Atmósfera 40, 35-73 (2026)
https://doi.org/10.20937/ATM.53497

Climate change adaptation measures in a highly productive maize area (Mexico): Are practices aligned with science?

Mónica TOLEDO GARCÍA[1], Cecilia CONDE[2], Patricia GALLARDO ARIAS[3] and Carolina URETA[1,4,5]*

[1] *Posgrado en Ciencias de la Sostenibilidad. Departamento de Ciencias Atmosféricas, Instituto de Ciencias de la Atmósfera y Cambio Climático, Universidad Nacional Autónoma de México, México.*
[2] *Departamento de Ciencias Atmosféricas, Instituto de Ciencias de la Atmósfera y Cambio Climático, Universidad Nacional Autónoma de México, Circuito de la Investigación Científica s/n, Ciudad Universitaria, 04510 Ciudad de México, México.*
[3] *Dirección de Etnohistoria, Instituto Nacional de Antropología e Historia, Victoria 110, Chimalistac, Coyoacán, 01070 Ciudad de México, México.*
[4] *Investigadora por México, Secretaría de Ciencia, Humanidades, Tecnología e Innovación, Av. Insurgentes Sur 1582, Col. Crédito Constructor, 03940 Ciudad de México, México.*
[5] *Laboratorio Nacional de la Biología del Cambio Climático, Ciudad de México, México.*
*Corresponding author; email: carolinaus@atmosfera.unam.mx

Received: May 23, 2025; Accepted: October 13, 2025

RESUMEN

Como centro de origen y diversificación del maíz, México depende en gran medida de su producción, por lo que los impactos del cambio climático representan un riesgo significativo para la seguridad alimentaria. Para evaluar las perspectivas de los agricultores sobre el cambio climático y la alineación entre las medidas de adaptación implementadas, las propuestas desde la ciencia y las políticas públicas, realizamos 30 entrevistas semiestructuradas en una zona altamente productiva de México (entre agosto de 2022 y enero de 2023), donde coexisten la agricultura de riego y la de temporal (La Piedad). También revisamos la literatura científica y todas las políticas aplicables al área. Los agricultores reconocen el cambio climático como una amenaza importante e implementan medidas de forma empírica. Lo que se recomienda desde la ciencia o la política pública rara vez se aplica. En cambio, se ven obligados a rentar sus tierras, lo que representa una mala adaptación que los aleja de su identidad. La estrategia más común para conservar la humedad es dejar los residuos de cosecha, pero requiere apoyo técnico para evitar plagas. El 87 % de los agricultores no tiene acceso a información climática confiable ni a alertas tempranas sobre eventos extremos como La Niña. Esta diferencia entre lo que se recomienda desde la ciencia y la política y las prácticas agrícolas, evidencia la falta de implementación de medidas basadas en evidencia científica.

ABSTRACT

As the center of origin and diversification of maize, Mexico heavily depends on its production, making climate change a significant risk to food security. Implementing adaptive measures is essential to mitigate production losses. To evaluate farmers' perspectives on climate change and the alignment between adaptive measures in practice, those proposed in scientific literature, and public policy, we conducted 30 semi-structured interviews in a highly productive area in Mexico (between August 2022 and January 2023) where rainfed and irrigated agriculture coexist (La Piedad). We then reviewed the scientific literature and analyzed all applicable policy instruments for the area. Our findings indicate that farmers recognize climate change as a significant threat and implement adaptive measures empirically. While scientific literature and public policies promote specific strategies, these are rarely implemented. Instead, practices such as leasing land to agave producers (which is not a good climate change adaptation measure) are becoming more common. The most widespread practice to retain moisture is leaving crop residues, though some farmers have abandoned it due to a lack of technical support. Despite acknowledging climate change, 87% of farmers lack access to reliable climate information or early warnings for extreme events like La Niña. This difference between practices highlights the need for vigorous efforts to bridge scientific recommendations with on-field practices. In conclusion, while farmers perceive climate change as a risk, effective implementation of science-based adaptation measures requires substantial support through policy and technical assistance.

Keywords: food security, center of origin and diversification, climate-smart agriculture.

1. Introduction

Agriculture is highly vulnerable to climate change, as it relies directly on environmental conditions to achieve specific production levels and quality standards (FAO, 2016). According to the Intergovernmental Panel on Climate Change (IPCC), rising temperatures will adversely affect food production (FAO, 2016; IPCC, 2022a). Mexico, traditionally an agrarian country—possessing approximately 30 million hectares of potentially cultivable land (Arreguín-Cortés et al., 2015)—can face food insecurity due to changes in climate (FAO-SAGARPA, 2012; IPCC, 2022a) and important economic losses given that primary sector activities, such as agriculture, contribute to ~4% of the national gross domestic product (World Bank, 2024). The most important cultivar in Mexico is maize, economically, socially, and culturally (Soto-Aguilar, 2004; Bellon et al., 2021). Mexico is the center of origin and diversification of maize, a diversity that is strategically vital for mitigating potential climate change impacts in Mexico, and globally, it is the cornerstone of natural and artificial selection (Bellon et al., 2011; Mercer et al., 2012). Until now, climate change studies related to Mexican maize have mainly been focused on impacts and risk assessments (Conde et al., 1997, 2006; Monterroso et al., 2011; Ureta et al., 2012, 2020; Nelson et al., 2014; Murray-Tortarolo et al., 2018; Arce-Romero et al., 2020; Haro et al., 2021), but the transition to studies about adaptation measures is needed. Adaptation measures in the context of climate change are initiatives aimed at reducing the risk to natural and human systems from the actual or expected effects of climate change (IPCC, 2022a).

In Mexico, between 2010 and 2022, the harvested maize agricultural area covered 77 168 463 hectares. Of this area, 20% corresponds to irrigated agriculture, while 80% is rainfed (SIAP, 2025). Rainfed agriculture is widespread and plays a critical role in conserving in situ agrobiodiversity (Govaerts et al., 2019). Most of this rainfed area has maize as the subsistence crop (Conde et al., 2006), helping farmers achieve food self-sufficiency while providing food security to their communities through surplus sales (Cruz-Herrera et al., 2021).

Conversely, the cultivated area under irrigation is significantly smaller than that of rainfed agriculture, but its productivity, expressed in $/ha, is 300% higher (Arreguín et al., 2015). The majority of maize production in Mexico comes from a few municipalities with extensive areas and high yields on an international scale (Govaerts et al., 2019). However, even with irrigation, climate change remains a significant threat to maize (Arreguín et al., 2015; Ureta et al., 2020). It is evident that both forms of agriculture are very important for the country's food security, not only for the conservation of agrobiodiversity but also to maintain and increase production.

One of the geographic regions with the highest irrigated yields, which also has a rainfed agricultural area, is the Bajío region in Mexico. In this region, the irrigation district called La Piedad (087) (CONAGUA, 2025) (Fig. 1) spans across two states, Michoacán and Guanajuato, both of which belong to the group of states with the greatest maize production in the country, along with Sinaloa, Jalisco, and the State of Mexico (SIAP, 2025).

Within this module, there are both internationally competitive irrigated agriculture producers (yielding up to 19 t/ha) and rainfed farmers with smaller plots (< 5 ha). Although races such as Celaya, Zamorano Amarillo, Pepitilla, Tuxpeño, and Elotes Occidentales have been documented in the municipalities that make up La Piedad and its surrounding areas (CONABIO, 2017), it has been observed that most farmers in the study site—both irrigated and rainfed—grow mostly hybrid varieties for their commercialization (field observation). The module operates under a decree and is managed by users through civil associations, as most modules do. Users in each module that have access to irrigation pay fees for maintenance,

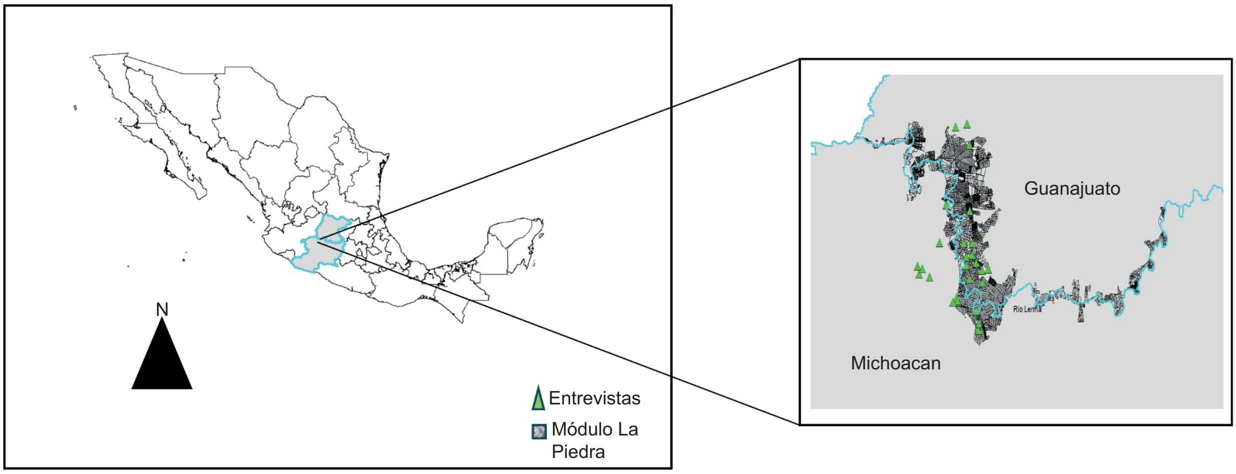

Fig. 1. Study site.

electricity, infrastructure, machinery, and irrigation water from the Lerma-Chapala basin to their plots. In contrast, rainfed plots are located away from irrigation channels and lack infrastructure to convey water from the river. This district frequently experiences droughts and flooding events (CENAPRED, 2023), which are expected to become more frequent and intense due to climate change (IPCC, 2022b).

Consequently, effective adaptation measures are needed in areas such as La Piedad. This locality is a good case study because different types of farmers coexist, each with distinct needs. Empirically, successful adaptation measures have been implemented in some areas worldwide, significantly reducing climate-related damage (IPCC, 2022b). We also know that scientific information suggests specific adaptation measures (A), and that the Mexican government has instruments to promote them for agricultural systems (Tables I and SI [in the supplementary material]). However, it remains unknown whether scientific knowledge aligns with policy instruments, and whether these correspond to farmers' practices in the field.

Adaptation solutions need to consider the unique and complex context of each region, and, consequently, people need to be involved in co-producing knowledge (New et al., 2022).

Also, given the importance of gender in the context of climate change—as women and girls are known to be more vulnerable to its impacts—we included this topic in our interviews (Aguilar-Revelo, 2021). This pioneer study aims to (1) document farmers' perception of climate change and measures currently being implemented in the study area; and (2) compare them with those mentioned in scientific literature and public policy instruments. Increasing understanding of people's needs for coping with climate change can help align these needs with governmental efforts.

2. Materials and methods

2.1 Interviews

A qualitative research study was conducted through semi-structured interviews with farmers from the La Piedad irrigation module between August 2022 and January 2023. The objective was to gather information on farmers' perceptions of climate change and extreme weather events linked to phenomena such as El Niño and La Niña, and the adaptation measures they are implementing to address these events, which are already affecting their crops.

Four categories and 21 interview questions were defined: (1) climate and agriculture, (2) adaptation and agroecological strategies, (3) risk, vulnerability, and support provided, and (4) gender (Table SIIa-e). The interviews were designed based on the methodology of Bogdan and Taylor (1987) and Díaz-Bravo (2013), who recommend creating a guide with key topics and categories, allowing interviewees to describe their experiences in detail through open-ended questions and dialogue while seeking to address the research question. Questions considered the importance

Table I. Comparison between adaptative measures in the agricultural sector of La Piedad*.

