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# Perception of climate change effects and adaptability practices of the coffee growers from Puebla, México.

# Percepción de los efectos del cambio climático y prácticas de adaptación de los caficultores del Estado de Puebla, México.

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## ABSTRACT

The present work is an effort to generate information related to the characteristics of coffee growers in Puebla state, the climatic conditions experienced, and activities that they already carry out to confront them. Interviews were applied in the macroregions of the state where coffee is produced, a descriptive statistic was generated and general recommendations were designed likely to be applied from a force-field analysis. 84 % of the producers are coffee growers by inheritance. Arabica and Costa Rica, followed by Robusta and Marsellesa are the most used varieties. 46 % of producers report the detrimental effects of extreme weather events. To counter the effects of climate change different techniques are used such as live barriers, mowing, and cleaning, among others. The most affected region by climate effects is the Sierra Nororiental. Sierra Norte presents a higher number of strategies to deal with it, as well as innovation activities different from those applied in the rest of the regions. All the macroregions have begun to replace varieties with those that affect the traditional production model. Finally, 11 synergistic actions at the producer, farm, and landscape levels are recommended to strengthen the coffee growing in Puebla.

**KEY WORDS:** Traditional farming, Varieties, Drought, Macroregion.

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## RESUMEN

El trabajo buscó generar información de las características de los caficultores del Estado de Puebla, las afecciones climáticas experimentadas y las actividades que llevan a cabo para enfrentarlas. Para ello se aplicaron entrevistas en las macrorregiones cafetaleras de la entidad, se generó estadística descriptiva y se propusieron recomendaciones generales susceptibles de ser aplicadas a partir de un análisis de campo de fuerzas. El 84% de los entrevistados son cafetaleros por herencia. Las variedades más empleadas son Arábiga y Costa Rica. La sequía es la afectación climática más referida. El 46% de los productores reporta impactos por fenómenos meteorológicos extremos. Para contrarrestar los efectos del cambio climático se emplean acciones con alcances diversos como barreras vivas, chapeo y limpieza. La macrorregión con mayores afectaciones es la Sierra Nororiental. La Sierra Norte presenta el número más elevado de estrategias de adaptación, así como actividades de innovación diferentes a las utilizadas en las otras zonas de estudio. Todas las macrorregiones han sustituido variedades con otras que impactan el modelo productivo tradicional. Se recomiendan 11 acciones sinérgicas a nivel de productor, finca y paisaje para fortalecer la caficultura en Puebla.

**PALABRAS CLAVE:** Cultivo Tradicional, variedades, Sequía, Macrorregión.

## Introduction

The impacts derived from climate change, such as erratic rainfall, temperature increase, decrease in water resources, and increase in extreme weather events, will generate negative effects on production and human welfare mainly in developing countries (Murillo *et al.*, 2018). It is urgent to design and implement actions that strengthen adaptation strategies that include research and extension, promote collaboration between local actors, encourage knowledge exchange, and support community planning strategies to face the challenges ahead (Nelson *et al.*, 2009). This is particularly necessary for rural areas where the population depends on agriculture and, at the same time, tends to be more exposed and more vulnerable to the negative impacts of climate (Altieri & Nicholls, 2008), understood as the susceptibility to face the negative effects of changes in temperature patterns, precipitation and extreme weather events (IPCC, 2007).

Coffee production is highly sensitive to climate change, primarily due to the geographic location of the producing areas, poverty, marginalization, and the educational level of producers, as well as their limited access to services and technologies (Jaramillo-Villanueva *et al.*, 2022). This is particularly relevant for Arabica coffee whose cultivation is one of the most widespread in the world and the most produced in Mexico (López-García *et al.*, 2016). It is expected that

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the main producing countries will experience drastic losses in their harvests if measures are not taken in the short term. Just the increase of 0.5 degrees Celsius that Latin America has already experienced in recent years is accelerating the ripening of grains with a consequent impact on their quality; on the other hand, the modification of rainy seasons and their alternation with sunny periods affects flowering, affecting yield (Muñoz, 2015). Recent studies show that variations in weather patterns are causing limitations in growth, interruption of flowering, poor fruit development, higher incidence of pests such as rust, and, consequently, low production yields in coffee plantations (Guerrero-Carrera *et al*., 2020). It is likely that, if current trends continue, the global temperature increase will reach 1.5 °C between 2030 and 2052, which would increase the risks to natural systems and humans and consequently to coffee production (Masson-Delmotte *et al*., 2018).

