Characterization of shade-grown coffee production in Totonac communities in the Northeastern Sierra of the state of Puebla, Mexico

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ABSTRACT

Objective: to characterize the production of shade-grown coffee (*Coffea arabica* L.) in Huehuetla, Ixtepec and Zongozotla, municipalities with Totonac population in Sierra Nororiental, Puebla, Mexico.

Design/Methodology/Approach: this study was conducted from January to June 2024. To collect data, 93 semi-structured interviews were conducted, consisting of three types of records; 1: general data, 2: socioeconomic and productive aspects; and 3: agronomic management. Among the surveyed participants, 69% were men and 31% were women.

Results: in these municipalities, 12 varieties of coffee are grown, associated with 50 plant species, 16 of which are used for shade. Coffee growers identified coffee rust (*Hemileia vastatrix*) as the main disease, and the coffee-berry borer (*Hypothenemus hampei*) as the primary pest. The yield of parchment coffee in this region is lower than the average in the state of Puebla (460 kg ha^{-1}). The most common practices identified are weed control, pruning of coffee plants, shade management, and soil fertilization.

Limitations/Implications of the study: foliar fertilization, application of insecticides and fungicides are implemented to a lesser extent; which suggest that coffee growers require attention and related training.

Findings/Conclusions: based on the results obtained, we suggest that agricultural activities be increased; while promoting the coffee sector through government agencies. Management plans should be designed in a way that, in addition to considering the biological requirements of coffee cultivation, they also incorporate the socioeconomic and cultural contexts.

Keywords: coffee growing, agroecosystem, diversity, agricultural practices.

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INTRODUCTION

There are more than 100 species of coffee in the world, however, Arabica coffee (*Coffea arabica*) represents 70% of the products in international trade, and Robusta (*Coffea canephora*) only 30%. Coffee is grown in the open air or under shade, mainly associated with native trees and with low use of inputs. These agroecosystems are fundamental because they provide ecosystem services and economic benefits; it is estimated that

coffee growing worldwide involves the participation of at least 25 million small producers (García-Domínguez *et al*., 2021).

At the national scale in Mexico, *C. arabica* represents 97% of production, with the varieties Típica, Borbón, Caturra, Mundo Novo, Garnica, Catuai, Pluma Hidalgo and Maragogype predominating, while 3% corresponds to *C. canephora* (Barrera-Rodríguez *et al*., 2021). Mexico ranks eleventh in coffee production worldwide, and represents 0.66% of Mexico's agriculture GDP. The main producing states are Chiapas, Veracruz, and Puebla, the latter ranking third nationally, followed by Oaxaca and others with a smaller contribution. Therefore, at the close of the 2023 agriculture cycle, the state of Puebla produced 225 663.84 tons (Megagrams, Mg) of coffee cherry, which represents 21.36% of Mexico's national production (SIAP, 2025).

In the Northeastern Sierra (Nororiental region) of the state of Puebla (Mexico), coffee growing is primarily done by native peoples, who play a fundamental role in the creation and maintenance of shade forest agroecosystems that house diverse plant strata. These are located in strategic locations for water collection, adjacent and priority areas for biodiversity conservation, and represent important biological corridors. Most coffee plantations are located in tropical and temperate zones (Aguirre-Cadena *et al*., 2018).

Coffee-growing areas have high levels of poverty, and in highly and very-highly marginalized communities, one characteristic is their lack of productive diversification, which impacts the low incomes of indigenous farmers. Since the elimination of global coffee price regulation, that coincided with the demise of the Mexican Coffee Institute (INMECAFE), the coffee-production sector has suffered significant abandonment, resulting in low yields, phytosanitary problems, and aging plantations. In addition, this crop currently faces uncertainty due to climatic factors, low prices, pests, and diseases, despite its economic, environmental, and social importance. In this region, some varieties are used that were developed and released by INMECAFE (Garnica variety) and the Mexico's National Institute of Research in Forestry, Agriculture, and Livestock-INIFAP (Oro Azteca variety), according to Gómez-Martínez (2019).

For this crop, should the importance be emphasized of agronomic management, environmental conditions, production systems, harvest and post-harvest management to increase yields and improve the quality of coffee products. Therefore, the diversification of agricultural practices in the crop is important. Nowadays, coffee production systems are classified into five types; rustic system, traditional polyculture, commercial polyculture, shade monoculture, and open-air monoculture (Escamilla-Prado, 2015).