Adaptation measures to climate change mentioned in the scientific literature	Political instruments (70%)	La Piedad (37%)
Improvement of drought-tolerant native seeds and their promotion	x	
Use of improved (hybrid) seeds for higher yields		x
Modernization of infrastructure for efficient irrigation and water conservation	x	x
Technological innovation for precision agriculture (software programs, climate models, scenario design)	x	
Agroecological strategies (use of microorganisms to optimize fertilizer, integrated pest management)	x	x
Climate-smart agriculture (CSA)		
Strengthening farmers' technical capacities (training)	x	
Projects for fair trade, value chains, export markets, and business models	x	
Fertilization techniques for increased yields	x	x
Adjusting planting dates based on updated climate patterns		x
Rituals of petition and gratitude		x
Using shorter-cycle seeds		x
Soil improvement strategies	x	x
Crop rotation and diversification, polyculture, cover crops	x	
Decarbonization of the agricultural sector	x	
Climatic information services	x	
Perception studies and methods of farmer participation and linkage with academia and government	x	
Agroforestry	x	
Design of public policies for adaptation in the agricultural sector	x	
Mulching (mulch practices)		
Rainwater harvesting	x	
Biotechnology and the use of genetically modified varieties		
Gender equality mesures	x	

*Reported coincidence between adaptation measures to climate change mentioned by the scientific literature for the agricultural sector, political instruments, and those implemented in the fields. Political instruments align with the scientific literature at about 70%, while implementation in fields aligns at 37%.

of the distinctions between weather and climate concepts. With these semi-structured interviews, we got both quantitative and qualitative information.

The identification and selection of key informants were conducted in the field by seeking out individuals and using a list of communities and ejidos (communal land) provided by the irrigation module's administrative office. Interviews were conducted with at least 30 individuals (García-García et al., 2013), covering 12 communities within the irrigation module. In quantitative research, a minimum sample size of 30 is generally recommended to achieve adequate statistical power (Ellis, 2010; Cohen et al., 2013). In contrast, qualitative studies using interviews rely on the concept of saturation, which occurs when no new information or themes emerge (Guest et al., 2006; Cobern and Adams, 2020). Saturation has been suggested to occur with as few as 12 participants in homogeneous populations, or around 30 in more heterogeneous populations, such as ours (Guest et al., 2006; Cobern and Adams, 2020). More recent research indicates that it depends strongly on the study type and objective, but proposes numbers between five and 30 (Ahmed, 2025).

The experimental design helped us ensure representation across the diversity of producers (including large internationally competitive producers, small rainfed producers, and diversity in terms of age and gender). We first divided communities/ejidos into deciles based on cultivated area. Three communities/ejidos were randomly selected from each decile, and, through personal communication with the module's administrative office, these initial selections were further filtered to include communities that were more accessible, less prone to security issues, and with a higher number of female producers. The interviewed individuals provided verbal consent for the interview in the field and written consent. Only one individual declined to be recorded; the rest accepted, and we have the original recordings (link to audio files). Upon completion of the interviews, they were transcribed to create a comprehensive database of responses (following Bodgan and Taylor, 1987; Coffey and Atkinson, 2003) (Table SIIa-e).

2.2 Scientific literature review

A review of scientific articles was conducted using search engines such as Scopus, Google Scholar, and Springer Science. Chapters from books, articles, and agricultural journals were also examined. Information on maize cultivation and climate change adaptation in agriculture was selected (Table SI). Measures and strategies for climate change adaptation implemented in other maize cultivation areas worldwide were documented to compare them with national and state-level public policies and the practices observed in our study area (Tables I and II). This information was then compiled into a database, where the adaptation measures found in scientific literature were synthesized and categorized into 24 categories. Additionally, a review of public policy instruments was conducted to understand the adaptation strategies promoted by the government (Table SIIIa-d). Adaptation measures taken by maize producers, those implemented in other regions of Mexico and the world, and those advocated in regional public policies were recorded and compared.

3. Results

Farmers at the study site perceive climate change and have taken adaptation measures empirically,

Table II. Adaptative measures to climate change applied by La Piedad farmers.

Measure	Irrigation	Rainfed
Emergency irrigation	x	
Leaving crop residue from the previous harvest	x	x
Choosing moisture-tolerant seed varieties	x	x
Agricultural insurance	x	
Applying manure to the soil		x
Planting shorter-cycle hybrid crops	x	x
Leaving rocks from the hill in the field	x	x
Changing planting dates	x	x
Letting the land rest in winter	x	x
Ceremonial rituals for requesting rain	x	x
Buying water from private wells	x	
Vertical tillage (loosening the soil)	x	x
Comprehensive and buried fertility	x	x
Use of native seeds for drought tolerance		x
Changing crops (sorghum and agave)	x	x
Making tortillas and feeding cattle with sorghum		x
Reseed when seedlings are lost or do not germinate	x	x
Dams for flooding due to river overflow	x	
Parcel leveling	x	
Drainage	x	x
Renting land to tequila companies for agave cultivation		x

which have not always resulted in positive outcomes. Further, there is quite a significant alignment between scientific knowledge about adaptation measures in agriculture in the context of climate change and the political instruments evaluated. However, most of these measures are not being implemented in the field. Both rainfed and irrigated farmers mentioned the need for agricultural insurance, fair prices for the sale of their crops, access to climate information, and training with technical support to implement proper adaptation strategies (Table SIIa-e).

3.1 Maize farmers' demographic characteristics and their perceptions about climate

Most of the interviewed farmers (70%) had access to irrigation water from Río Lerma, while 30% owned rainfed parcels only, and 17% cultivated agricultural plots using both irrigation and rainfed systems (Table SIIa). Of the individuals interviewed, 63% were men and 37% were women; ages ranged from 26 to 90 years, with 67% being over 50 years old.

Agricultural activities in the region are primarily the responsibility of men in families, except in the community of El Triunfo, Michoacán, where, due to migration, these activities are predominantly carried out by women who stayed behind. Of the 11women interviewed engaged in agriculture, five mentioned that they perceive limitations in their agricultural tasks due to gender discrimination. Notably, 55% of the interviewed women do not own the lands they work on, despite being responsible for all agricultural activities, including weeding, pesticide application, administration, and hiring laborers (Table SIIe).

Almost all interviewees (97%) reported that they had observed changes in the weather over the past 10-30 years; the most noticeable change was an increase in temperature, particularly in the last 10-15 years (link to audio files). In the cultivated fields, the temperature rise has led to thermal stress on plants and, consequently, a reduction on crop yields. The interviewees also mentioned that this temperature increase has led to higher populations of certain maize pests, such as red spider mites and corn earworms. Overall, they noted that the region has experienced prolonged drought and erratic rainfall, making it difficult to determine optimal planting dates. Drought was identified as the most feared meteorological event (Table SIId).

Regarding access to climate information, 87% of the farmers reported not having access to this type of information during each agricultural cycle, and 97% reported not receiving early warnings of extreme weather events. Only those with internet access check weather forecasts, such as information from the National Meteorological Service of the National Water Commission. People over 50 years old report difficulty using technology to obtain weather information. Most farmers expressed a lack of confidence in the climatic forecasts they have easy access to. Occasionally, climate information for each cycle is provided by hybrid seed and agricultural input companies through technical conferences for both irrigated and rainfed farmers (Table SII).

In terms of traditional knowledge, farmers mentioned that in the past they used observations of the moon and clouds, and their movements over nearby hills. They relied on "cabañuelas" (early rains of the year) or the "canícula" (midsummer drought) to project whether there would be a good rainy season. They also used the Galván calendar, an almanac published in Mexico since 1826, which contains saints' days, lunar phases, astronomical events, and recommended maize planting dates. Another way to determine planting time was to use the specific dates of patron saint celebrations or festivals, which were traditionally associated with certain weather patterns. For example, the feast of Santiago Apóstol on July 25th was associated with guaranteed heavy rainfall. They mentioned that due to changes in rainfall patterns, they can no longer plan plantings as they did before (link to audio files).

All farmers mentioned that both traditional techniques for weather forecasting and maize production no longer work for them. They believe that the climate has changed significantly and is now unpredictable. As a result, they expressed the need for new agricultural techniques that ensure good yields under high temperatures and extended drought (link to audio files).

Regarding extreme weather events that have impacted the area, interviewees mentioned the years 1957 to 2022 as critical (Fig. 2). Some individuals did not recall these years precisely or how they coped with them. Comparing critical years with El Niño-Southern Oscillation (ENSO) variability, a clear relationship was found with the negative phase (La Niña) and the presence of extreme precipitation events (Fig. 2).

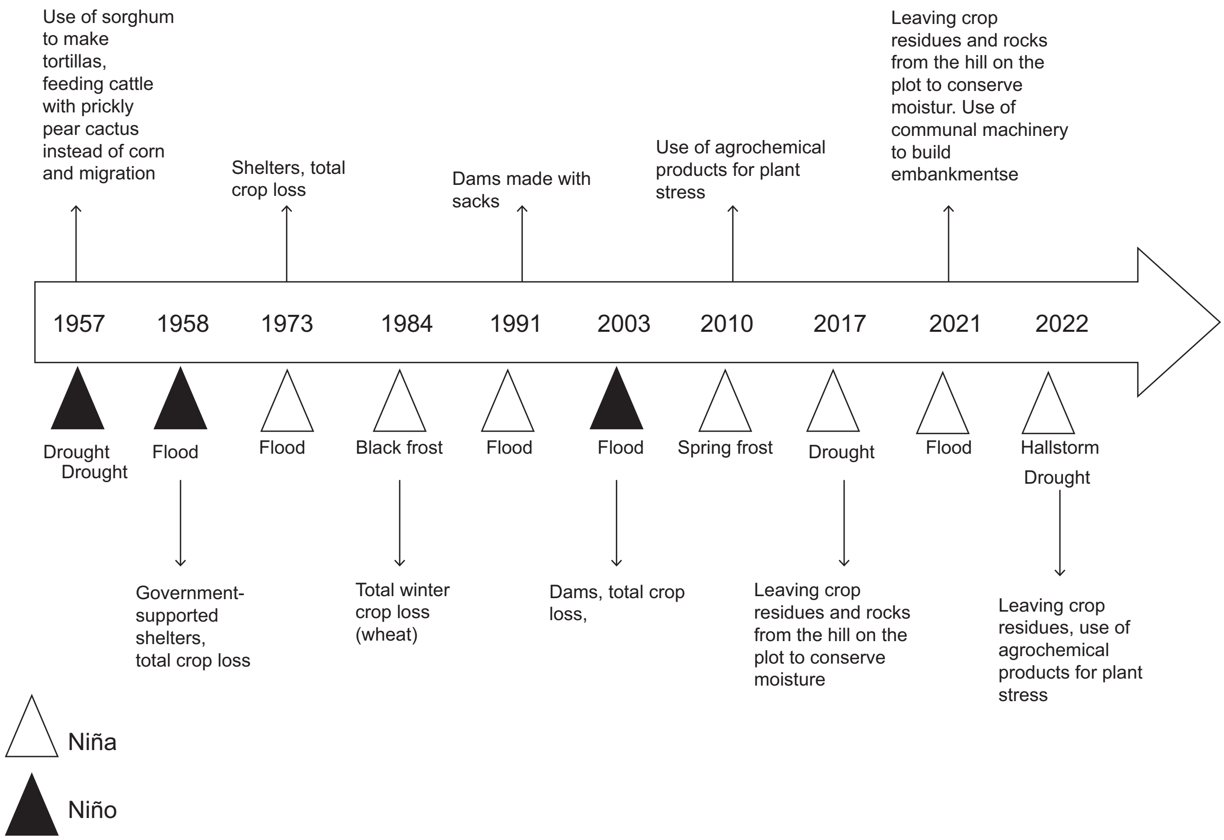

Fig. 2. History of extreme meteorological events related to ENSO that were remembered by interviewed farmers.