Although the climate change impacts on coffee growing are different for each country and even between producing regions within them, in general, in the future coffee growers will need to plant earlier, harvests will be brought forward, suitable areas for growth will change, higher temperatures will favor the proliferation of diseases, less frequent rains will force the use of irrigation systems and activities such as natural drying of the bean will be limited (Isaza & Cornejo, 2014). These conditions will influence on quality and market price, in addition to increased economic uncertainty due to international price variations, all of which will ultimately affect the survival strategies of coffee growers (Robles, 2011; Morales *et al*., 2020), who in general are highly vulnerable to climate change. This is mainly due to the income derived from production does not allow for the improvement of crucial socioeconomic conditions (Guerrero-Carrera *et al*., 2020). Available data from coffee farmers in the state of Puebla show that the yields derived from coffee beans are historically below the minimum wage, $1,500.00 monthly/per capita (Tapia-Hervert, 2006) and $1,288.50 monthly/per capita (Benítez-García el at., 2015) and that these present in highly representative sites of the activity, a schooling level of only 5 to 6 years (Jaramillo-Villanueva *et al*., 2022).

However, several investigations suggest that many producers are already preparing and adapting to climate fluctuations by taking actions to minimize potential affectations, including the use of more resistant varieties, harvesting water, and promoting crop mixtures (Altieri & Nicholls, 2008; Moreira & Castro, 2016; Viguera *et al*., 2019). Alternatives are also explored to add value or diversify production, highlighting specialty coffee, the generation of local brands and by-products and derivatives, as well as the search for more profitable markets based on criteria of socio-environmental responsibility (Pérez-Akaki, 2009). Thus, the adaptation of coffee growers to climate change can be defined as a process of adjustment to climate and its effects, to try to moderate or avoid damage, as well as to take advantage of the opportunities it generates (IPCC, 2014).

How such adaptation occurs, as well as the barriers it faces, can be understood under the paradigm of socio-ecological systems considering three main aspects, the actors (coffee farmers), the objects on which they act (farms), and the context where these develop (territory) (Moser & Ekstrom, 2010), being influenced by the perception of coffee growers with respect to climate hazards, since this is a process of extraction and selection of relevant information that allows detonating decision-making, in this case, to adapt to climate variations (Jaramillo-Villanueva *et al*., 2022).

Since the impacts of climate change on coffee production are experienced at a local level and those adaptation responses to climate change occur in specific places and regions (Embden Drieshaus & Epping Consulting GMBH, 2016), it is essential to know the aforementioned aspects in each of the various areas in which it is intended to strengthen change projects and design strategic lines of action. Hence, this study sought to generate data from the different producing regions of Puebla state, information related to characteristics of the producers, climatic affectations experienced, perception regarding the same, and the activities they carry out to adapt.

## Material and Methods

The study area comprised four macroregions of Puebla state, which included the nine coffee-growing regions of the state. These are briefly described below.

### Valle de Serdán Macroregion

Is represented by the coffee-growing region of Quimixtlán, where the penultimate and penultimate municipality in terms of coffee production in the state is located. It is expected that by 2039, as a result of climate change, more than half of the area that is currently ideal for cultivation will be reduced in the area (Hernández-Castán, 2022).

### Sierra Negra Macroregion

Integrated exclusively by the coffee-producing zone of the same name, prospects calculated by Hernández-Castán (2022) for 2039 indicate that the most suitable sites for cultivation, in terms of temperature and precipitation, could disappear from this territory, primarily in the areas with the highest production.

### Northeastern Sierra Macroregion

Includes three coffee-growing regions: Huehuetla, Zacapoaxtla, and Teziutlán. The most discrete coffee-producing municipality in the state is located here. As in the previous case, it is expected that by 2039 the optimal area for cultivation will decrease almost completely, as a result of an increase in rainfall and also in maximum temperatures in the area (Hernández-Castán (2022).

### Macroregion Sierra Norte

This is the largest macroregion and is comprised of regions of Xicotepec, the most productive in the state; the region of Huauchinango, Zacatlán, and Chignahuapan. Hernández-Castán (2022) estimates that by 2039, 96 % of the region will present precipitation conditions and extreme temperature peaks in the hottest months of the year that will not favor coffee cultivation.

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During April, May, and June 2022, a total of 84 semi-structured telephone interviews were conducted with producers in the four macroregions previously described, which constituted a qualitative sample that represents a confidence level of 95 % with a maximum error of 10.59 % considering the population of 40,466 producers that are registered for the entity (SDRSOT, 2017). The availability of producers for each region made it difficult to distribute interviews in the different work zones, however, a greater effort was made aimed at the areas with more surface area and production in the entity, having carried out 4 surveys in Valle de Serdán, 16 Sierra Negra, 19 Sierra Norte, and 45 in Sierra Nororiental.

Obtained responses were categorized by the climate change effects perceived by the interviewed coffee growers, the effects that they imply for coffee production and their livelihoods, the strategies currently employed to adapt to them, the relationship with the biodiversity present in the cultivation areas, the main impediments that they face to adaptation and priority attention matters that they need to overcome. General information was also obtained on the producers, varieties used, average farm size, and time dedicated to cultivation. Obtained data were used to perform descriptive statistics.