In the Sierra Nororiental of Puebla, the rustic system predominates (Benítez-García *et al*., 2015). The main characteristics of this system are the low use of agrochemicals and that agricultural works are done only to a lesser extent; among those, the most notable are the pruning of coffee plants, and weed control under the canopy. The management of coffee plantation species is an activity in which the producer analyzes and decides what to plant, maintain, or eliminate. Therefore, growers design coffee plantations with specific trees present, this considering biological, economic, and cultural needs (López-Santiago, 2019). The importance of this knowledge is emphasized, for it provides ecosystem services and biodiversity conservation (Espinoza-Guzmán, 2020).

Puebla is the third-largest coffee cherry producer nationwide, with a production of 225 663.84 Mg at the close of the 2024 agriculture cycle. Coffee production is the main source of income for farming families in the Northeastern Sierra. To have a record of those agricultural activities that coffee growers do would help identifying those aspects that require attention. The objective of this study was to characterize the shade-grown coffee (*Coffea arabica* L.) production system in Huehuetla, Ixtepec, and Zongozotla, municipalities with Totonac population in Sierra Nororiental, Puebla, Mexico.

MATERIALS AND METHODS

Location of the study area

The study was developed in Huehuetla, Ixtepec and Zongozotla, all localities belong to the Sierra Nororiental in the state of Puebla, Mexico (Figure 1).

In Huehuetla there is a humid semi-warm climate with rain throughout the year, temperatures range from 18-24 °C with precipitations from 2900 to 3600 mm, Leptosol soil predominates. Ixtepec also has a humid semi-warm climate with rain throughout the year, temperatures range from 18 to 24 °C, precipitations from 2400 to 3600 mm where Leptosol soil predominates. Whereas, Zongozotla has humid semi-warm and humid temperate climates, with rain throughout the year, with temperatures ranging from 16 to 22 °C, precipitations from 1900 to 2100 mm, where luvisol and andosol soils predominate (INEGI, 2025). In regard to socioeconomic characterization, Huehuetla is considered a

