix anglica*, *Tamarix gallica*, *Tamarix juniperina*, *Tamarix parviflora*, and *Tamarix pentandra*. Natale *et al.* [2], based on their plant taxonomy, they conclude that *Tamarix juniperina*, *Tamarix pentandra*, and *Tamarix anglica* are synonyms of *Tamarix chinensis* [10-11], as well as *T. ramosissima* and *T. gallica* [10, 12-13], respectively. These findings confirm the existence of four species in Argentina: *T. gallica*, *T. ramosissima*, *T. chinensis*, and *T. parviflora*.

The cedar or salt pine was primarily introduced for erosion control, as a physical windbreak, and as an ornamental in the 19th century [14]. It is considered an aggressive plant colonizer with adaptation to a various of environmental conditions, allowings it to displace all types of plants. However, it has caused severe ecological and economic damage to water resources and wildlife in western North America [15]. Salt pine can be controlled by chemical herbicides, mechanical removal, and burning [14], but these methods are costly and can cause significant damage to native plants and wildlife. Despite this, *Tamarix* spp., in arid-saline environments, is considered a plant with resistance to water stress and tolerance to salts [16].

While for some, the invasion of *Tamarix* is considered one of the worst ecological disasters in the riparian ecosystems of North America [5], other studies have found that it can be beneficial for other living organisms such as *Apis mellifera* [17] and the willow flycatcher (*Empidonax traillii*) [18]. For *Apis mellifera*, *Tamarix* spp. cannot be considered a toxic tree. The same authors [17] conducted a palynological characterization of honey bees in the Mexicali Valley and Ensenada, Baja California, showing that 65% of the honey was monofloral, mainly from *Tamarix* spp. and *Prosopis* spp., respectively. Similarly, Alaniz *et al.* [17] indicated that the main nectar resources used by *Apis mellifera* in the Mexicali Valley are *Tamarix* spp., *Prosopis*, and *P. strice*. The honey production in the Mexicali Valley contains 60% of the dominant pollen from *Tamarix* spp. [17]. The predominant species of *Tamarix* spp. in the Mexicali Valley is unknown. Due to the scarce information available, this study aims to expand the knowledge of the morphology of *Tamarix* spp. in the Mexicali Valley, Baja California, Mexico, identifying the plant morphology (root type, stem type, flower type, leaf type) and the main chemical characteristics of the soil where it develops.

MATERIALS AND METHODS

Description of the study area

The soil and plant sampling of *Tamarix* spp. was conducted at four strategically chosen sites in the Mexicali Valley during the flowering season from March to August 2017 in

Mexicali, Baja California. These sites were: 1. On the lands of a cooperating farmer at Kilometer 26 on the Mexicali-Algodones highway, 32° 37' 17.4" N, 115° 08' 28.1" W; 2. Agricultural Sciences Institute of Autonomous University of Baja California (ICA-UABC), 32° 14' 14.93" N, 115° 12' 6.67" W; 3. Ejido Nuevo León (Ej. Nuevo León), 32° 24' 25.09" N, 115° 11' 33.01" W; and 4. Ejido Delta (Ej. Delta), 32° 21' 28.83" N, 115° 11' 20.91" W, respectively. The combined georeferenced locations of these three areas are 32° 25' 10.9" N, 115° 11' 32.8" W.

The Mexicali Valley is characterized by a desertic climate, with summer temperatures peaking at 50 °C and winter temperatures dropping to as low as −7 °C. The average annual temperature is 22.3 °C, and the average annual precipitation is 58 mm. The region's flat topography, with an altitude ranging from −2 to 43 meters above sea level (masl), plays a significant role in the study [19].

Soil sampling

Soil sampling was carried out, obtaining 10 samples in each selected area to prepare a composite sample, aiming to collect salt cedar and soil roots during the flowering stage of approximately 20-year-old specimens. The samples were identified and transported to the Water and Soil Laboratory at the Institute of Agricultural Sciences, UABC. Additionally, during the soil and root collection, branches with leaves and inflorescences were collected and transferred to the Laboratory of Agricultural Sciences to verify, using taxonomic keys for plants, the specific specimen of salt cedar being analyzed [20].

Three subsamples were taken per tree (500 g of soil and roots) at depths of 20 cm, 40 cm, and 60 cm, respectively. Trees were selected based on their robustness (1.40±10 cm diameter measured at 1.50 m height), tree height (15.0±1.0 m), and color (intense opaque green) (Figure 1). The collected material was placed in dark plastic bags, labeled with corresponding collection data, and stored in a thermal container with ice, maintaining a temperature between 4±2 °C during transport to the laboratory. Soil electrical conductivity and pH analyses were conducted according to Aguilar *et al.* [21].