3.2 Adaptation measures implemented in the field

Farmers are already implementing measures to adapt to climate change, with the most commonly used measures aimed at coping with drought. One of the traditional practices for conserving soil moisture that farmers continue to use is the maintenance and burial of agricultural residues (crop residues) (Table II). Irrigation is used partially or fully by 70% of the farmers interviewed, and although they do not consider it a climate change adaptation measure, it is indeed part of the solution to water scarcity.

The implementation of agroecological measures has been reported in scientific literature as optimal for increasing agroecosystem resilience and reducing vulnerability (Nicholls et al., 2015; FAO, 2023). However, most farmers interviewed (70%) do not even recognize the concept of agroecology (link to audio files). Some farmers mentioned applying certain measures, including (a) maintaining agricultural residues (43%), (b) using compost and increasing biodiversity in their plots (3%), and (c) reclaiming mesquite groves/reforestation (3%) (Table SIIc). Another measure they are implementing, not traditionally promoted as agroecological techniques, is using seeds with different life cycle durations: short (early) and long (late). Finally, although farmers did not recognize growing native maize as an adaptation strategy, those who cultivate it on a small portion of their fields for self-consumption (field observation) reported being aware that these varieties are more drought-resistant (link to audio files).

All the people interviewed mentioned that they are open to changing some practices to adapt to climate change conditions, but they also commented that they need proper training and technical assistance throughout implementation, for example, in managing residues (Table SII). Without technical support and guidance, some issues arising from moisture, such as increased pest infestations and plant damage, appear, and farmers do not know what to do. Farmers who use agroecological practices face challenges that discourage them from continuing without technical support (Table SIIb, c).

None of the interviewed individuals feels capable of adapting to drought or any other extreme weather event. At the same time, almost all of them recognize climate factors (drought, abnormal rainfall) as the highest risk to their agricultural activities. Another significant percentage of interviewees mentioned that they need fair prices for their crops (33%) (Table SIId). Without fair prices, farmers may rent their plots to tequila companies for agave cultivation.

Most farmers interviewed do not have agricultural insurance because they find the cost too high ($2000-4100 MXN per hectare (~$100-200 USD per hectare) and do not trust insurers (link to audio files). Rainfed farmers, who are the most dependent on climate, do not even have the option of insurance because the service is not provided to them.

3.3 Adaptation measures to climate change reported in scientific literature and promoted by public policies instruments

A total of 42 scientific articles published from 2008 to 2022 from 15 different countries were reviewed. The literature on maize is primarily focused on Africa and Mexico (Table SI). In Africa, the countries with more studies are Kenya, Ethiopia, and Nigeria. The adaptation measures to climate change identified in this review were synthesized and classified into 24 adaptive measures encompassing various recommendations (Table SIIa-e). The most frequently mentioned measure is the technification of infrastructure for efficient irrigation and water conservation (Fig. 3).

It is important to highlight that in the study area a set of measures is applied, rather than a single one. Therefore, it is recommended that the design and implementation of adaptation measures integrate actions across multiple dimensions, including technical (agronomic), economic, and governance aspects.

At a public political level, a review of 18 federal and state-level instruments focused on climate change adaptation of the agricultural sector was also conducted (Table SIII a-d). It included political instruments from the states of Guanajuato, Michoacán, and at a national scale. It was confirmed that the actions described in the public policy instruments align with the adaptation measures described in scientific literature but have limited alignment with the measures being implemented in the study area (Table I).

There are federal programs that primarily target small-scale producers, such as the Ley de Desarrollo Rural Sustentable (Sustainable Rural Development Law [SAGARPA, 2001]), and various actions and programs by the Secretaría de Agricultura y Desarrollo Rural (Secretariat of Agriculture and Rural Development [SADER, 2023]). In the case of Guanajuato, policies are geared toward high-yield farmers (SDAyR, 2023).

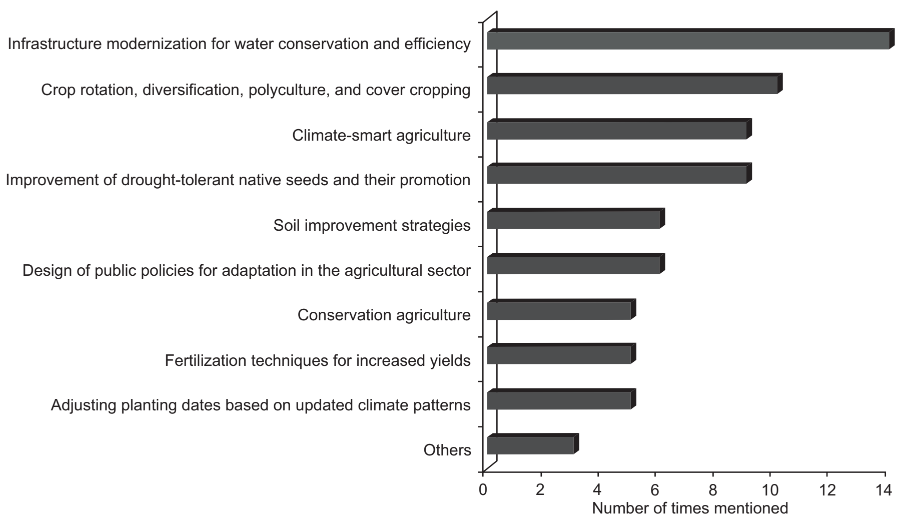

Fig. 3. Most mentioned adaptation strategies found in the scientific literature. Forty-two scientific papers were reviewed from different geographic areas across the world. The keywords used were climate change adaptation, maize, and agriculture.

For Michoacán, the only public policy instrument related to climate change adaptation is directed at both types of producers (SADER Michoacán, 2023). So far, the Plan Estratégico de Cambio Climático del Sector Agroalimentario (Strategic Plan for Climate Change in the Agri-food Sector, PLECCA) is the most important national-level public policy instrument for agriculture and climate change, but it was published in 2022 and has not yet been implemented (SADER, 2022). This instrument includes specific actions to address climate change in the agricultural sector, including deadlines and responsible entities.

There are various instruments that address different aspects within the agricultural sector. For example, the Programa Nacional de Semillas (National Seed Program) stimulates research, innovation, production, and certification of high-quality seeds. This program is expected to serve as a foundation for the improvement and promotion of national seeds that can help farmers achieve high yields, enabling them to market their products and sustain their livelihoods without the excessive cost of purchasing seeds from multinational companies (SADER, 2020).

One very important action mentioned in the Ley General de Cambio Climático (General Law on Climate Change) is the improvement of early warning systems for extreme weather events. However, in the interviews, farmers mentioned that they do not have access to early warning systems or climate information either before or during the agricultural cycle.

4. Discussion

All the interviewed farmers stated they do not feel capable of adapting to a changing climate, despite already implementing some measures (Table SIId). This study gave us insight into farmers' perceptions of climate change, what they are doing on their fields to address these changes, and how this compares with the climatic knowledge generated by science and promoted by public institutions.

4.1 Adaptation measures to climate change in the study area

One of the adaptation measures in the field is the rental of land to tequila producers for agave cultivation (Tables II and SII; link to audio files). This measure leads to farmers feeling sadness, nostalgia, and a loss of identity, as they no longer perceive the land as their own: "It makes me sad because I feel like it's no longer my land; we don't even visit the plot anymore. I wish the climate would improve so I could grow maize again because that's what my father taught me" (Martha Pérez, 52 years old).

Mexican farmers, as in other parts of the world, need their cultural identity to sustain their existence (Table SII). Climate change in these agricultural areas is not only affecting yields and production—and the corresponding consequences for food security and sovereignty—but also culture (Adger et al., 2013). Further, measures that are considered useful for enhancing agroecosystem resilience according to scientific literature, such as incorporating compost or using heirloom seeds, are not regarded as good measures by the local farmers. They believe these practices attract pests and result in low yields. Both land rental for agave cultivation and the use of compost or native seeds can be considered as maladaptations for the local farmers (IPCC, 2022a). Maladaptation refers to measures that can help adapt to climate change but carry the risk of adverse outcomes in other aspects. In another context, in Spain, there was a maladaptation in maize cultivation, as a large-scale irrigation adaptation project led small and medium-sized farmers to sell or rent their land to those who could afford the project's inputs. This adaptation measure increased inequality, reduced crop diversity, and now a private company covers the costs of large-scale irrigation (IPCC, 2022a). To avoid these maladaptations at our study site, La Piedad, and in other municipalities, it is important to support farmers who are open to modifying certain practices, provided there is technical and scientific support and that these changes do not result in significant economic losses or counterproductive risks.

One of the most commonly used and recommended adaptation measures to climate change in international scientific literature is modernizing irrigation for more efficient water use (Fig. 3). Mexico is facing an important hydric crisis on over 60% of its territory (CONAGUA, 2023, 2024), similar to other regions across the world (Carvalho, 2019). Also, the hydric extraction in the studied area strongly exceeds natural recharge (Cruz-Ayala and Megdal, 2020). According to our interviews, the weather event that farmers fear the most is drought (Table SIIb), and the study area is represented by municipalities with a high number of disaster declarations due to extreme weather events (CENAPRED, 2023): “There is something left after the water, but after the drought, nothing remains” (Germán García, 58 years old); “It is better to die drowned than to die dry” (Margarita Barrón, 80 years old). This hydric crisis complicates the viability of some traditional practices that are also being recommended in the scientific literature (Table I).

Measures to address water scarcity implemented in the field focus on preserving soil moisture or securing water by purchasing it, building embankments, or replanting. Still, these measures are emergency measures and are unsatisfactory to farmers due to their associated high costs. There is a strong need for well-planned infrastructure investments to improve water storage and distribution, including the construction of dams and efficient irrigation systems, as well as the modernization of supply networks to reduce leakage losses. Efforts have been made to seek assistance from the state government to build a pump station that facilitates the extraction of river water through channel piping, but interviews indicate these measures have not been sufficient. Finally, educating the population on responsible water use is also an essential aspect of resource management (Attari, 2014).

Today, we know that many of the claims made by farmers have been to preserve not only their land but also the natural resources it holds. In the farming world, the land, its resources, and its inhabitants are seen as a whole. The environment possesses for farmers a religious and therefore sacred quality: based on territorial characteristics, people connect with their relatives and ancestors, with their community, and reproduce what we call a cultural tradition (Arrioja, 2011). In La Piedad, small stakeholders have their own land, but water resources are inefficiently and inequitably distributed. Based on field observations, rainfed farmers are excluded from efficient irrigation measures because their plots are too far from irrigation canals. This result implies that individuals in this group, especially women and the elderly, should be considered a priority for support when implementing government programs related to water resources.

The La Niña phenomenon has the greatest impact in the study area, as extreme weather events cause disasters (Fig. 2). Providing climate information as an adaptation measure and alerting farmers specifically in La Niña years is crucial. This data can also serve as a basis for future climatological research in the area and foster collaboration in co-producing knowledge projects between the government and academia to implement early warnings.

The use of improved seeds with late or short cycles is also mentioned in scientific literature as an adaptation measure. Responses from farmers emphasize that both types of cycles have advantages and disadvantages. A longer cycle is not favorable when irrigation is unavailable. On the other hand, a shorter cycle, also known as an early cycle, reduces yield, making it unfavorable in terms of production. In this context, scientific literature has long suggested improving and prioritizing the promotion of native and resilient seeds (Fig. 3) (Bellon et al., 2011; Mercer et al., 2012; Hellin et al., 2014). However, farmers in the study area view this practice negatively, stating that there is no market for native seeds that yield poorly. They are primarily used for subsistence in a few cases in a small portion of rainfed plots. However, they acknowledge that native varieties are more drought-resistant than hybrids, which is one of their greatest climatic concerns (Table SIIb, d). Also, there are options to improve yields in native maize, for example, through participatory improvement (Gómez, 2019). In other regions, participatory improvement programs have been implemented to maintain the characteristics of native seeds preferred by farmers, including their resistance to adverse weather conditions, while using scientific support to enhance yields through genetic improvement (Gómez, 2019). Such programs can be promoted as a means to increase agrobiodiversity and reduce dependence on seeds from transnational companies, given that in this area maize is cultivated primarily for commercial purposes and rarely for subsistence. Furthermore, it is necessary to expand the market for native maize in the area or to establish stronger connections between producers and consumers in regions where native maize could be more valued.