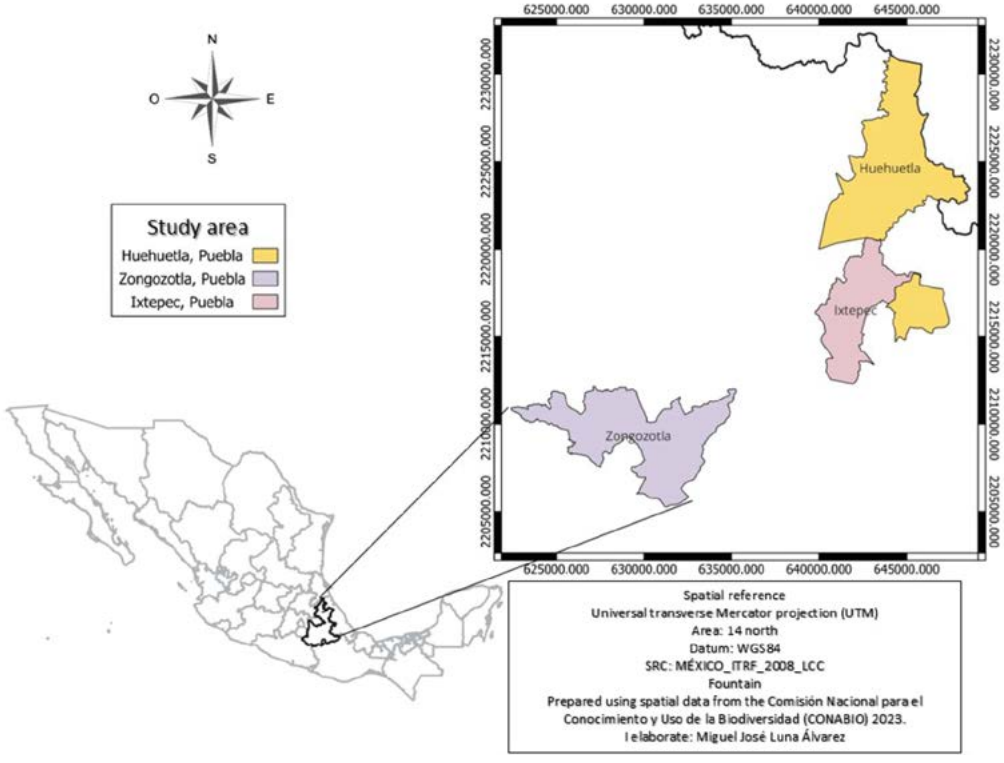

Figure 1. Location of the study area; the municipalities Huehuetla, Ixtepec, and Zongozotla, in the state of Puebla, Mexico. Source: prepared in ArcGIS® 10.5 with vector information from CONABIO.

municipality with very-high marginalization index, while Ixtepec and Zongozotla present a high marginalization index (CONAPO, 2025).

Collaboration with local authorities and organizations

Before beginning field survey activities, meetings were held with representatives of the municipalities of Huehuetla and Ixtepec. In the case of Zongozotla, a meeting was held with representatives of the Cooperative Association "Productora y Procesadora de café CAPERSA S.C. de R.L. de C.V." During those meetings, the objective of this study was discussed, as we requested authorization for its implementation.

Sample selection

Through representatives of the Rural Development Directorate and the representative of the Cooperative Association, the number of coffee growers in each municipality was obtained. There were 596 in Huehuetla, 450 in Ixtepec, and 1200 in Zongozotla. Simple random sampling was used; the sample size was determined using the formula described by Santiago-Hernández *et al.* (2023).

$$n = \frac{NZ_{a/2}^2 pq}{Nd^2 + Z_{a/2}^2 pq}$$

where, N: total population (2246 coffee producers); $Z_{a/2}^2$, 95% reliability (1.96), p=0.5, q=0.5, d=precision (0.10). Therefore, a sample size of 93 producers was obtained.

Semi-structured interviews

Ninety-three semi-structured interviews were conducted in Huehuetla (24 producers), Ixtepec (19 producers), and Zongozotla (50 producers). The interviews consisted of 20 questions grouped into three sections; 1: general information; 2: socioeconomic and productive aspects; sex, age, occupation, educational level, ethnic group, importance of the crop, coffee varieties grown, other plants in the coffee plantations, shade trees, planting frame and density, age of coffee plants, annual production, presentation, and selling price; 3: agronomic management; implemented agronomic practices and phytosanitary management. Producers who reported owning their property were interviewed; the interviews were conducted in Spanish and in their native language (Totonac). The information was systematized in a database and analyzed using descriptive statistics.

RESULTS AND DISCUSSION

Socioeconomic aspects

The ages of the coffee growers ranged from 19 to 81 years, 69% of those interviewed were men and 31% women. The low participation of women as owners of the coffee plantation is due to the fact that in these communities the role of women focuses on domestic tasks. According to Alvarado-Méndez *et al* . (2006), the tradition in the municipality of Huehuetla is that the head of the family is the man, while women are dedicated to household chores and family care.

The 100% of the producers were Totonac speakers, although some are bilingual and also communicate in Spanish (Figure 2). Their main activity is coffee farming, as they consider it the best productive option and a traditional activity. For this reason, coffee production is widely accepted, although it is sometimes not profitable. In this regard, indigenous farmers represent 51% of the total number of producers in the state of Puebla. Among them, 60% are Nahua, 34% are Totonac, 4% are Mazatec, and 2% are Otomi (Alvarado-Méndez *et al.*, 2006).

Figure 2. Participation of producers in informational meetings on coffee growing in the municipality of Ixtepec, located in the Northeastern Sierra (Nororiental Region) of the state of Puebla.

Through the interviews we found that educational level of coffee growers is low; 43% reported that have finished just primary education, 26% with secondary education, only 8% graduated from high school, while 23% have no education. However, one notable finding is that some producers' children, regardless of sex, are pursuing bachelor's degrees outside of these municipalities. This occurs because in the municipalities of Ixtepec and Zongozotla there are only elementary and secondary education up to high school. Meanwhile, in the municipality of Huehuetla, in addition to elementary and intermediate education, there are three higher education institutions; where the Intercultural University of the State of Puebla is outstanding because they offer undergraduate and graduate programs related to coffee growing (Aguilar-Tlatelpa and Fajardo-Franco, 2020).