In addition, to identify strategic actions for change, the information was processed using a force-field analysis technique, which is applied to identify the most viable courses of action for transformation processes (Baulcomb, 2003). The force-field approach makes it possible to study a given situation from a whole perspective, assigning a negative valence to any contextual element that makes it impossible for an individual to achieve a desired goal, as well as a positive valence to that which empowers him/her. This facilitates the identification of the most viable or unfeasible actions that can be promoted from the categorized transforming or restrictive forces (Rivera, 2019).

## Results

Of the total number of interviewees, 23 % were women and 77 % were men, 84 % identified themselves as coffee growers by inheritance, i.e. they are second-generation producers or more. Ninety-one percent expressed the intention of continuing to engage in the coffee growing activity in the future. Fifty-six percent of those interviewed reported traditional cultivation, 23 % commercial cultivation, 16 % monoculture and/or full sun cultivation, and only 5 % rustic cultivation. The most commonly used varieties were Arabica and Costa Rica, followed by Robusta and Marseillaise (Figure 1), with 15 %, 12 %, 11 %, and 11 % respectively. In the plantations where it was possible to identify other products in combination with coffee (84 %), fruit trees were the most frequent combination with 51 % of incidence, followed by non-tree edible plants with 32 %. Of the latter, 16 % were referred to as wild.

Drought was the most reported climatic affectation by producers, 88 % of producers affected, followed by torrential rains 82 %. Four other climatic conditions were also reported for the entity, in order of frequency: landslides, delayed rains, frost, and fires (Figure 2). The main impacts associated by coffee growers with the aforementioned conditions were the loss of fruit blossoms,

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lower production, and alteration of production cycles (Figure 3). Forty-six percent of farmers reported affectations of extreme weather events such as Hurricane Grace in 2020. Regarding the general plot, the most reported impacts were associated with soil loss, felled trees, loss of crops/ plants, increased erosion, and landslides.

To deal with these conditions, coffee growers implemented seven different actions. The most frequent was clearing and cleaning (30 %), followed by terracing (20 %) and other soil protection techniques such as physical retention with woody material (17 %) and contour lines (11 %). Replanting was the least common activity (3 %). On the other hand, 100 % of those who did mowing and clearing said they perceived the need to do it more frequently and in shorter cycles. Actions such as the use of live barriers showed low frequency (7 %); however, 100 % of those interviewed who carried them out agreed that they have had favorable results in minimizing the effect of extreme weather phenomena such as hurricanes.

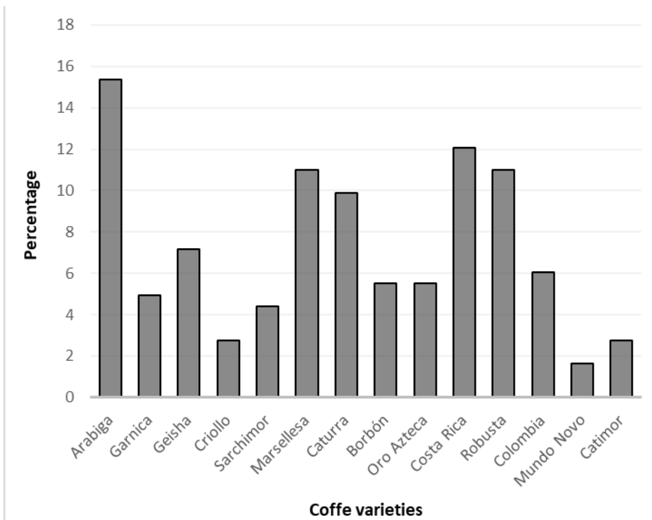


**Figure 1. Distribution of planted varieties (percentage).**

Source: Own elaboration based on this study data.