Agroecological measures mentioned in scientific literature, such as integrated pest management, soil conservation, the use of microorganisms, organic fertilizers, agroforestry, mulching, and crop rotation, can be good measures for the study area. However, despite farmers’ awareness of these measures and their implementation through campaigns and demonstration plots (Govaerts et al., 2019), they are afraid of implementing them due to a lack of technical and economic support (Table SII; link to audio files in the supplementary material). We recommend government-funded programs to implement demonstration plots with long-term technical and scientific support, monitoring, and evaluation. With these conditions in place, it is easier to assist farmers in their transition.

In the review of scientific literature, we observed that the adaptation approach does not focus on a single measure but rather on a combination of measures across different domains that can lead to successful climate change adaptation (Kirina et al., 2022). This set of measures includes training (farmer schools), market analysis and export, value chains, as well as technical agricultural measures like climate-smart agriculture and governance projects (Table SIII).

We noticed that public policy instruments align with adaptation measures promoted in other countries (Table I). However, these practices are not being implemented in the field. This situation may result from a lack of access to information, limited promotion of adaptation measures, and, primarily, a lack of execution and allocated budgets for implementation. The study of the existing challenges to bridge scientific information with farmers' practices through political instruments needs further research. We suggest government funding to promote and implement measures ensuring long-term technical support.

Despite the existence of national and state subsidies (SADER, 2023; SDAyR 2023), there is a lack of climate change adaptation-focused measures in the area. Federal subsidies primarily target small-scale farmers, but we believe there should also be budget allocations for medium and large-scale farmers, as the states with the highest maize production are also the states facing the most significant challenges due to organized crime: Sinaloa, Jalisco, Michoacán, and Guanajuato (IEP, 2023). Therefore, large-scale farmers whose crops are not profitable may resort to adaptation measures that could have consequences for national security. Climate change has a multidimensional impact, affecting not only yields and production but also culture, traditions, and security. Despite the existence of public policy instruments emphasizing the protection of traditional knowledge and the exchange of experiences (SADER, 2020, 2022), culture and traditions are being lost in the field.

4.2 Perceptions, vulnerability, and climate change

In the study area, the identity and cultural heritage of the local population are closely linked to maize production. However, traditional knowledge and practices have been affected by climate change and the high production costs of unprofitable crops. This particularly affects rainfed farmers: "As rainfed farmers, each season we go relying solely on God's will" (Carlos Herrera, 79 years old). Farmers in the region do not express an interest in returning to past agricultural practices, even if they are more agroecological, as they associate these practices with poverty, low crop yields, and intensive physical work without machinery Table SIIb-d; link to audio files); "We used to wear cotton shorts, we didn't go to school, we were very poor, and farming kept us in the fields from sunrise to sunset" (Carlos Herrera Vargas, 79 years old).

Among the interviewed individuals, three vulnerable groups were identified: women, farmers aged 50 or older, and rainfed farmers. Women farmers, in particular, expressed a desire to be actively involved in all aspects of farming but acknowledged the limitations they face due to their gender. It is worth noting that nearly half of the interviewed women recognized gender discrimination in their agricultural roles. Some women may not perceive this discrimination due to societal norms or fear of repercussions, while others, in certain communities, have taken on agricultural responsibilities due to widowhood, lack of male relatives, or their husbands' migration to the United States. However, only 45% of these women own land. These findings underscore the importance of incorporating a gender perspective into climate change adaptation measures, considering the additional unpaid labor and responsibilities women bear. It also highlights the need for gender-sensitive training for women farmers, as well as government and independent agricultural agencies that provide guidance on agricultural practices. Gender vulnerability to climate change has already been recognized by the IPCC (IPCC, 2022a) and the Sustainable Development Goals (UN, 2023).

Farmers aged 50 and older also constitute a more vulnerable group because they are hesitant to adopt new farming methods and may struggle to adopt technology (Table SIIa-d). In contrast, younger farmers express enthusiasm for innovation and adopting new strategies to adapt to a changing climate. Both younger and older farmers exhibit dedication and passion for agriculture, rooted in their cultural identity and the historical significance of maize in their communities. Maize has been considered a sacred plant representing Mexican culture since pre-Hispanic times (SAGARPA, 2017).

A third vulnerable group comprises rainfed farmers, who are more dependent on rainfall and lack access to agricultural insurance options (Murray-Tortarolo et al., 2018). According to the scientific literature, efficient irrigation is among the most commonly recommended strategies for climate change adaptation. However, rainfed farmers lack access to irrigation and rely solely on rainfall for maize production. This lack of access to both water resources and insurance makes them particularly vulnerable. Thus, a woman with rainfed land may be more vulnerable than a woman who belongs to only one vulnerable group. This underscores the concept of multidimensional vulnerability, as described by the IPCC, in which climate variability is interconnected with social, economic, age, and gender-related factors (IPCC, 2022a). To take into account all social, economic, and environmental aspects of each locality and ensure the efficient implementation of climate change adaptation measures, there is a need for co-producing knowledge (New et al., 2022).

5. Conclusions

There is congruence between climate change adaptation strategies in the scientific literature and those promoted in state and federal public policies. However, this information does not reach the agricultural field effectively. Some adaptation strategies are implemented in the field, with the most common being leaving or burying crop residues. Rainfed farmers are the ones who implement the most adaptation strategies because they depend more on climate conditions. Individuals in this group, especially women producers and those over 50 years old, should be considered a priority group for state government programs.

The lack of climate information is considered a significant obstacle to farmers' adaptive capacities. The dissemination of this information can be implemented in the short term through collaboration between academia and the irrigation module administration. Other requirements suggested by farmers include agricultural insurance, fair prices, access to water, and subsidies when necessary. The design of climate change adaptation strategies in La Piedad, as well as other similar study sites, especially in the developing world, should encompass a set of measures that include efficient and equitable water resource management, integration of farmers' needs by co-production of knowledge (New et al., 2022), and a specific focus on vulnerable groups. This should involve improving drought-tolerant native seeds, technological innovation, agroecological techniques, and access to climate information.

It is essential to generate locally tailored climate change adaptation strategies, as recommended by the IPCC (2022a, b). This study serves as a diagnostic tool that confirms that, although political policies are based on scientific literature on agriculture and climate change, the adaptation measures are not being implemented in the field. It is suggested to continue with local studies that give a voice to farmers. This approach allows us to understand what farmers are already doing to address the impacts of climate change, their perceptions, and their actual support needs from the government and academia.

Acknowledgments

We would like to express our gratitude to the graduate program Ciencias de la Sostenibilidad of the Universidad Nacional Autónoma de México (UNAM) and the Secretaría de Cultura, Humanidades, Tecnología e Innovación for the graduate scholarship provided. We also extend our thanks to Salvador Toledo, Karina Escobar, Viridiana Méndez, Juan Pablo Elías Camilo de la Garza, and David Robledo for their assistance. Our appreciation also goes out to each of the 30 farmers who participated in the interviews.

References

Adger WN, Barnett J, Brown K, Marshall N, O'Brien K. 2013. Cultural dimensions of climate change impacts and adaptation. Nature Climate Change 3: 112-117. https://doi.org/10.1038/nclimate1666

Aguilar-Revelo L. 2021. La igualdad de género ante el cambio climático: ¿Qué pueden hacer los mecanismos para el adelanto de las mujeres de América Latina y el Caribe? Serie Asuntos de Género 159 (LC/TS.2021/79). Comisión Económica para América Latina y el Caribe, Santiago. Available at: https://repositorio.cepal.org/items/b06be710-eea2-4f88-8f79-a301caf1fdda (accessed on July 8, 2023).

Ahmed SK. 2025. Sample size for saturation in qualitative research: Debates, definitions, and strategies. Journal of Medicine, Surgery, and Public Health 5: 100171. https://doi.org/10.1016/j.glmedi.2024.100171

Arce-Romero A, Monterroso-Rivas AI, Gómez-Díaz JD, Palacios-Mendoza MÁ, Navarro-Salas EN, López-Blanco J, Conde-Álvarez AC. 2020. Crop yield simulations in Mexican agriculture for climate change adaptation. Atmósfera 33: 215-231. https://doi.org/10.20937/ATM.52430

Arreguín-Cortés FI, López-Pérez M, Rodríguez-López O, Montero-Martínez MJ. 2015. Atlas de vulnerabilidad hídrica en México ante el cambio climático. Instituto Mexicano de Tecnología del Agua, Jiutepec, Morelos, Mexico, 150 pp.

Arrioja Díaz Virruell LA. 2011. Pueblos de indios y tierras comunales. Villa Alta, Oaxaca: 1742-1856. Fideicomiso "Felipe Teixidor y Monserrat Alfau de Teixidor". El Colegio de Michoacán, Zamora, Michoacán, Mexico.

Attari SZ. (2014). Perceptions of water use. Proceedings of the National Academy of Sciences 111, 5129-5134. https://doi.org/10.1073/pnas.1316402111

Bellon MR, Hodson D, Hellin J. 2011. Assessing the vulnerability of traditional maize seed systems in Mexico to climate change. Proceedings of the National Academy of Sciences 108: 13432-13437. https://doi.org/10.1073/pnas.1103373108

Bellon MR, Mastretta-Yanes A, Ponce-Mendoza A, Ortiz-Santa María D, Oliveros-Galindo O, Perales H, Acevedo F, Sarukhán J. 2021. Beyond subsistence: The aggregate contribution of campesinos to the supply and conservation of native maize across Mexico. Food Security 13: 39-53. https://doi.org/10.1007/s12571-020-01134-8

Bogdan R, Taylor S. 1987. Toward a sociology of acceptance: The other side of the study of deviance. Social Policy 18: 34-39.

Carvalho KMD. 2019. The global water security: An approach for multilevel governance on hydric resources. International Journal of Innovation and Sustainable Development 13: 57-78. https://doi.org/10.1504/IJISD.2019.096706

CENAPRED. 2023. Sistema de consulta de declaratorias. Centro Nacional de Prevención de Desastres, Mexico. Available at: http://www.atlasnacionalderiesgos.gob.mx/apps/Declaratorias/# (accessed on September 9, 2023).

CONABIO. 2017. Proyecto global de maíces nativos. Comisión Nacional para el Uso y Conocimiento de la Biodiversidad, Mexico. Available at: https://www.biodiversidad.gob.mx/diversidad/proyectoMaices (accessed on September 20, 2025).

Cobern W, Adams B. 2020. When interviewing: How many is enough? International Journal of Assessment Tools in Education 7: 73-79. https://doi.org/10.21449/ijate.693217

Cohen J, Cohen P, West SG, Aiken LS. 2013. Applied multiple regression/correlation analysis for the behavioral sciences (3rd ed.). Routledge, New York, 536 pp. https://doi.org/10.4324/9780203774441

Coffey A, Atkinson P. 2003. Encontrar el sentido a los datos cualitativos. Estrategias complementarias de investigación. 1st. ed. Editorial Sage-Universidad de Antioquia, Colombia.

Conde C, Liverman D, Flores M, Ferrer R, Araújo R, Betancourt E, Villarreal G, Gay C. 1997. Vulnerability of rainfed maize crops in Mexico to climate change. Climate Research 9: 17-23.