Productive aspects

Up to 12 coffee varieties are grown in the study area, ranging from short growth habit, to medium and tall. These varieties include Marsellesa, Oro Azteca, Costa Rica 95, Mundo Novo, Garnica, Tipica, Sarchimor, Caturra, Colombia, Borbon, Obata, and Geisha. In both Huehuetla and Ixtepec, the most common variety mentioned was Costa Rica 95, while in Zongozotla the most mentioned was Oro Azteca (Figure 3).

Damage such as chlorotic to necrotic spots and defoliation due to coffee rust have been reported in the Typica and Garnica varieties in the study area (Fajardo-Franco *et al.*, 2020). The occurrence of diseases in different coffee-growing regions, particularly coffee rust, has led to the use of commercial varieties called catimores for the renewal of coffee plantations.

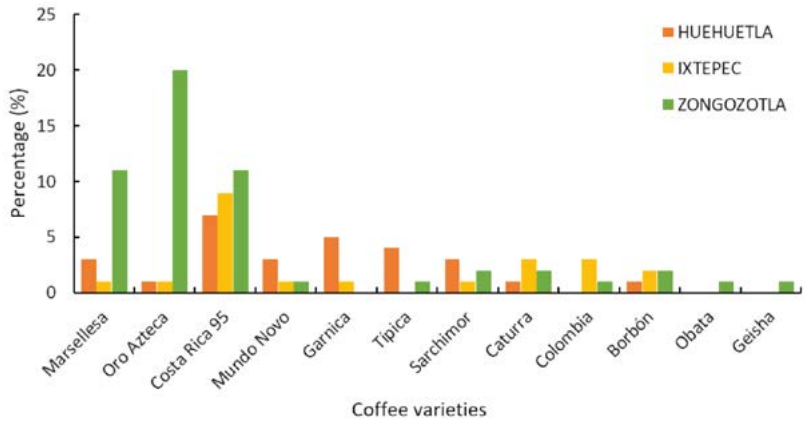

Figure 3. Coffee varieties grown by Totonac producers in municipalities of the Northeastern Sierra (Nororiental Region) of the state of Puebla.

Among these varieties tolerant to that disease are Costa Rica 95, Colombia, and Oro Azteca (Hernández-Martínez and Velázquez-Premio, 2016).

In regard to the age of the coffee plantations, it was found that some of the producers interviewed have plants up to 50 years old. Among those, Garnica outstands with a lifespan from 5 to 50 years; Caturra from 3 to 30 years, Borbón from 3 to 30 years, Tipica 5 to 20 years, Mundo Novo 5 to 15 years. However, an aspect to highlight is that in the last 15 years, varieties resistant to rust have been incorporated. It was found that of the Costa Rica 95 variety there are plantations from 2 to 15 years; of Sarchimor from 2 to 10 years; with Oro Azteca from 1 to 8 years, Marsellesa from 3 to 8 years. Plantations with variety Colombia ranged from 3 to 7 years, in the case of Geisha from 3 to 5 years, and with Obata, only young plantations, 2 years-old, were found. These results suggest a lack of coffee plantation renewal, as some plantations were identified over 20 years old from establishing. According to Díaz-Gutiérrez (2019), a renewal plan should be implemented for older crops to avoid phytosanitary problems that can be detrimental to production capacity.

The average surface area of each producer is 1.35 ha in Huehuetla, 1.25 ha in Ixtepec, and 0.55 ha in Zongozotla. In areas of these sizes, the average production of parchment coffee per hectare (kg ha^{-1}) is 190.9 kg (3.32 quintales) in Huehuetla. One "*quintal*" is equivalent to 57.5 kg of parchment coffee beans, that is the local traditional unit for measuring coffee yield. While in Ixtepec coffee growers obtain 242.7 kg ha^{-1} (4.22 *quintales*), Zongozotla stands out with a production of 460 kg ha^{-1} (8 *quintales*). This coincides with a previous study in Huehuetla and the entire region, that reported coffee producers have small plots ranging from one quarter of hectare to one hectare and their average production is 402.5 kg ha^{-1} (7 *quintales*) of parchment coffee (Alvarado-Méndez *et al.*, 2006).