Morphological description of the plant

For each tree (10 in each area), five branches with inflorescences and roots of selected *Tamarix* spp. trees were obtained at each site. Collection took place during the flowering season from March to August, focusing on branches between 2.50 and 3.50 cm in height. Morphological descriptions were based on fresh plants, and an Olympus optical microscope was used. For the morphological description and comparison of the tree, descriptions from species outlined by Natale *et al.* [2] and Arianmanesh *et al.* [22] were referenced, along with the Technical Guide for varietal description of Jamaica [23], the latter aiming to include additional plant structures not described by other authors.

RESULTS AND DISCUSSION

The selected *Tamarix* plants aged over 5 years for flower sampling are shown in Figure 1.

Figure 1. *Tamarix* spp. plants.

Table 1 presents the results of electrical conductivity ranging from 110 to 20 dS m^{-1} and soil pH ranging from 7.16 to 8.2 for the sampling sites. Figures 2 and 3 graphically illustrate these findings showing higher electrical conductivity in the upper soil layer (20 cm depth), which correlates with increased salt concentration. These findings are crucial for understanding the impact of *Tamarix* spp. on soil salinity levels [24].

Previous studies have shown that *Tamarix* spp., through its root system, can extract water from great depths with high salt content due to survival needs and ultimately excrete it through special glands in its leaves [25-27]. This process explains the higher salinity values in the upper soil layer [28-30]. As for the soil pH, is characteristic of soils in arid zones to be slightly alkaline, which limits nutrient absorption [31], and electrical conductivity indicates soil salinity levels [26].

Table 2 presents the morphological description of the *Tamarix* spp. according to various authors [2, 10-13, 22], the plant is presented, which corresponds to *Tamarix chinensis*. Additionally, Alaniz *et al.* [17] conducted a study on the identification of pollen types in species in the Mexicali Valley. Of the 52 honey samples analyzed, 38% were monofloral from *Tamarix* spp. (salt cedar) (Figure 4), indicating that this species is significant for honey production.

Table 1. Soil characteristics of *Tamarix* spp. growth.

Sampling site	Soil depth (cm)	Electrical conductivity (dS/m)	pH
Instituto de Ciencias Agrícolas, UABC	20	110.80	7.16
	40	101.30	7.31
	60	97.30	7.52
Ejido Delta	20	82.20	7.42
	40	86.00	8.07
	60	69.5	7.52
Ejido Nuevo León	20	18.34	8.02
	40	21.29	7.76
	60	37.50	7.54
Km 26. Carr. Mexicali-Algodones	20	115.00	7.80
	40	109.00	8.00
	60	102.00	8.20

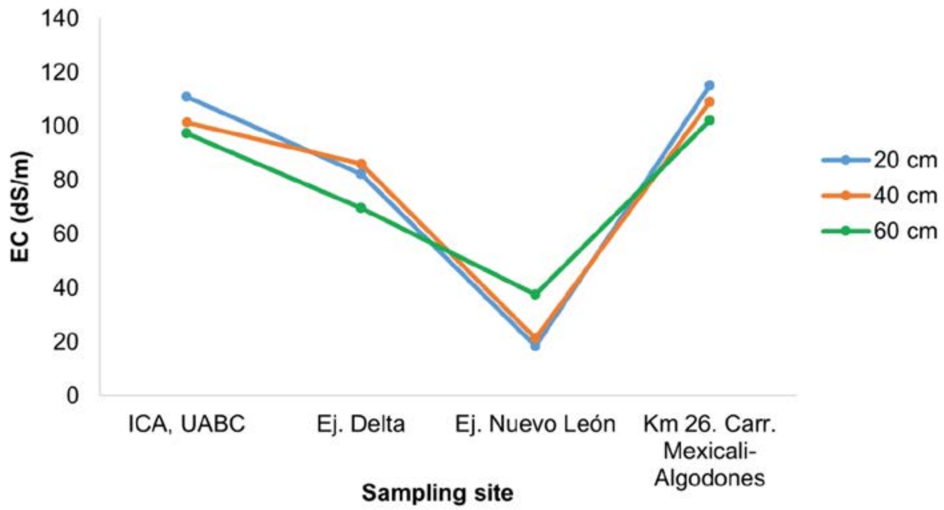


Figure 2. Variability of electrical conductivity at sampled soil depths.