Conde C, Ferrer R, Orozco S. 2006. Climate change and climate variability impacts on rainfed agricultural activities and possible adaptation measures. A Mexican case study. Atmosfera 19: 181-194.

CONAGUA. 2023. Monitor de sequía en México (MSM). Comisión Nacional del Agua, Mexico. Available at: https://smn.conagua.gob.mx/es/climatologia/monitor-de-sequia/monitor-de-sequia-en-mexico (accessed on August 23, 2023).

CONAGUA. 2024. Actualización de la disponibilidad media anual de agua en el acuífero Chalco-Amecameca (1506), Estado de México. Subdirección General Técnica, Gerencia de Agua Subterráneas. Comisión Nacional del Agua, Mexico. Available at: https://sigagis.conagua.gob.mx/gas1/Edos_Acuiferos_18/edomex/DR_1506.pdf (accessed on February 12, 2025).

CONAGUA. 2025. Acciones y programas. Disponibilidad por acuíferos. Comisión Nacional del Agua, Mexico. Available at: https://www.gob.mx/conagua/acciones-y-programas/michoacan-74856 (accessed on March 25, 2025).

Cruz-Ayala MB, Megdal SB. 2020. An overview of managed aquifer recharge in Mexico and its legal framework. Water 12: 474. https://doi.org/10.3390/w12020474

Cruz-Herrera KL, Valdivia-Alcalá R, Martínez-Damián MÁ, Contreras-Castillo JM. 2021. Autosuficiencia alimentaria en México: precios de garantía versus pagos directos al productor. Revista Mexicana de Ciencias Agrícolas 12: 981-990. https://doi.org/10.29312/remexca.v12i6.2533

Díaz-Bravo L, Torruco-García U, Martínez-Hernández M, Varela-Ruiz M. 2013. La entrevista, recurso flexible y dinámico. Investigación en Educación Médica 2: 162-167. https://doi.org/10.1016/s2007-5057(13)72706-6

Ellis PD. 2010. The essential guide to effect sizes: Statistical power, meta-analysis, and the interpretation of research results. Cambridge University Press. https://doi.org/10.1017/CBO9780511761676

FAO. 2016. Cambio climático y seguridad alimentaria y nutricional. América Latina y el Caribe. Organización de las Naciones Unidas para la Alimentación y la Agricultura, Santiago. Available at https://www.uncclearn.org/wp-content/uploads/library/cambioclimatico.pdf enero 2021 (accessed on January 25, 2023).

FAO. 2023. Resiliencia: mejorar la resiliencia de las personas, las comunidades y los ecosistemas es fundamental para lograr sistemas alimentarios y agrícolas sostenibles. Organización de las Naciones Unidas para la Alimentación y la Agricultura. Available at https://www.fao.org/agroecology/knowledge/10-elements/balance/es/ (accessed on July 21, 2023)

FAO-SAGARPA. 2012. México: el sector agropecuario ante el desafío del cambio climático. Vol. I. Organización de las Naciones Unidas para la Alimentación y la Agricultura-Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. Available at: https://www.agricultura.gob.mx/sites/default/files/sagarpa/document/2019/01/28/1608/01022019-cambio-climatico.pdf (accessed on January 13, 2023).

García-García JA, Reding-Bernal A, López-Alvarenga JC. 2013. Cálculo del tamaño de la muestra en investigación en educación médica. Investigación en Educación Médica 2: 217–224

Gómez Martínez E. 2019. Mejoramiento del maíz nativo para autoconsumo. In: Guías técnicas para el desarrollo agropecuario (Barradas-Miranda P, Cuevas-Reyes V, Baca-del Moral J, Eds.). Universidad Autónoma Chapingo, Mexico.

Govaerts B, Chávez X, Fernández A, Vega D, Vázquez O, Pérez M, Carvajal A, Ortega P, López P, Rodríguez R, Kruseman G, Donnet ML, Palacios-Rojas N, Verhulst N, Gardeazabal A, González G, Sánchez KC, Rosado LG. 2019. Maíz para México. Plan estratégico 2030. Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT), México.

Guest G, Bunce A, Johnson L. 2006. How many interviews are enough? An experiment with data saturation and variability. Field Methods 18: 59-82. https://doi.org/10.1177/1525822X05279903

Haro A, Mendoza-Ponce A, Calderón-Bustamante Ó, Velasco JA, Estrada F. 2021. Evaluating risk and possible adaptations to climate change under a socio-ecological system approach. Frontiers in Climate 3: 674693. https://doi.org/10.3389/fclim.2021.674693

Hellin J, Bellon MR, Hearne SJ. 2014. Maize landraces and adaptation to climate change in Mexico. Journal of Crop Improvement 28: 484-501. https://doi.org/10.1080/15427528.2014.921800

IEP. 2023. Índice de Paz México 2023: identificación y medición de los factores que impulsan la paz. Instituto para la Economía y la Paz. Available at: https://www.indicedepazmexico.org/ (accessed on July 25, 2023).

IPCC. 2022a. Bezner Kerr R, Hasegawa T, Lasco R, Bhatt I, Deryng D, Farrell A, Gurney-Smith H, Ju H, Lluch-Cota S, Meza F, Nelson G, Neufeldt H, Thornton P. 2022. Food, fibre, and other ecosystem products. In: Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Pörtner HO, Roberts DC, Tignor M, Poloczanska ES, Mintenbeck K, Alegría A, Craig M, Langsdorf S, Löschke S, Möller V, Okem A, Rama B, Eds.). Cambridge University Press, Cambridge and New York, 713-906. https://doi.org/10.1017/9781009325844.007

IPCC. 2022b. Hicke, JA, Lucatello S, Mortsch LD, Dawson J, Domínguez Aguilar M, Enquist CAF, Gilmore EA, Gutzler DS, Harper S, Holsman K, Jewett EB, Kohler TA, Miller KA. 2022. North America.In: Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Pörtner HO, Roberts DC, Tignor M, Poloczanska ES, Mintenbeck K, Alegría A, Craig M, Langsdorf S, Löschke S, Möller V, Okem

A, Rama B, Eds.). Cambridge University Press, Cambridge and New York, 1929-2042. https://doi.org/10.1017/9781009325844.016

Kirina T, Groot A, Shilomboleni H, Ludwig F, Demissie T. 2022. Scaling climate smart agriculture in East Africa: Experiences and lessons. Agronomy 12: 820. https://doi.org/10.3390/agronomy12040820

Mercer KL, Perales HR, Wainwright JD. 2012. Climate change and the transgenic adaptation strategy: Smallholder livelihoods, climate justice, and maize landraces in Mexico. Global Environmental Change 22: 495-504. https://doi.org/10.1016/j.gloenvcha.2012.01.003

Monterroso-Rivas AI, Conde-Álvarez C, Rosales-Dorantes G, Gómez-Díaz JD, Gay-García C. 2011. Assessing current and potential rainfed maize suitability under climate change scenarios in México. Atmósfera 24: 53-67.

Murray-Tortarolo GN, Jaramillo VJ, Larsen J. 2018. Food security and climate change: The case of rainfed maize production in Mexico. Agricultural and Forest Meteorology 253-254: 124-131. https://doi.org/10.1016/j.agrformet.2018.02.011

Nelson GC, Valin H, Sands RD, Havlík P, Ahammad H, Deryng D, Elliott J, Fujimori S, Hasegawa T, Heyhoe E, Kyle P, von Lampe M, Lotze-Campen H, Mason D'Croz D, van Meijl H, van Der Mensbrugghe D, Müller C, Popp A, Robertson R, Schmid E, Schmitz C, Tabeau A, Willenbockel D. 2014. Climate change effects on agriculture: Economic responses to biophysical shocks. Proceedings of the National Academy of Sciences of the United States of America 111: 3274-3279. https://doi.org/10.1073/pnas.1222465110

New M, Reckien, D, Viner D, Adler C, Cheong SM, Conde C, Constable A, Coughlam de Perez E, Lammel A, Mechler R, Orlove B, Solecki W. 2022. Decision-making options for managing risk. In: Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Pörtner HO, Roberts DC, Tignor M, Poloczanska ES, Mintenbeck K, Alegría A, Craig M, Langsdorf S, Löschke S, Möller V, Okem A, Rama B, Eds.). Cambridge University Press, Cambridge and New York, 2539-2654. https://doi.org/10.1017/9781009325844.026

Nicholls CI, Henao A, Altieri MA. 2015. Agroecología y el diseño de sistemas agrícolas resilientes al cambio climático. Agroecología 10: 7-31

SADER. 2020. Programa Nacional de Semillas: 2020-2024. Secretaría de Agricultura y Desarrollo Rural, Mexico. Available at: https://www.gob.mx/cms/uploads/attachment/file/616553/PROGRAMA_Nacional_de_Semillas_2020-2024baja.pdf (accessed on May 25, 2023).

SADER. 2022. Plan Estratégico de Cambio Climático para el Sector Agroalimentario. Secretaría de Agricultura y Desarrollo Rural, Mexico. Available at: https://www.gob.mx/agricultura/documentos/plan-estrategico-de-cambio-climatico-del-sector-agroalimentario?idiom=es (accessed on January 26, 2023).

SADER. 2023. Acciones y programas. Secretaría de Agricultura y Desarrollo Rural, Mexico. Available at: https://www.gob.mx/agricultura#341 (accessed on August 12, 2023).

SADER Michoacán. 2023. Convocatorias. Secretaría de Agricultura y Desarrollo Rural del Estado de Michoacán, Mexico. Available at: https://sader.michoacan.gob.mx/categoria/convocatorias/ (accessed on July 25, 2023).

SAGARPA. 2001. Ley de Desarrollo Rural Sustentable. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. Diario Oficial de la Federación, Mexico, December 7.

SAGARPA. 2017. El maíz, base de la dieta mexicana desde época prehispánica. Fideicomiso de Riesgo Compartido, Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, Mexico. Available at: https://www.gob.mx/firco/articulos/el-maiz-base-de-la-dieta-mexicana-desde-epoca-prehispanica (accessed on January 22, 2023).

SIAP. 2025. Anuario estadístico de la producción agrícola. Servicio de Información Agroalimentaria y Pesquera, Mexico. Available at: https://nube.agricultura.gob.mx/cierre_agricola/ (accessed on September 18, 2025).

SDAyR. 2023. Programas. Secretaría de Desarrollo Agroalimentario y Rural del Estado de Guanajuato, Mexico. Available at: https://secam.guanajuato.gob.mx/apoyos_secam (accessed on August 14, 2023).

Soto-Aguilar OA. 2004. Las élites del maíz. Ph.D. thesis in Political and Social Sciences. Centro de Investigación y Docencia en Humanidades del Estado de Morelos-Universidad Autónoma de Sinaloa, Mexico.

UN. 2023. Objetivos y metas de desarrollo sostenible (ODS). Organización de las Naciones Unidas. Available at: https://www.un.org/sustainabledevelopment/es/objetivos-de-desarrollo-sostenible/ (accessed on April 12, 2023).

Ureta C, Martínez-Meyer E, Perales HR, Álvarez-Buylla ER. 2012. Projecting the effects of climate change on the distribution of maize races and their wild relatives in Mexico. Global Change Biology 18: 1073-1082. https://doi.org/10.1111/j.1365-2486.2011.02607.x

Ureta C, González EJ, Espinosa A, Trueba A, Piñeyro-Nelson A, Álvarez-Buylla ER. 2020. Maize yield in Mexico under climate change. Agricultural Systems 177: 102697. https://doi.org/10.1016/j.agsy.2019.102697

World Bank. 2025. Agriculture, forestry, and fishing, value added (% of GDP). Available at: https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS (accessed on September 18, 2025).

Supplementary materials

Table SI. Scientific literature reviewed to find effective climate change adaptation measures for maize production.