The yield in parchment coffee (the bean with its softest husk) is smaller than the state (Puebla) average 782 kg (13.6 *quintales*), also smaller than Mexico's national average 368 kg (6.4 *quintales*), except in Zongozotla (SIAP, 2025). Production leaves an annual income per hectare of approximately 7500 Mexican pesos (MXN) in Huehuetla, MXN 9700 in Ixtepec and MXN 20 600 in Zongozotla. However, this income is unstable due to price

fluctuations and the very small area per producer. Therefore, these amounts are insufficient facing the level of poverty of the Totonacs in the Northeaster Sierra (Nororiental region) of Puebla (SADER, 2020). In this region, more than 80% of Totonac population live in poverty; Ixtepec and Zongozotla show high marginalization, while Huehuetla is officially recorded as of very high marginalization (CONAPO, 2025).

Given this situation, diversifying coffee agroecosystems is an important strategy to strengthen the resilience of farming families, thus reducing the risk of dependence on a single product. Diversification would increase access to food to improve the family diet; therefore, the implementation of agroforestry systems is suggested (Fonseca-Castillo *et al.*, 2025). The production of each plot is different, as well as the form of sale and price. In this study, 68% of producers sell coffee cherry at a price ranging from 7-10 MXN kg^{-1}, while only 32% of producers handle the wet and dry processing to obtain parchment coffee to sell in a range 3-45 MXN kg^{-1}; On the other hand, green or gold coffee is marketed from 120-180 MXN kg^{-1}, while roasted or ground coffee reaches a value between 140-200 MXN kg^{-1}. The opposite occurs in Pantepec, Chiapas, where Vázquez-López *et al.* (2022) reported that 78.8% of coffee growers sell parchment coffee, 18% coffee cherry, and only 3.3% ground coffee.

Planting frames are also a key factor in coffee production per hectare. In Huehuetla and Ixtepec, the most common distances are 2 m between plants and 2 to 3 m between rows. Whereas, in Zongozotla, the distances are 1.5 to 2 m between plants and rows, resulting in a higher plant density per hectare. The coffee harvest lasts approximately four months; in that period women's participation for that activity is particularly significant (Figure 4).

Figure 4. Women participate in coffee harvesting at the cutting of coffee cherry.

Plants associated with coffee plantations

Seventy-three percent of producers grow coffee under shade, and 27% grow coffee under the sun without any other cover. Shade trees are pruned and used to provide fuel for homes. In other cases, the waste is used to generate organic fertilizer. Shade trees

also provide seasonal fruit, which is harvested for personal consumption and local sale. Regarding plant community associated to coffee, those interviewed mentioned up to 50 plant species present in the coffee plantations, of which 16 are used as shade trees.

Totonac families use firewood to cook food, which is obtained from shade trees in coffee plantations such as chalahuite (*Inga vera*), tropical cedar (*Cedrella odorata*), allspice (*Pimenta dioica*), carboncillo (*Ocotea puberula*), sangregado or dragon's blood (*Croton draco*), coffee (*Coffea arabica*), Jamaican nettletree (*Trema micrantha*), ocote (*Pinus montezumae* o *P. teocote*). However, in coffee plantations there are also trees whose sole purpose is to provide shade and habitat for fauna, such as jonote (*Heliocarpus appendiculatus*) know in some countries as majagua, chaca– "gumbo-limbo" (*Bursera simaruba*), Mexican kidneywood (*Eysenhardtia polystachya*), tawaxkatat Totonac for the broadleaf alchornea (*Alchornea latifolia*). There are also some fruit trees such as, orange (*Citrus sinensis*), mango (*Mangifera indica*), pahua– the coyo avocado (*Persea schiedeana*), banana (*Musa paradisiaca*), and mamey (*Pouteria sapota*) (Figure 5).

In the case of sangregado (locally known as, dragon's blood), its importance in the medicinal field is outstanding, as it is used as a wound-healing agent. This use has also been documented in the Totonac municipality of Filomeno Mata, in Veracruz, where it is used to treat wounds (López-Santiago, 2019). Plant community in coffee plantations is a very important aspect for maintaining the cover in the various tree strata, since it promotes an internal microclimate and also favors the diversity of fauna. Libert-Amico & Paz-Pellat (2018) indicated that shade trees in coffee plantations are carbon stores in aboveground and soil biomass, they also provide a variety of environmental services and contribute to the amortization of climatic stress and nutritional imbalance.