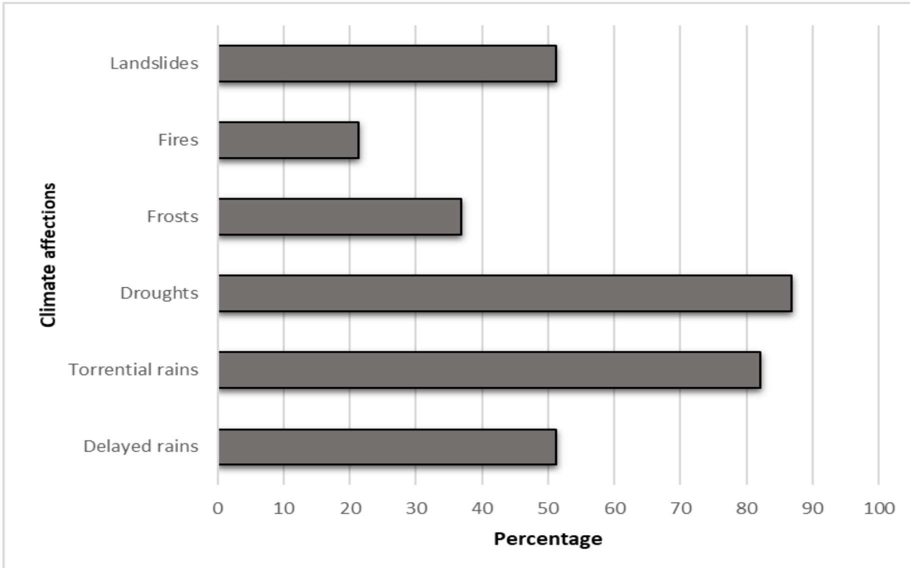


**Figure 2. Main climatic affections (percentage).**

Source: Own elaboration based on this study data.

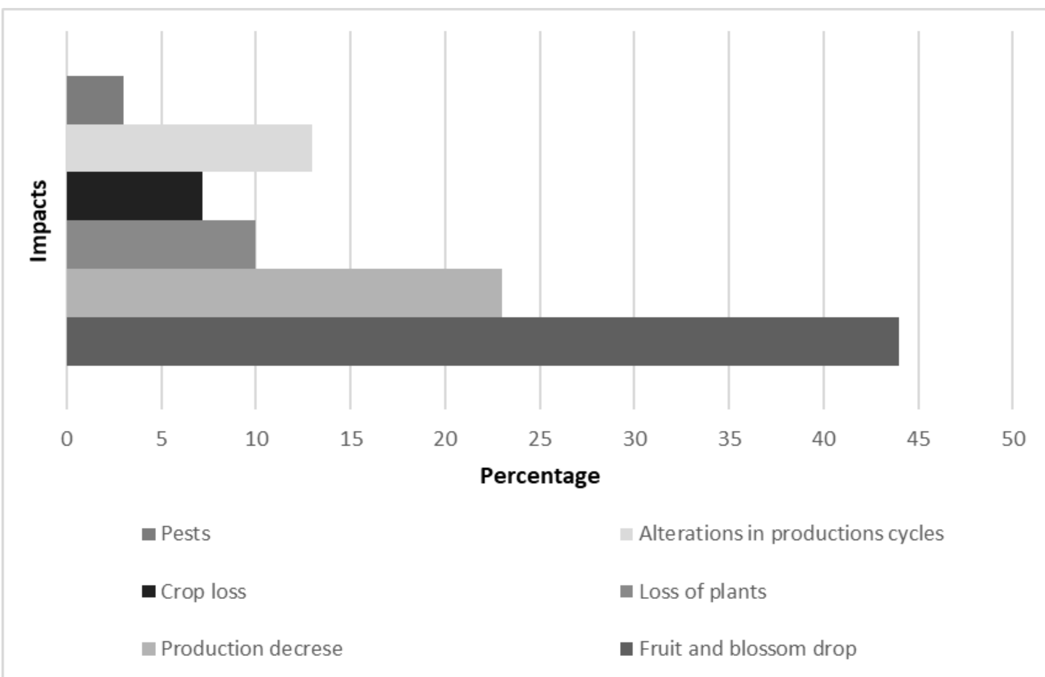


**Figure 3. Main impacts on crops (percentage).**

Source: Own elaboration based on this study data.

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Seventy-six percent of the producers considered that the loss of forests is detrimental to the crop since it harms humidity and temperature. On the other hand, 73 % of the producers perceived biodiversity as important for the activity, mainly because of its contribution to ecosystem services (ES) such as pollination. They also identified other benefits of both elements, such as water supply, food security, timber supply, and natural pest control.

### Particularities by macroregión

Based on the conducted interviews and the macroregions that were considered for this study, the conditions reported by the producers in each of them are described below. The corresponding field analysis of forces is also presented as a contribution to facilitate the design of effective adaptation actions in each site.

### Valle de Serdán Macroregion

Although coffee growers reported perceiving climatic alterations such as delayed rains (75 % of those interviewed), there were also environmental impacts such as soil loss and fires (50 % of those interviewed), however, a third of the detrimental forces detected in the interviews were related to the presence of pests and delayed rains (50 % of those interviewed). There was a high incidence of farms smaller than 1.5 hectares (33 %), as well as the absence of roasting or milling of the grain. There has been a migration to Hass avocado cultivation. Growers reported applying four main actions to counteract the above-identified problems: diversification of varieties, terracing, contour lines, and mowing/fertilizing (Table 1).