No.	Title	Study site	Author	Year	DOI or web page
1	Estrategias para la producción de maíz frente a los impactos del cambio climático	Mexico (Guerrero)	Munguía et al.	2015	https://www.redalyc.org/journal/280/28043815007/html/
2	Sustainable agriculture development strategy for 2021 2030 and vision to 2050	Vietnam	Ministry of Agriculture and Rural Development	2021	https://hdl.handle.net/10568/117436
3	An assessment of agricultural vulnerability in the context of global climate change: a case study in Ha- Tinh province, Vietnam	Vietnam	Duong et al.	2022	https://doi.org/10.3390/su14031282
4	Towards climate smart agriculture. How does innovation meet sustainability?	Hungary-Budapest	Katalin et al.	2022	https://doi.org/10.19040/ecocycles.v8i1.220
5	Strengthening Indonesian farmers' resilience	Indonesia	Utomo and Pieter	2021	https://doi.org/10.1088/1755-1315/950/1/012002
6	Ensuring future food security and resource sustainability: Insights into the rhizosphere	China	Liyang Wang et al.	2022	https://doi.org/10.1016/j.isci.2022.104168
7	Climate change adaptation of Austrian farms	Austria	Zeilinger et al.	2021	https://doi.org/10.22004/ag.econ.317083
8	Scaling climate-smart agriculture in East Africa: Experiences and lessons	East Africa: Ethiopia, Kenia, Uganda, Tanzania	Kirina et al.	2022	https://doi.org/10.3390/agronomy12040820
9	Climate change impacts and adaptation strategies for 2 crops in West Africa: A systematic review	West Africa: Nigeria, Guinea	Carr et al.	2022	https://doi.org/10.1088/1748-9326/ac61c8
10	Competing priorities: adressing climate change in an agriculture-dependent region. How Sub-Saharan Africa is handling this	Sub-Saharan Africa	Jepchumba et al.	2022	https://doi.org/10.2870/509102

Table SI. Scientific literature reviewed to find effective climate change adaptation measures for maize production.

No.	Title	Study site	Author	Year	DOI or web page
11	Policy advice strategies for climate change adaption in international cooperation with Malawi and Namibia	Southeast Africa (Malawi and Namibia)	GIZ	2013	https://www.researchgate.net/publication/359217100_Literature_Review_-_Policy_Advice_Strategies_for_Climate_Change_Adaption_in_International_Cooperation_with_Malawi_and_Namibia
12	Multi-stakeholder dialogue space. Together scaling climate smart agriculture and climate information services in zambia	Africa-Zambia	AICCRA Zambia funded by World Bank	2022	https://digitalarchive.worldfishcenter.org/handle/20.500.12348/5347
13	Comparative profitability and relative risk of adopting climate-smart soil practices among farmers. A cost-benefit analysis of six agricultural practices	Kenia	Ombati Mogaka et al.	2022	https://doi.org/10.1016/j.cliser.2022.100287
14	Crops and climate change impacts	Global	FAO	2022	www.fao.org/3/cb8030en/cb8030en.pdf
15	Building climate resilience in Indian farm households: An analysis of national and state policies and initiatives	India	Suresh et al.	2022	https://doi.org/10.38039/2214-4625.1010
16	Modeling crop production under climate change in southeast Nigeria: Agroecology as a response	Nigeria	Otum Ume et al.	2022	https://doi.org/10.20944/preprints202207.0119.v1
17	Los impactos del cambio climático sobre las comunidades campesinas y de agricultores tradicionales y sus respuestas adaptativas	Mexico	Altieri et al.	2008	https://revistas.um.es/agroecologia/article/view/95471
18	Evaluating risk and possible adaptations to climate change under a socio-ecological system approach	Mexico	Abi Haro et al.	2021	https://doi.org/10.3389/fclim.2021.674693

Table SI. Scientific literature reviewed to find effective climate change adaptation measures for maize production.

No.	Title	Study site	Author	Year	DOI or web page
19	Agricultura colombiana: adaptación al cambio climático	Colombia	Lau et al.	2013	https://cgspace.cgiar.org/items/81291d3f-4e25-4d93-8602-2d409e170e29
20	A systematic review on farmers' adaptation strategies in Pakistan toward climate change	Pakistan	Saddique et al.	2022	https://doi.org/10.3390/atmos13081280
21	Simulating the climate change impacts and evaluating potential adaptation strategies for irrigated corn production in northern high plains of Texas	USA	Kothari et al.	2022	https://doi.org/10.1016/j.crm.2022.100446
22	Agriculture and water resources: UNFCCC influence on Peruvian adaptation regulations to increase resilience against climate change	Peru	Ruedas et al.	2022	https://doi.org/10.17268/sci.agropecu.2022.020
23	Agricultural innovation and adaptation to climate change: Insights from US maize	USA	Seungki Lee et al.	2022	https://doi.org/10.1002/jaa2.20
24	Sustainable agriculture and food security	Ethiopia, Mexico, Bangladesh,	Walter Leal Filho et al.	2022	https://doi.org/10.1007/978-3-030-98617-9
25	Género, cadenas de valor agroalimentarias y agricultura resiliente al clima en pequeños estados insulares en desarrollo	Caribbean, Pacific, Atlantic, and China	Percy et al.	2022	https://doi.org/10.4060/cb9989es
26	Climate-resilient agri-fisheries (CRA). Assessment, targeting and prioritization for the adaptation and mitigation initiative for Tarlac province	Philippines	Lilibeth et al.	2022	https://doi.org/10.1063/5.0094762
27	Climate change and climate variability impacts on rainfed agricultural activities and possible adaptation measures. A Mexican case study	Mexico	Conde et al.	2006	https://www.scielo.org.mx/scielo.php?pid=S0187-62362006000300003&script=sci_abstract&tlng=pt

Table SI. Scientific literature reviewed to find effective climate change adaptation measures for maize production.

No.	Title	Study site	Author	Year	DOI or web page
28	Maize landraces and adaptation to climate change in Mexico	Mexico	Hellin et al.	2014	https://doi.org/10.1080/15427528.2014.921800
29	Social identity, perception and motivation in adaptation to climate risk in the coffee sector of Chiapas, Mexico	Mexico	Frank et al.	2010	https://doi.org/10.1016/j.gloenvcha.2010.11.001
30	Climate change and the transgenic adaptation strategy: Smallholder livelihoods, climate justice, and maize landraces in Mexico	Mexico	Mercer et al.	2012	https://doi.org/10.1016/j.gloenvcha.2012.01.003
31	Predicting maize (Zea mays) productivity under projected climate change with management options in Amhara region, Ethiopia	Ethiopia	Mohammed et al.	2022	https://doi.org/10.1016/j.indic.2022.100185
32	Response of dryland crops to climate change and drought-resistant and water-suitable planting technology for spring maize	China	Fan et al.	2022	https://doi.org/10.1016/j.jia.2022.08.044
33	The effect of smallholder maize farmers' perceptions of climate change on their adaptation strategies: The case of two agro-ecological zones in Ghana	Ghana	Colecraft et al.	2021	https://doi.org/10.1016/j.heliyon.2021.e08307
34	Understanding the determinants of climate change adaptation strategies among smallholder maize farmers in southwest Nigeria	Nigeria	Adeagbo	2021	https://doi.org/10.1016/j.heliyon.2021.e06231
35	Saberes tradicionales locales y el cambio climático global	Mexico	Cruz Hernández et al.	2020	https://doi.org/10.29312/remexca.v11i8.2748

Table SI. Scientific literature reviewed to find effective climate change adaptation measures for maize production.

No.	Title	Study site	Author	Year	DOI or web page
36	Response to climate change in a rainfed crop production system: Insights from maize farmers of western Kenya	Kenia	Kipkemboi Kogo et al.	2022	https://doi.org/10.1007/s11027-022-10023-8
37	La agricultura española y el cambio climático	Spain	Picazo et al.	2011	https://oa.upm.es/12061/
38	Improving the water-use eficiency and the agricultural productivity: An application case in a modernized semiarid region in north-central Mexico	Mexico	Gónzalez-Trinidad et al.	2020	https://doi.org/10.3390/su12198122
39	Climate change and climate variability impacts on rainfed agricultural activities and possible adaptation measures. A Mexican case study	Mexico	Conde et al.	2006	https://www.scielo.org.mx/scielo.php?pid=S0187-62362006000300003&script=sci_abstract&tlng=pt
40	Climate smart sgriculture governing the sustainable development goals in sub-Saharan Africa	Kenia, Tanzania, Ethiopia, and Rwanda	Newell et al.	2019	https://doi.org/10.3389/fsufs.2019.00055
41	“Si no comemos tortilla, no vivimos”. Women, climate change, and food security in central Mexico	Mexico	Bee	2014	https://doi.org/10.1007/s10460-014-9503-9
42	What information do policy makers need to develop climate adaptation plans for smallholder farmers? The case of Central America and Mexico	Mexico and Central America	Donatti et al.	2017	https://doi.org/10.1007/s10584-016-1787-x

Table SIIa. Answers from the semi-structured interviews. General data.

No.	Age	Sex	Rainfed/irrigation
1	26	M	I
2	42	M	I
3	65	M	I
4	64	M	R/I
5	45	M	R/I
6	68	M	I
7	64	M	I
8	48	F	I
9	55	F	I
10	65	F	I
11	40	M	R/I
12	90	M	R
13	43	M	I
14	28	M	R/I
15	47	M	I
16	73	M	I
17	58	M	I
18	63	F	I
19	88	F	I
20	80	F	I
21	52	F	R
22	79	M	R
23	73	M	R
24	42	M	R/I
25	56	M	R
26	60	F	R
27	73	M	R
28	71	F	R
29	52	F	I
30	28	F	R

Table SIIb. Answers from the semi-structured interviews. Climate.

	Have you received alerts about extreme weather events? If yes, was it before, during, or after the event? Do you trust available weather services?
1	No. There is no trust in weather information
2	No, no alerts at all
3	No. They are never warned in advance. They are told to evacuate in the exact moment. They monitor the river themselves because they live nearby and observe it daily. No trust in weather information
4	No. When an extreme event happens, the communal farmers (ejidatarios) take care of it. They only observe the river
5	No, no alerts, even in areas close to the river
6	No, they just check the forecast from CONAGUA or the local module. Trusts CONAGUA more, but it's not always accurate
7	No, unless they see it on TV or the internet. There's not much trust in weather forecasts
8	No, everything was lost
9	No, the lagoon merged with the river, and they were evacuated
10	No, nothing
11	No
12	No, only on television. Trusts it
13	No, nothing
14	No. Checks the phone
15	No
16	No, but they use a cane to measure the river's water level
17	No, but they receive some information from seed companies
18	No, and there is no trust in weather information
19	No
20	No
21	Yes, the municipal government warns houses near the river to evacuate because the community is close to it. There is little trust in the media
22	No, nothing
23	No
24	No, nothing, and no trust in forecasts
25	No, not much trust, but they still check the weather regularly
26	No, nothing, they don't check forecasts because they are not accurate
27	No
28	No, nothing
29	No
30	No

Table SIIc. Answers from the semi-structured interviews. Ecology.