In a study conducted in Huehuetla, Basilio-González *et al.* (2022) mentioned that coffee cultivation has better indices of richness, abundance and diversity of species, therefore,

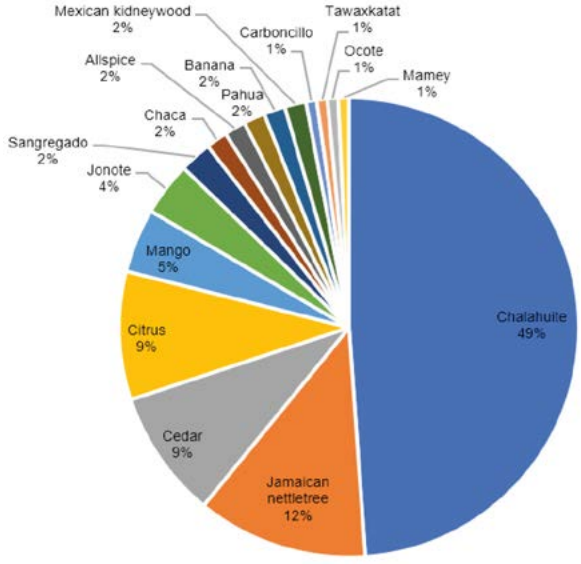

Figure 5. Shade trees in coffee plantations in the Northeastern Sierra (Nororiental region) of the state of Puebla.

it presents better conditions for development compared to other crops such as maize. Producers who cultivate coffee plants using the shade system, they prune the trees from March to May to allow sunlight to reach the coffee plants. They also remove dead or diseased branches, which decompose and generate organic fertilizer that is reintegrated into the soil. Coffee growers observe that coffee plantations with abundant trees have less water erosion because the drops fall on leaves of the trees and not directly onto the soil. The time when they do shade control is from April to June, because agricultural activities are fewer or scarce.

Agronomic management

Producers perform a variety of practices, primarily by hand, with hand-made tools and materials. However, as a result of the recent Governmental program "Recuperación del Campo Poblano", some producers have benefited with chainsaws, brush cutters, and motor-powered sprayers, among other pieces of equipment. The practices with the greatest positive impact on production and pest and disease reduction are the pruning of coffee plants, weed removal, shade control, soil fertilization, and the incorporation of organic matter. On the other hand, those implemented in less than 50% of cases are living fences, deadfalls, terracing, contour planting, associated crops, coffee plantation renovation, '*pepena*' (the local word for the collection of fruits remaining on soil), foliar fertilization, and the application of insecticides and fungicides (Table 1).

These practices coincide with those mentioned by Venegas-Sandoval *et al.* (2021) in a research implemented in a coffee-growing area of the state of Chiapas, Mexico.

Table 1. Agronomic and phytosanitary practices in coffee cultivation in the municipalities of Huehuetla, Ixtepec and Zongozotla, in the Northeastern Sierra of Puebla, Mexico.

Management Practice	Huehuetla		Ixtepec		Zongozotla	
	Y (%)	N (%)	Y (%)	N (%)	Y (%)	N (%)
Pruning of coffee plants	96	4	84	16	100	0
Weed control	100	0	100	0	100	0
Shade management	96	4	100	0	52	48
Soil fertilization	38	62	37	63	100	0
Foliar fertilization	13	87	11	89	10	90
Application of insecticides and fungicides	50	50	16	84	14	86
Level curves	8	92	11	89	4	96
Terraces	17	83	16	84	8	92
Living fences	33	67	21	79	22	78
Dead barriers	29	71	11	89	10	90
Organic matter	96	4	100	0	52	48
Associated crops	17	83	16	84	36	64
Replanting	13	87	16	84	28	72
Gathering of fruits on soil (pepena)	25	75	21	79	36	64

Source: original prepared with data from surveyed participants, 2024 (Huehuetla n=24, Ixtepec n=19, Zongozotla n=50). Y: yes, practice is present; N: no, practice is not present at; Municipalities with Totonac population: Huehuetla, Ixtepec, Zongozotla (Puebla), Mexico.