### Sierra Negra Macroregion

Regarding climatic disturbances, producers reported very strong and prolonged droughts (68 %), torrential rains (68 %), fires (25 %), loss of springs (87 %), and, as in the previous case, delays in rainfall (62 %). Environmental problems such as landslides and forest loss (37 %) were also reported. There is little development of brands (10 %), and producers reported a lack of organization and changes in land use due to the expansion of cattle ranching from the Veracruz state. Nearly half of the farmers reported having plots of less than 1.5 ha, where the only crop is coffee with a high dominance of the Coffea robusta species (75 %), which is mainly sold locally (68 %). It is noteworthy that 84 % of those interviewed for this macroregion reported maintaining agroforestry systems, with tree species linked to the provision of shade, as well as non-tree species, mainly edible, to complete nutrition and promote health (Table 2).

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**Table 1. Force field analysis into Valle de Serdán macroregion.**

| Driving forces | Desired change | Detracting forces |
|---|---|---|
| High shading percentage (greater than 50 %) | Effective adaptation of coffee production to climate change | Rains delay alternated with periods of drought (75 %) |
| High incidence of professionals (60 %) | | Forest fires (50 %) |
| High attachment to land production (66 % are producers from 3 or more generations) | | Discontinuous production (100 %) |
| Varieties diversification (100 %) | | Forest loss (50 %) |
| Terracing (50 %) | | Soil erosion (50 %) |
| Contour lines application (50 %) | | Spring loss (50 %) |
| Mowing-cleaning and fertilization (100 %) | | Coffe Berry borer presence (50 %) |
| High incidence of recognition of the forests influence for humidity conservation and temperature control (100 %) | | Coffee leaf rust presence (50 %) |
| High incidence of recognition of biodiversity impact for pollination and biological control (100 %) | | Presence of Moths (50 %) |
| Diversified income (Remittances and trade) (100 %) | | Aphids presence (50 %) |
| | | Screwworm presence (50 %) |
| | | No increase in added value (75 %) |
| | | Local trade (100 %) |
| | | Swap coffee crop for Hass avocado (50 %) |
| | | High incidence of plots smaller than 1.5 ha (33 %) |

Source: Own elaboration based on this study data.

## Macroregion Sierra Norte

It presents very particular conditions in relation to the others, here although producers reported climatic alterations such as delayed rain cycles (37 %) and torrential rains alternating with droughts (95 %), landslides and soil erosion (42 %), they also identified frost damage (68 %), which has led to the perception of an increase in the loss of flowers and fruits; it is the only area in which a significant increase in gullies is perceived (16 %). Changes in the varieties traditionally cultivated to encourage adaptation were reported, however, the coffee trees introduced so far have been dependent on the use of agrochemicals and a full sun production model. This macroregion was the only one that presented experiences of Carbon

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Neutral certification (1), it also registered farms with organic certification (9), as well as some production areas in which innovation activities, cooperation with research organizations, and development agencies have been developed (1). There was also a high incidence of added value (83 %).

**Table 2. Force field analysis in Sierra Negra macro-region.**

| Driving forces | Desired change | Detracting forces |
|---|---|---|
| High attachment to land production (60 % are producers from 3 or more generations) | Effective adaptation of coffee production to climate change | High dominance of a single variety (Robusta) (75 %) |
| High intention to continue producing coffee (100 %) | | High incidence of plots smaller than 1.5 ha (46 %) |
| Terracing (50 %) | | Low level of schooling (26 % professionals) |
| Contour lines application (43 %) | | Rains delay (62 %) |
| Mowing-cleaning and fertilization (68 %) | | Torrential rains (68 %) |
| High incidence of recognition of the forests influence for humidity conservation and temperature control (100 %) | | Extremely severe and extended droughts (68 %) |
| Drip irrigation and water saving techniques (46 %) | | Forest fires (25 %) |
| Biological control applications (37 %) | | Landslides (37 %) |
| Value addition (31 %) | | Low production due to climate changes (50 %) |
| Diversified income (Livestock, farming and trade) (68 %) | | Soil erosion (37 %) |
| High incidence of agroforestry (84 %) | | Forest loss (37 %) |
| | | Springs loss (87 %) |
| | | Coffe Berry borer presence (62 %) |
| | | Initial presence of coffee leaf rust (19 %) |
| | | Screwworm presence 37 %). |
| | | Low development of own brands for marketing (10 %) |
| | | Mainly local trade (68 %) |
| | | Lack of organized groups (19 %) |
| | | Change in land use for livestock (19 %) |
| | | High incidence of lack of recognition of the biodiversity value for ecosystem services supply (40 %) |

Source: Own elaboration based on this study data.