No.	What past agricultural techniques do you think could help deal with current climate conditions?	What agroecological strategies do you know? (Please specify which ones)	Which ones have you implemented and why? Which have you not implemented and why?	Would you be willing to change certain practices to adapt to climate change?
1	Not burning crop residues	Conservation tillage	Sometimes it is applied, depending on the crop	Of course, if there is machinery available
2	Not burning crop residues	Conservation agriculture	Burying crop residues requires special machinery and is expensive. There is a lack of machinery to promote it	Yes
3	There were no specific techniques, just avoiding burns	Not burning	Incorporating crop residues into the soil. But government support is needed. Sometimes pheromones are used, but it's expensive, and all the farmers need to use them for them to work. There should be information to promote new practices, and people dedicated to agriculture should promote them	Yes, if there are supports to implement them, yes
4	Planting trees, not burning crop residues	Agroecological pest management, conservation agriculture	Conservation agriculture, no longer doing deep plowing, pheromones, fungi	Yes, but they would need to guarantee good performance. As long as there is moisture, it's the best
5	Making hay bales	I don't know what it is	None, burning because there's a lot of trash left, and it cannot be planted	Yes. As long as they support with machinery or funding to buy it
6	Using fewer chemicals	I don't know, not burning	Still burning because the crop residues absorb a lot of fertilizer. There's a lack of information and environmental awareness	Yes
7	I don't think those techniques would help much now because the climate back then was different, and yields were lower	I don't recognize them	It's said not to burn the crop residues, but we don't have machinery to shred them. It's been tried, but if too much residue is left, the planting doesn't go well and it doesn't produce as much because it gets in the way. More is produced when there's no residue	Yes, if it improves production, takes care of the environment, and doesn't generate too much cost

Table SIIc. Answers from the semi-structured interviews. Ecology.

No.	What past agricultural techniques do you think could help deal with current climate conditions?	What agroecological strategies do you know? (Please specify which ones)	Which ones have you implemented and why? Which have you not implemented and why?	Would you be willing to change certain practices to adapt to climate change?
8	Leaving crop waste	No. Don't burn, but sometimes neighbors burn and it affects us	Not burning. But the trash takes time, and it needs to be cleared for planting	It depends on who is promoting them
9	Not burning and leaving crop waste	Don't burn, leave trash, and retain moisture	Not burning	Yes
10	Burning was avoided, and crop residues were used as livestock feed	Don't burn, but recently we have been selling the crop residues	Not burning, but we prefer to sell the crop residues. Pests are only controlled with a lot of chemicals	Yes, as long as it doesn't cost too much
11	I don't think those techniques would help now; hybrid seeds yield better, but some are less climate-tolerant	No, don't burn	Three years ago, I started burying the crop residues, the soil becomes softer and more humid	Yes. They should be cheap, and I need all the necessary machinery
12	Leaving stones in the field, changing planting dates, fallowing, letting the land rest, and leaving crop residues for the soil and livestock	I don't know	Not burning	Yes
13	I don't think they would be useful now	I don't know	Not burning, but not always, because we don't have machinery, and we rush to prepare the land. It helps retain moisture	Yes
14	Contour plowing; I think combining past techniques with modern technology is better	Vertical tillage, leave crop residues, don't plow, increase biodiversity, recover mesquite areas, and crops on embankments	Leaving crop residues, applying pheromones. Not all are applied because now agriculture is seen only as a business	Yes
15	I don't think any would work	I don't know. Don't burn crop residues	Not burning corn residues, pheromones seem expensive	Yes. Machinery support is needed

Table SIIc. Answers from the semi-structured interviews. Ecology.

No.	What past agricultural techniques do you think could help deal with current climate conditions?	What agroecological strategies do you know? (Please specify which ones)	Which ones have you implemented and why? Which have you not implemented and why?	Would you be willing to change certain practices to adapt to climate change?
16	Leaving crop residues, preparing the soil	I don't know	Not burning, but sometimes when too much trash is left, it doesn't germinate. It's better to leave it unshredded because if it's shredded, there are germination problems	Yes
17	None from the past would help with today's climate	I don't know	Leaving crop residues caused fungi due to the humidity, it attracts fusarium which burns maize and wheat	Yes, but more research is needed on managing crop residues and moisture. Changing crops
18	Keeping trees and not burning	I don't know the term	Making bales (with crop residues)	Yes
19	In the past, people knew the rain cycles, which helped, but now everything has changed. Maybe weeding helps control invasive plants. Now, the soil is exhausted from too many chemicals, and past techniques are no longer effective	I don't know	Making bales (with crop residues)	Yes, as long as it doesn't cost too much
20	There used to be wells and natural springs, which helped during droughts	I don't know	Making bales and still burning because there's no machinery to bury the crop residues, and they say leaving it causes fungi	Yes, as long as there is support and it's not too expensive
21	Manure could provide moisture, and the manure quality has improved	I don't know	It used to be burned due to a lack of machinery	Yes, to be able to plant maize again
22	Manure for moisture, stones	I don't know the term	Not burning and leaving crop residues	Yes
23	I don't think they help much now because it's too much work, and the result is the same. Manure helps retain moisture, and the corn looks healthier	I don't know	Leaving crop residues, but there was a chicken disease due to the humidity, and I stopped doing it	Yes
24	I don't think any techniques would work because the land and climate are very different now	I don't know	Conservation tillage and not burning so that the soil doesn't get damaged, it gives me yields of 12 tons in dryland	Yes

Table SIIc. Answers from the semi-structured interviews. Ecology.

No.	What past agricultural techniques do you think could help deal with current climate conditions?	What agroecological strategies do you know? (Please specify which ones)	Which ones have you implemented and why? Which have you not implemented and why?	Would you be willing to change certain practices to adapt to climate change?
25	I don't think they help much because they were too labor-intensive. Plowing and deep tillage help retain moisture	Yes, don't burn, bury crop residues	None, because they are too expensive	Yes
26	Tilling the soil and plowing helped retain moisture, as did leaving crop residues	Yes, compost	I don't do it because we buy fertilizer for convenience. I burn because if I leave the crop residues, the tractor doesn't pass well, and the seeds don't germinate properly. Also, I don't leave it so that seeds from the previous cycle don't sprout	Yes
27	The land is already exhausted and doesn't produce without fertilizer. In the past, manure was used, and fields were left to rest by planting chickpeas	I don't know	Leaving crop residues sometimes	Yes
28	I feel the land was worked better before and retained moisture, but now it's depleted. Leaving crop residues helps retain moisture	I don't know	I don't burn; we make bales and sell the crop residues	Yes
29	Leaving small amounts of crop residues	I don't know the term	Leaving crop residues, the amount must be monitored because sometimes it doesn't germinate	Yes
30	Leaving crop residues	I don't know the term	None	Yes

Table SIId. Answers from the semi-structured interviews. Vulnerability.

No.	What do you consider is currently the greatest risk to agriculture in this area? (climate, pests, input costs, insecurity, markets)	What extreme weather event do you fear the most and why?	Do you think you have the ability to adapt to a changing climate?	Do you have agricultural insurance in case of a climate disaster?	If the answer is "yes," how much does it cost?	3.6 Do you receive government support for insurance?	3.7 What kind of support do you consider necessary from the government?
1	Input costs and climate conditions	Drought, because without water, there is nothing to irrigate. In excess water conditions, we can pump and remove the water	No, because nothing remains after a drought	I don't take insurance because they don't fulfill what they promise and don't respond	N/A		
2	The climate. The loss of the harvest	Drought. It's better to die drowned than to die dry	No, with drought, it's not adaptable	No. There's no trust	N/A	No	Support for diesel
3	The river, cost, and trade of the harvest. Those who say they pay better take too long and make it hard with tax procedures, so they prefer to sell their harvest at a lower price but get paid quickly	Drought, it erodes the soil, and winds come and knock down the plants. The situation looks different during a drought. Water leaves us with humidity to keep working	No	Yes, because if not, they don't give us credits	Prices vary, from $2000 per hectare, and it doesn't cover 100%. It depends on the yield. They think it's just a business	No, before yes.	Insurance for farmers. Information

Table SIId. Answers from the semi-structured interviews. Vulnerability.

No.	What do you consider is currently the greatest risk to agriculture in this area? (climate, pests, input costs, insecurity, markets)	What extreme weather event do you fear the most and why?	Do you think you have the ability to adapt to a changing climate?	Do you have agricultural insurance in case of a climate disaster?	If the answer is "yes," how much does it cost?	3.6 Do you receive government support for insurance?	3.7 What kind of support do you consider necessary from the government?
4	Climate, pests, and diseases	Drought and flooding	No	Yes	\$2000 to \$3000	No	Dredging the river, machinery to bury crop residues, climate information for each agricultural cycle to help with planning. Early alerts on floods and river rises, new strategies that suit them for adapting to climate change. Support like Procampo. Subsidies for fertilizers, which have become so expensive, and irrigation equipment
5	Harvest prices, climate	Drought and flooding, more towards drought, "there's still something left from the humidity."	No, there's a lack of organizational capacity, they are not united	No, there's no trust in insurance	N/A	No	Subsidies for high productivity and premium for grain quality

Table SIId. Answers from the semi-structured interviews. Vulnerability.

No.	What do you consider is currently the greatest risk to agriculture in this area? (climate, pests, input costs, insecurity, markets)	What extreme weather event do you fear the most and why?	Do you think you have the ability to adapt to a changing climate?	Do you have agricultural insurance in case of a climate disaster?	If the answer is "yes," how much does it cost?	3.6 Do you receive government support for insurance?	3.7 What kind of support do you consider necessary from the government?
6	Climate, excessive use of agrochemicals	Drought	No	Yes	Doesn't remember	No	Fair prices for crops, support for inputs
7	Climate, pests, and harvest price	Drought	No	Yes	$2000 per hectare	No, they used to receive a percentage but now nothing	They need information about the climate and how to adapt. Stimulus and support for farmers. Transparency in support
8	Climate	Flooding	No	Yes	$4,100	There's no government support for insurance	Fair prices for the harvest
9	Losses due to climate, unfair prices	Drought	No	Yes	$4,100	No	Fair prices
10	Climate	Flooding	No	Yes	$4,100	No	Fair prices
11	Climate and prices	Drought	No, but we have to adapt	Yes, only for irrigation, not for dryland farming	$2,500	No	Fair prices and information
12	Price, pests, and climate	Drought and flooding	No	No, they don't insure dryland crops	N/A	No	Fair prices

Table SIId. Answers from the semi-structured interviews. Vulnerability.

No.	What do you consider is currently the greatest risk to agriculture in this area? (climate, pests, input costs, insecurity, markets)	What extreme weather event do you fear the most and why?	Do you think you have the ability to adapt to a changing climate?	Do you have agricultural insurance in case of a climate disaster?	If the answer is "yes," how much does it cost?	3.6 Do you receive government support for insurance?	3.7 What kind of support do you consider necessary from the government?
13	The changing climate	Drought	No	No, there's no trust in insurance	N/A	No	Procampo and support for climate disasters in dryland farming
14	Climate and production costs	Drought	No, I think it's due to a lack of information	Yes	$2,800	No, nothing	Climate monitoring and information
15	Water scarcity due to climate	Drought	No	Yes, to access credits	$2000 to $3000	No	Support for insurance, information for farmers, assistance with new strategies, strengthening capacities, support for machinery
16	Prices and climate	Drought	No	Yes	$2500	No, they removed the support	Information about the climate, good harvest prices, and seed support
17	Uncertainty regarding climate and prices	Drought: without water, we can't do anything	No. We have to adapt by force	No	N/A	No, they removed it	Information, early alerts, good harvest prices
18	Costs and climate	Drought and flooding	No	No	N/A	No	Support from trained government personnel

Table SIId. Answers from the semi-structured interviews. Vulnerability.