Weed control

Weed control is made by all the producers (100%), who emphasize its importance because it is complicated to get other activities done if the plot is invaded by weeds and shrubs. This practice consists of cutting the weeds with a long blade (called machete) to a height of 5 to 10 cm from the ground, to prevent erosion in the rainy season, and for the roots to help avoiding the loss of soil; to a lesser extent, the hoe or a brush cutter are used. In coffee plantations in the productive stage, weeding is done 2 to 3 times a year, in January, May and September; whereas, in plantations in growing stage, more than 3 cuttings are made. This coincides with Hernández-Solabac *et al.* (2011) who emphasized that timely weed control is the main practice in coffee-growing communities in Veracruz, because it favors production by preventing the coffee plant from competing for water and nutrients with other species.

Pruning of coffee plants and shade control

Almost all coffee growers (96%) do at least one annual pruning, mainly topping, coppicing and cleaning. Topping stands out, which has the purpose of forming new shoots, thus eliminating unproductive shoots in plants. In second place, coppicing which corresponds to cutting the top-shoots of coffee plants to stop the height growth of the plant. Coffee growers do this at a height determined by each producer (1.60 m is the most usual). According to experience this practice favors the generation of secondary branches and increases production. In terms of cleaning, they cut the damaged "bandolas" (first-order branches bearing leaves and fruits); they do it throughout the crop coppice. Merlín-Uribe et al. (2018) mentioned that pruning strengthens production and decreases the incidence of coffee rust. On the other hand, 100% of producers do shade control in this shade-grown production system.

Fertilization

Up to 71% of farmers fertilize the soil, primarily with urea, while only 10% of them apply foliar fertilization, two to three times a year with chemicals such as Gro Green® or Bayfolan®. In this regard, the municipality of Zongozotla is highlighted because 100% of producers fertilize the soil, applying an average of 300 grams per plant spread over three applications per year. In contrast, only 38% growers fertilize the soil in Huehuetla, and 37% do so in Ixtepec, applying approximately 200 grams per year spread over two to three applications.

Therefore, it is suggested to promote practices that strengthen plant nutrition, not only at the soil level, but also integrating foliar fertilization into agricultural practices, since the latter is not a widespread practice among producers. In the case of Zongozotla, producers apply fertilizers to the foliage 3 to 12 times a year. The most common dose is 50 grams of fertilizer dissolved in a 20L-sprinkler. Seventy-three percent of farmers use organic fertilizers such as compost and pruning waste as alternatives due to the high cost of chemical products. Producers do not have a schedule for fertilizer application, so the frequency of applications depends on their own financial means and on the government programs that provide technology packages to producers.

Pests and diseases

Farmers (75%) also mentioned coffee rust (*Hemileia vastatrix*) as the main disease affecting coffee crops and the coffee-berry borer (*Hypothenemus hampei*) as the most important pest, similar to what was reported by Leguizamo-Sotelo *et al.* (2024) in Amatepec, State of Mexico. Producers recognize and detect the severity of this disease, however, only 23% implement prevention practices or control activities through foliar application of chemicals. Among them, 15% receive fungicides through government agencies, mainly through the head of their Municipality and the State Committee for Plant Health in the state of Puebla (CESAVEP); while others acquire agrochemicals in stores outside their communities.

Locally the sale of agricultural inputs is scarce and it is difficult to find a specific product for a pest or disease for the management of coffee plantations. Fifty percent of Huehuetla producers apply fungicides and insecticides, while only 15% of Ixtepec and Zongozotla producers do so, making it essential to adopt phytosanitary practices. Producers in Huehuetla reported that the highest incidence of rust occurs in December and April, while in Ixtepec they mentioned December. In Zongozotla, they noted that the disease is most common in September and October.

The application of insecticides and fungicides is a very essential practice to maintain the sanitation of crops and is an essential part of obtaining good harvests and economic resources for the sustenance of Totonac families dedicated to coffee production. However, temperature and relative humidity also affect production, as mentioned by Jaramillo-Villanueva *et al.* (2022), the increase in pests and diseases, strong winds, excessive rain and droughts are events that are attributed to climate change, this seriously affects production because it is reduced by up to 30%.