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It is noteworthy that in this macroregion, 100 % of those surveyed stated that they had production areas larger than 1.5 ha, which also differed from the rest of the areas analyzed. Seventy-two percent of the producers identified pollination as an ecosystem service and in general, 85 % of those interviewed recognized its importance. Regarding management practices, this is the only macroregion where farmers reported the use of mulch to retain humidity and influence soil temperature (10 %), as well as stakes to which they tie coffee plants to protect them from strong winds (10 %). In this zone, there was an experience of incorporating tourism as part of the diversification of production activities to complement the income of producers (Table 3).

### Northeastern Sierra Macroregion

The analysis of this site showed that producers identified the highest number of environmental impacts such as delayed rains (53 %), torrential rains alternating with droughts (89 %), frost (40 %), sleet (5 %) and increased incidence of extreme weather events such as hurricanes and tropical storms (49 %). It coincided with other areas in the incidence of landslides (68 %), soil erosion (78 %), discontinuous production (31 %), and decreased yields (33 %), but unlike other areas, there were also alterations in the maturation of both plants and fruits (13 %), as well as total losses of plants and crops (24 %).

This macroregion has also initiated a migration of shade coffee varieties towards those that are adapted to full sun cultivation; 68 % of the producers who participated reported less than 50 % of shade coffee as their main variety. Among the practices carried out to promote adaptation were terracing (24 %), contour lines (29 %), diversification of varieties (89 %), mowing and fertilization (96 %), as well as the application of living barriers (24 %).

Although the majority of respondents reported not adding value to coffee (60 %), there were also, as in the case of the Sierra Norte, brands with quality certifications such as organic coffee (24 % of respondents), as well as innovation activities related to collaboration with retail stores and product diversification through the production of liqueurs and confectionery (13 %). This is the only zone that presented an experience of incorporating beekeeping as a productive activity complementary to coffee production (Table 4).

## Discussion

According to the present results, most of the coffee growers in the state were men; this is similar to what occurs in other areas of the country (Hernández-Sánchez & Travieso-Bello, 2021; Jaramillo-Villanueva *et al*., 2022). Likewise, the dominance in Puebla of the traditional cultivation system with respect to others such as rustic or full sun production was similar to that reported by Escamilla-Prado *et al*. (2021) for the state of Chiapas (52 %).

As reported by López-García *et al*. (2016), the main variety cultivated in Mexico is Arabiga, which is coincident with the results of the present study. However, unlike the aforementioned author, derived from the interviews conducted, in Puebla Costa Rica coffee was reported as the second most produced variety, followed by Marseillaise. The latter is consistent with what was

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locally recorded in states such as Oaxaca, where these varieties occupy the first positions in terms of plantation (García-Domínguez *et al*., 2021).

**Table 3. Force field analysis in Sierra Norte macroregion.**

| Driving forces | Desired change | Detracting forces |
|---|---|---|
| High attachment to land production (50 % of producers from 3 or more generations) | Effective adaptation of coffee production to climate change | High Presence of crops (34 %) with low percentages of shading (less than 40 %) |
| High intention to continue with coffee production (100 %) | | Increased crops in full sunshine (26 %) |
| High shading percentage (greater than 60 %) | | Low incidence of professionals (30 %) |
| Varieties diversification (84 %) | | High incidence of plots dedicated exclusively to coffee (72 %) |
| High incidence of plots with surface area greater than 1.5 ha (100 %) | | Rains delay (37 %) |
| Terracing (58 %) | | Torrential rains (95 %) |
| Contour lines application (69 %) | | Droughts (68 %) |
| Mowing-cleaning and fertilization (95 %) | | Frosts (69 %) |
| Mulch application (10 %) | | Landslides (42 %) |
| Shade tree planting/Reforestation (16 %) | | Fruits and blossoms drops (74 %) |
| Use of  stakes to protect plants from winds (10 %) | | Low production as a result of climate changes (52 %) |
| High incidence of recognition of the forests influence for humidity conservation and temperature control (87 %) | | Soil erosion (42 %) |
| High incidence of recognition of the importance of forests for self-regulation, conservation and maintenance of the water cycle (87 %). | | Significant gullies increase (16 %) |
| High incidence of recognition of the value of biodiversity for the supply of ecosystem services such as pollination and biomass generation in most of the producers (72 %) | | Coffe Berry borer presence (32 %) |
| High incidence in the increased value (83 %, Parchment, roast and ground coffee) | | Coffe leaf rust presence (57 %) |
| Presence of certified brands under carbon neutral, tourism and specialty coffee certifications (21 %) | | High incidence of agrochemicals use (33 %) |
| Incipient market diversification (20 % - CDMX; Querétaro, North of Mexico) | | High incidence of local trade (61 %) |
| Incipient development of innovation activities (20 % - Collaboration with local stores, international cooperations agencies, research institutions) | | Change of varieties to resistant organisms but dependent on agrochemicals (26 %). |
| Diversified income (agriculture, livestock, commerce, tourism) (84 %) | | Low prevalence in the use of biological controls (13 %) |

Source: Own elaboration based on this study data.