No.	What do you consider is currently the greatest risk to agriculture in this area? (climate, pests, input costs, insecurity, markets)	What extreme weather event do you fear the most and why?	Do you think you have the ability to adapt to a changing climate?	Do you have agricultural insurance in case of a climate disaster?	If the answer is "yes," how much does it cost?	3.6 Do you receive government support for insurance?	3.7 What kind of support do you consider necessary from the government?
19	Climate, pests, and harvest price	Flooding	No	No	N/A	No	Procampo
20	Climate, drought	Flooding	No	No	N/A	No, because they removed the support	Good prices and support for post-harvest and grain quality
21	Climate and input prices	Flooding because we live near the river and drought for dryland	Renting agave	They don't offer it to dryland farmers	N/A	No, they removed it and we didn't want to insure anymore	Procampo, water purchase, and good harvest prices
22	Investment costs and climate. Despite the risks, we keep doing it.	Drought despite being next to the river	No	No, insurance doesn't support dryland farmers	N/A	No, nothing	Insurance for dryland farming, wells, water
23	Drought, climate	Drought	No	No, insurance doesn't support dryland farmers	N/A	No	Wells for dryland farming in the Ejido
24	Drought, climate	Drought	No	No	N/A	No	Support for hybrid seeds and wells, climate information for each season
25	Drought and pests, climate	Drought	No	No, insurance doesn't support dryland farmers	N/A	Nothing	Support for climate disasters and covering debts (insurance)

Table SIId. Answers from the semi-structured interviews. Vulnerability.

No.	What do you consider is currently the greatest risk to agriculture in this area? (climate, pests, input costs, insecurity, markets)	What extreme weather event do you fear the most and why?	Do you think you have the ability to adapt to a changing climate?	Do you have agricultural insurance in case of a climate disaster?	If the answer is "yes," how much does it cost?	3.6 Do you receive government support for insurance?	3.7 What kind of support do you consider necessary from the government?
26	I don't recognize risks because we always plant, whether it rains or not, this is what we do	Drought	No	No, insurance doesn't support dryland farmers, and anyway, there's no trust that they'll respond	N/A	Nothing	Support to buy fertilizers and inputs because dryland farming yields are not the same as irrigated farming, priority to dryland farmers
27	Drought, climate	Drought	No, only by having wells	No	N/A	No, there used to be Procamo but now it's only for producers with less than 5 hectares	I hadn't thought about that.
28	Drought and input costs	Drought	No	No	N/A	Nothing	Wells
29	Costs and climate	Drought	No	Yes	$3400 per hectare	Not for dryland farming, nothing	Support for wells and Procampo
30	Climate, drought	Drought	No	No, there's no insurance for dryland farming	N/A	No, nothing	Training and support for agricultural inputs and insurance
						No	Agroecology training, support for insurance

Table SIIe. Answers from the semi-structured interviews. Gender.

No.	Women’s participation in the ejido
1	10% of the ejido and meetings are women, and sometimes they are the ones who discuss the most
2	There is no participation from women, even though they are owners; they pay for the work to be done. Sometimes it’s due to age, or they simply don’t get involved. In meetings, they participate, but not in fieldwork
3	There were more women working in the fields before, and they were even harderworking than men. Nowadays, it seems they are embarrassed to be seen working among only men
4	Yes, there are women working in the fields, particularly in the repela (sorting). 10% of the ejido are women
5	In vegetable cultivation, there are more women, and in greenhouse work, while maize cultivation is dominated by men, women rarely take charge
6	Women are now much more involved, especially in greenhouse work. There are very few in the ejido
7	Nowadays, ejido women attend meetings
8	Those who own land often transfer it to others
9	When women grow older, they no longer work the land
10	There are very few women, with only about 10% in the ejido
11	My wife has always helped me with agricultural activities
12	Women do not attend meetings because they are not comfortable discussing matters with men, but they are participating more in fieldwork
13	It is dangerous for women; very few get involved, and there is machismo in Cerritos
14	There are very few women in this area
15	There aren’t many women in this community. They do not participate much, and it is considered better that they don’t, to avoid gossip
16	There is very little participation from women in this ejido. However, women are listened to when they speak
17	
18	
19	Less than 5%
20	Less than 10%
21	
22	Few women own land; they used to struggle a lot because they worked both in the field and at home. Today, it is easier because tortillas are bought ready-made, but women continue working, mostly in greenhouses, not on their own plots
23	Only widows own land. My wife helps me with everything, from removing stones to working in the field
24	Most women in the village work in greenhouses, but they do not get involved in corn cultivation
25	In El Triunfo, women participate a lot, and there is not much machismo. They work on the land and in rainfed plots
26	
27	In this area, all women participate
28	
29	
30	

Table SIIIa. Adaptation. Summary of adaptation measures implemented by producers.

Adaptation measure	Description	Irrigation	Rainfed
Auxiliary irrigation	Irrigation after the corn has sprouted, with water coming from the river	x	
Leaving crop residue from the previous harvest	Leaving crop residue from the previous harvest on the soil after making bales or rolls to retain moisture	x	x
Choosing seed varieties tolerant to moisture	Purchasing seeds advertised as drought-tolerant	x	x
Agricultural insurance	Buying insurance for damages from extreme weather events through financial companies or banks	x	
Applying manure to the soil	Using manure from cattle on the field		x
Planting hybrids with shorter cycles	Purchasing hybrid seeds with short cycles	x	x
Leaving rocks from the hill in the plot	Using porous rocks in the soil	x	x
Changing planting dates	Planting at different times than traditional ones, depending on the first rains or access to irrigation from the river	x	x
Letting the land rest in winter	Not planting between November and March	x	x
Ceremonial rituals for requesting rain	Catholic masses and prayers, especially to ask for rain	x	x
Buying water from private wells	Buying water from producers who have wells for the autumn-winter cycle	x	
Vertical breaking	A technique that involves mechanically loosening the soil to improve water infiltration	x	x
Integral and buried fertility	Smart use of fertilizers based on technology that determines what nutrients the soil and plant require. Applying fertilizers with machinery that buries them in the soil for better absorption	x	x
Using native seeds for drought tolerance	Production of native maize from traditional seeds with more drought tolerance than hybrid ones		x
Changing crops (sorghum and agave)	Planting another cereal besides maize	x	x
Making sorghum tortillas and feeding livestock with prickly pear	In cases of extreme drought and maize production failure, sorghum is used for livestock feed		x
Replanting when seedlings are lost or don't sprout	If the plants do not sprout due to drought or flooding, more seeds are bought and replanted in areas where the crops did not grow	x	x
Building embankments for flooding from river overflow	Construction of embankments in case of flooding	x	
Leveling the plot	Removing soil from the higher parts of the plot to create a flat surface makes agricultural tasks, irrigation, and drainage easier	x	
Draining systems	Building channels to allow excess water to flow off the plot into canals	x	x
Renting land to tequila companies for agave planting	Renting agricultural land to tequila companies to plant agave, with the owner receiving a fee in exchange, no longer planting maize		x

Table SIIIb. Adptation. Challenges of the implemented agroecological strategies.

Strategy	Disadvantages	Irrigation	Rainfed
Leaving crop residues from the previous harvest	Excess moisture attracts pests like gallina ciega; leaving wheat residues led to its proliferation	x	x
Agricultural insurance	Rainfed farmers do not have access and lack trust in the system	x	
Application of manure as fertilizer	Attracts gallina ciega		x
Planting short-cycle hybrids	Low yield		x
Letting the land rest in winter	They would be unable to plant wheat, affecting the economy	x	
Buying well water from private owners	Excessive cost	x	x
Vertical tillage (loosening the soil)	Technical advice and follow-up are necessary, but not available	x	x
Integrated and deep soil fertility management	Requires technical support, follow-up, and machinery, which are not available	x	x
Use of native seeds for drought tolerance	Lacks a market and has very low yield. Farmers show little interest in growing native seeds for commercial purposes	x	x
Leasing farmland to tequila companies for agave cultivation	Farmers experience a sense of loss and nostalgia		x

Table SIIIc. Adaptation. Summary of adaptation measures found in the scientific literature.

No.	Adaptation measures	Description
1	Improvement and promotion of the use of drought-tolerant native seeds	Promotion of drought-tolerant native seeds and improvement of native seeds
2	Use of improved (hybrid) seeds for higher yields	Use of improved or commercial hybrid seeds that guarantee higher yields
3	Technification of infrastructure for efficient irrigation and water conservation	Reduction of irrigation needs, piping channels to reduce evapotranspiration, drip irrigation, designing water usage regulations, adjusting water usage volumes, soil studies, and promoting water conservation
4	Technological innovation for precision agriculture (software programs, climate models, scenario design)	Climate scenario modeling, use of technology for precision agriculture, climate information services using technology
5	Agroecological strategies	Use of organic fertilizers, use of microorganisms to optimize fertilizers, intercropping, integrated pest management
6	Climate-smart agriculture (CSA)	Sustainably increasing agricultural productivity and improving farmers' incomes; enhancing farmers' resilience to climate change and helping them find ways to adapt; and reducing greenhouse gas emissions
7	Strengthening of farmers' technical capacities (training)	Farmers' schools, technical and trade training
8	Projects for fair trade, value chains, export markets, and business models	Support and fair trade policies
9	Fertilization techniques for increased yields	Buried fertilization, precision agriculture for fertilization, increased use of fertilizers
10	Changing planting dates according to updated climate patterns	Modification of planting dates according to new rainfall patterns
11	Rituals for requesting and giving thanks	Rain blessings, petitions for a good season, blessing of tools
12	Use of short-cycle (early) seeds	
13	Soil improvement strategies	Mixing organic and inorganic fertilizers, minerals, and conservation works such as ditches and vertical tillage
14	Crop rotation, intercropping, diversifying crops	Intercropping
15	Decarbonization of the agricultural sector	Designing low-carbon measures for mitigating greenhouse gas emissions
16	Climate information services	Promotion of climate information every cycle, maps, risk atlases, and water availability
17	Perception studies and methods of farmers' participation, linking with academia and government	Dialogues with farmers, participatory workshops, perception studies, and social identity
18	Agroforestry	Reforestation with native species
19	Conservation agriculture	Minimal mechanical soil disturbance with plant matter (zero tillage) and crop diversification

Table SIIIc. Adaptation. Summary of adaptation measures found in the scientific literature.

No.	Adaptation measures	Description
20	Design of public policies for adaptation in the agricultural sector and promotion of the implementation of adaptation measures through policy	Inclusion of adaptation measures in public policies
21	Mulching	Cover crops or straw to reduce radiation and heat levels on newly planted surfaces, inhibiting moisture loss and absorbinenergy
22	Rainwater harvesting	Designing rainwater harvesting systems for dryland farming
23	Biotechnology and use of genetically modified varieties	Genetically modified organisms
24	Gender equality practices	Access to agricultural services and resources for women, reducing household work burdens so they can participate more actively in agriculture

Table SIIId. Adaptation. Instruments of public policy.

No.	Public policy instrument	Level
1	Ley General de Cambio Climático	Federal
2	Plan Estratégico de Cambio Climático del Sector Agroalimentario (PLECCA)	Federal
3	Programa Sectorial de Agricultura y Desarrollo Rural	Federal
4	Programa Especial de Cambio Climático	Federal
5	Programa Especial Concurrente para el Desarrollo Rural Sustentable 2020-2024	Federal
6	Programa Nacional de Semillas	Federal
7	Ley de Desarrollo Rural Sustentable	Federal
8	Estrategia Nacional de Suelo para la Agricultura	Federal
9	Programa Institucional 2020-2024 de la Comisión Nacional de Zonas Áridas	Federal
10	Primera Comunicación sobre Adaptación	Federal
11	Estrategia Nacional de Polinizadores	Federal
12	Programa de Gobierno del estado de Guanajuato 2018-2024	State
13	Programa Sectorial Desarrollo Ordenado y Sostenible 2019-2024 del estado de Guanajuato	State
14	Actualización de la Ley de cambio climático del estado de Guanajuato	State
15	Presupuesto Transversal de Cambio Climático establecido en la Ley de Egresos	State
16	Ley de Cambio Climático del Estado de Michoacán de Ocampo	State
17	Programa Estatal de Cambio Climático del Estado de Michoacán de Ocampo 2014	State
18	Reglamento de la Ley de Cambio Climático del Estado de Michoacán de Ocampo	State