These affectations have been constant since the appearance of rust, an example is what was reported by Escamilla-Prado (2016) who observed that the period between 2012 and 2016 was very complicated for coffee growers, for there is the estimation from the attack of rust that it caused a decrease of up to 50% of the national figure of coffee production in Mexico. Weed control, the pruning of coffee plants, shade control, and fertilization are the main maintenance activities. On the other hand, rust and the coffee-berry borer are the main pathogens that require phytosanitary solutions (Figure 6).

Among other practices that could be strengthened in the Totonac communities is the design of plantation in contour lines, considering that there are steep slopes in the region. Therefore, it is suggested to implement plantations with individual terraces, terraces in furrows, as well as to rehabilitate drainage ditches for each plant. However, living fences and deadfalls should also be encouraged. They serve to delimit plots, act as windbreaks, thus providing crop protection from climatic factors such as hurricanes, droughts, or excessive rainfall.

Deadfalls should be constructed using the existing materials on the plots; stones, branches, and logs should be placed transversely to the slope. This will reduce the velocity of water flow, thus retaining organic matter. In the coffee plantations of the study sites there is a diversity of plants in the cultivation areas; however, the association of crops through a spatial arrangement with which different products are obtained in the same surface unit is essential.

Figure 6. Agricultural activities most commonly implemented by coffee growers in the Northeastern Sierra (Nororiental region) of Puebla, Mexico. A: monitoring damage by the coffee-berry borer, B: monitoring damage by coffee rust, C: manual weed removal with a machete, D: shade control with a chainsaw, E: pruning of coffee plants (shoot reactivation), F: foliar fertilizer application, G: mechanized weed removal with a brush cutter, H: traditional shade control with handy tools, I: pruning of coffee plants, J: fertilization with agrochemicals, K: organic fertilization by compost application, L: shade control and firewood production.

On the other hand, replanting and renewal of coffee plantations is a critical point because in the study area they found plantations that exceed 30 years of production, which require a renewal plan, agronomic and phytosanitary management. This coincides with what was mentioned by Cardeña-Basilio *et al.* (2019) in a study on the production system established in Hueytamalco, (Puebla) Mexico (Figure 7).

Fourteen agricultural practices were identified, the most common is weed control, pruning of coffee plants, shade management, soil fertilization, and use of organic matter. However, gathering fruits on soil, crop association, living fences, foliar fertilization, application of insecticides and fungicides, replanting coffee plants, use of deadfalls, terracing, and planting on contour lines are implemented to a lesser extent. Therefore, it is necessary to strengthen and increase government support programs for coffee growing, based on the design of inclusive public policies in accordance with the linguistic, cultural, economic, and geographic contexts of the Northeastern Sierra. In addition, phytosanitary and soil fertility diagnoses should be done, in order to design management and technical support plans that allow determining the most appropriate agricultural activities for each production unit.

Figure 7. Less common practices that could be implemented in coffee plantations in the Northeastern Sierra (Nororiental region) of the state of Puebla, Mexico. A: furrow terraces; B: furrow layout on contour lines using the "A" frame level; C: individual draining ditch construction; D: individual terraces; E: coffee plantation renovation.

CONCLUSIONS

The age of the coffee growers ranged from 19 to 81 years; their predominant native language is Totonac. Coffee growing in Huehuetla, Ixtepec, and Zongozotla is established in diversified agroecosystems where coffee plants coexist other with fruit, medicinal, food, fuel, construction, and shade tree species. Among those, the Mexican chalahuite (*Inga* sp.) is predominant. Twelve varieties of coffee are grown in these municipalities; the varieties Costa Rica 95, Oro Azteca, and Marsellesa are the most prominent, established in young plantations with less than 15 years old. Although there are other plantations, with varieties Garnica, Caturra, and Borbón that were established over 30 years ago.

Thus, regarding phytosanitary aspects, the presence of coffee rust (*Hemileia vastatrix*) and the coffee-berry borer (*Hypothenemus hampei*) are the main problems. Average cultivation surface is one hectare per producer; where they obtain in average, 297.85 kg (5.18 quintales) of parchment coffee. These results can be considered for decision-making and the design of actions in the sustainable management of the coffee agroecosystem in the region.

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