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**Table 4. Force field analysis in Sierra Nororiental macroregion.**

| Driving forces | Desired change | Detracting forces |
|---|---|---|
| High attachment to land production (44 % are producers from 3 or more generations) | | High Presence of crops (68 %) with low percentages of shading (less than 50 %) |
| High intention to continue with coffee production (90 %) | | Increased crops in full sunshine (38 %) |
| Varieties diversification (89 %) | | Low incidence of professionals (77 %) |
| Terracing (24 %) | | High incidence of plots smaller than 1.5 ha (43 %) |
| Contour lines application (29 %) | | Initial presence of monocultures (10 %) |
| Mowing-cleaning and fertilization (96 %) | | Rains delay (53 %) |
| Live barriers application (24 %) | | Torrential rains (89 %) |
| Incipient application (20 %) of biological and natural pest controls. | | Droughts (100 %) |
| Presence of brands with quality certificates (organic) (24 %) | | Frost (40 %) |
| Incipient market diversification (17 % -CDMX, Japan and other export sites) | Effective adaptation of coffee production to climate change | Landslides (68 %) |
| Incipient development of innovation activities (13 % - Collaboration with local stores, transformation to liquor) | | Fruits and blossoms drops (73 %) |
| Diversified income (agriculture, livestock, commerce, Beekeeping) (80 %) | | Strong winds (68 %) |
| Diversification with productive shade (67 %) | | Sleets (5 %) |
| High incidence of recognition of the importance of forests to regulate temperature/Humidity (33 %) | | Soil erosión (78 %) |
| High incidence of recognition of the value of biodiversity for the supply of ecosystem services such as pollination and generation of biomass in a large part of the producers (80 %) | | Increase in the incidence of hurricanes and tropical storms effects (49 %) |
| | | Pests presence (82 %) |
| | | Low production as a result of climate changes (33 %) |
| | | Discontinuous production (31 %) |
| | | Alterations of plant and fruits cycles (maturation mainly) (13 %) |
| | | Total crop loss from extreme weather events (24 %) |
| | | Change of varieties to resistant organisms but dependent on agrochemicals and full sunshine (38 %) |
| | | High incidence of local trade (61 %) |
| | | High incidence of agrochemicals use (32 %) |
| | | No increase in added value (60 %) |

Source: Own elaboration based on this study data.

The identification of climate risks by farming families dedicated to coffee production in other parts of the world (Mulinde *et al*., 2019) and also in Mexico (Villers *et al*., 2009; Rivera *et al*., 2013), are coincident with the main problems found in the present study, such as prolonged rains with alternating droughts, landslides, and loss of flowering and fruit.

Ruiz (2014), indicates for some other areas of the country, that the actions developed by coffee growers to cope with the effects of climate change have been mostly limited, and their applicability, although satisfying elements in the short term, can increase the vulnerability of producers on a broader time scale. This is congruent with the findings for the state of Puebla since the substitution of coffee varieties mainly for those with full sun conditions could increase deforestation, increase microclimatic variations, the risk of landslides, modify production practices, and hinder effective adaptation in the future. In addition, research conducted by Sánchez *et al*. (2018) shows that, although coffee growers in places like Colombia have introduced varieties tolerant to changing climatic conditions, pests, and diseases, these are not as productive from the experiences collected directly from them. This coincides with the perception of the surveyed producers regarding the need to replant more frequently and in shorter cycles. The use of live barriers, scarce in the entity according to the results of the present study, has been reported with much higher frequencies in other states such as Veracruz (Hernández-Sánchez & Travieso-Bello, 2021), being the opposite case applicable to actions such as contour lines, since in Puebla state their application was reported with a much higher frequency than in the neighboring entity.

Authors such as Frank *et al*. (2011), consider that the perception of climate change is essential to dimension the phenomenon, its complexity, and possible mechanisms of action, which could explain why the areas where less climatic affectations are perceived today, although with important prospects of temperature and humidity changes in the future, were where a smaller variety of management actions were manifested (Valle de Serdán and Sierra Negra macroregions). The high presence of agroforestry systems in Sierra Negra in which food species have been included coincides with the information of Olvera (2016), who identified 20 species of qualities consumed in the municipality of Coyomeapan located in the aforementioned area.

Previous works such as those conducted by Benítez-García *et al*. (2015) indicate, for some regions of the state, plot sizes similar to those found in this study. The same occurs in other entities of the country (García-Domínguez *et al*., 2021), however, the case of the Sierra Norte macroregion is singular because, as has been expressed, there the cultivation areas, based on the sample, are larger.