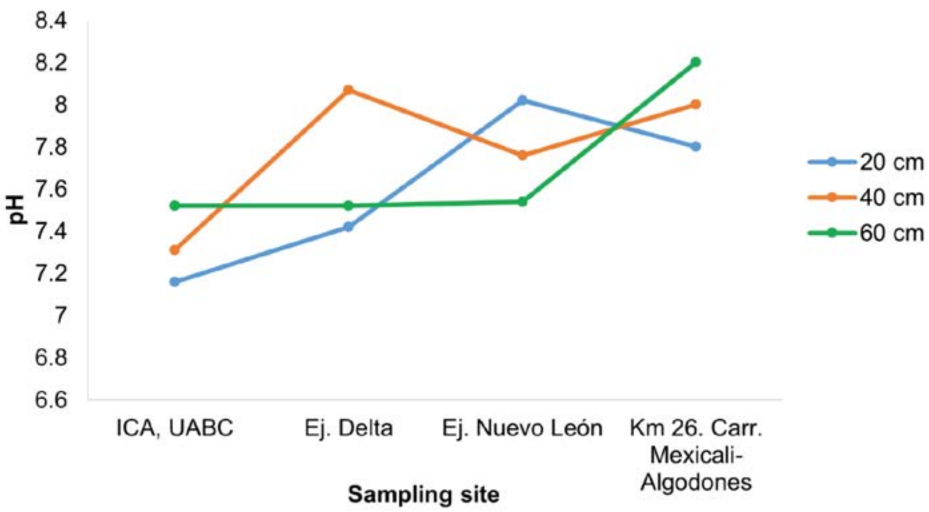


Figure 3. Variability of pH at sampled soil depths.

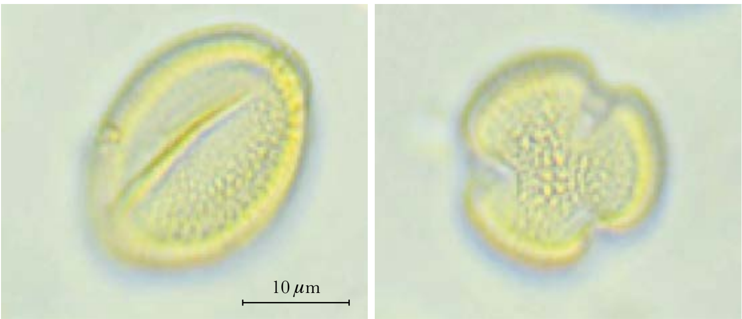
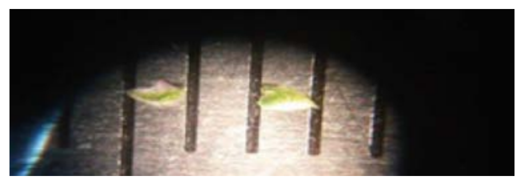


Figure 4. Pollen of *Tamarix* spp., selected by *Apis mellifera* in the Mexicali Valley, B.C., permission granted by the author: Luis Alaniz G. [17].

Table 2. Morphological description of the *Tamarix* plant.

Stem	Red-brown color	
Leaf	Pubescence on upper surface (absent or very weak), leaf shape and color (lanceolate, green), leaf margin (smooth).	
Root	Adventitious roots	
Inflorescences	1.5-6 cm	
		
Flower	They are sepals of 1 mm with smooth margins, green in color.	
	Ovate petals, 2 mm in size.	 
	Flowers pentamerous or with five stamens opposite the sepals, with filaments alternating with the lobes of the nectary disc, some or all, similar to what was reported by Natale *et al*. [2].	

CONCLUSIONS

The species of *Tamarix* collected at sampling points in the Mexicali Valley are similar to *Tamarix chinensis*. In some locations, this species is considered harmful due to its displacement of native species, as its water and soil requirements are not restrictive. However, it could also be considered beneficial for reforesting arid and saline soils due to its minimal soil and climate requirements. Its ability to extract salts from groundwater and deposit them in the surface soil layer can inhibit the germination of other vegetation types, as demonstrated by the results showing higher conductivity in the top 20 cm of soil. Conversely, in the Mexicali Valley, this species has brought benefits to sustainability in honey production due to the selectivity of its pollen by *Apis mellifera*.

Although Alaniz found benefits in honey production, with 38 % of honey derived from *Tamarix* spp. pollen, more detailed studies are needed to determine if the presence of this species has led to a reduction in native vegetation and, therefore, a loss of biodiversity.

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