The global initiative Coffee and Climate (Embden Drieshaus & Epping Consulting GMBH, 2016), reports that changes in precipitation and temperature regimes, as well as storms, intense winds, and cold spells, among other climatic events, are affecting productivity levels and coffee quality. As a result, coffee growers are facing increasingly unpredictable conditions that alter the conditions of the crop and make it necessary to look for varieties that tolerate extreme conditions, as has been reported in the Sierra Norte and Northeastern macr-regions. In these areas, moreover, the results coincide, in terms of the climatic effects on coffee growing as perceived by producers, with those developed by Hernández-Castán (2022), who, through a cartographic analysis based on the official information available for Mexico, showed a potentially greater impact of climate change to coffee production in these areas of the state.

The use of living barriers mainly to mitigate the effects of extreme meteorological phenomena reported for the Sierra Nororiental macroregion is also registered in neighboring states such as Veracruz, where it is also associated with a decrease in water flows and a reduction in soil erosion (Hernández-Sánchez & Travieso-Bello, 2021).

The lack of clear regional strategies from a holistic vision to promote coffee production, the reduction or disappearance of governing bodies on the subject, the granting of unharmonized subsidies, and the stagnation of the economic condition of producers, add to the previous aspects and can lead to ineffective or limited adaptation to climate change (Benítez-García *et al*., 2015; Eakin *et al*., 2004). Therefore, actions should be designed and implemented to encourage the adaptation of producers based on local knowledge, and research and extension programs should be strengthened, as well as the socialization of existing information (Nelson *et al*., 2009). In addition, and given that coffee production does not occur in a social vacuum, but rather is the result of a process of interaction with nature, the ability of communities to strengthen their social infrastructure, to make agreements and decisions, is also a strategic aspect to enhance to cope with climatic disturbances (Altieri & Nicholl, 2008 ; Altieri & Nicholls, 2013).

## Conclusions and recommendations

According to the present study, it was possible to identify that coffee growers in Puebla state are already developing actions to address climate change; however, the level of response is dissimilar in the various macroregions of the state. In general, it is necessary to reinforce activities such as the use of living barriers, the application of biological controls for the management of pests that afflict the different regions, the recovery of shade, in the crops and the strengthening of value addition, which as part of the explicit knowledge expressed in this study and the literature reviewed, have proven to be effective actions to improve coffee production in a changing climatic environment.

Examples of the development of own brands are present in 3 of the 4 macroregions of the study except for Serdán Valley, however, only in one of these there are certifications associated with aspects directly linked to climate, as is the case of the carbon neutral certification identified in the Sierra Norte. On the other hand, in this same macroregion, unique adaptation actions are being developed in Puebla, such as the use of stakes to prevent the negative effects of intense gusts of wind and cooperation with research organizations and development agencies.

Hence, the following actions are recommended to improve the perception and practices of adaptation to climate change of coffee growers in the Puebla state:

Regarding the actions that coffee growers could develop in their crops, is recommended:

- Increase management under agroforestry systems in coffee crops to regulate the microclimate and buffer the negative effects of heavy rains.
- Modify the calendar of activities associated with the crop to respond to changes in production cycles.
- Implement the use of stakes to cope with winds.
- Implement the use of mulching to retain moisture and control erosion.

Regarding actions that could be promoted as an exchange of experiences between farms in the different macroregions:

- Exchange of knowledge from producer to producer regarding the benefits in the face of climate change of maintaining agroforestry systems from the Sierra Negra macroregion to the other producing areas of Puebla.
- Socialize existing experiences of organic and carbon-neutral certification from the Sierra Norte macroregion to the rest of the state.
- Knowledge exchange among producers regarding the challenges of including tourism and beekeeping as forms of productive diversification associated with coffee production, from the Sierra Norte and Northeastern Sierra macroregions to the rest of the state.

*Regarding the actions that could be implemented by decision-makers in the territory/landscape, it is recommended:*

- Strengthen the recognition of the value of biodiversity in relation to coffee producers to favor its maintenance and the benefits it generates for coffee growing.
- Promote complementary economic alternatives for producers that are based on the preservation of forests (for example, the establishment of Wildlife Management Units and Areas Voluntarily Destined for Conservation).
- Encourage the management of agroforestry systems that have helped mitigate the effects of Climate Change and favor the permanence of Ecosystem Services.

## Authors contribution

Conceptualization of the work, author 1, author 2; methodology development, author 1, author 2.; experimental validation, author 1, author 2.; analysis of results, author 1, author 2.; data management, author 1, author 2.; manuscript writing and preparation, author 1, author 2.; drafting, revising and editing, author 1, author 2.; project manager, author 1; fund acquisition, author 1. All authors of this manuscript have read and accepted the published version of this manuscript.

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## Statement of informed consent

Informed consent was obtained from all subjects involved in the study.

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## Conflict of interest

The authors declare that they have no conflicts of interest.

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