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Essay

Impacts of climate change on corn production in Mexico

Alejandro Cruz-González[1,§]
Ramón Arteaga-Ramírez[1]
Ignacio Sánchez-Cohen[2]
Jesús Soria-Ruiz[3]
Alejandro Ismael Monterroso-Rivas[4]

1 Posgrado en Ingeniería Agrícola y Uso Integral del Agua-Universidad Autónoma Chapingo. Carretera México-Texcoco km 38.5, Chapingo, Estado de México. CP. 56230. Tel. 712 2474131. (rarteagar@taurus.chapingo.mx).

2 Centro Nacional de Investigación Disciplinaria en Relación Agua-Suelo-Planta-Atmósfera-INIFAP. Margen derecha canal Sacramento km 6.5, Zona industrial, Gómez Palacio, Durango. CP. 35140. Tel. 871 1590105. (sanchez.ignacio@inifap.gob.mx).

3 Laboratorio de Geomática-Sitio Experimental Metepec-INIFAP. Carretera Toluca-Zitácuaro, Zinacantepec, Estado de México. CP. 52176. (soria.jesus@inifap.gob.mx).

4 Departamento de Suelos-Universidad Autónoma Chapingo. Carretera México-Texcoco km 36.5, Chapingo, Estado de México, México. CP. 56230. Tel. 595 9521633. (aimrivas@correo.chapingo.mx).

Autor para correspondencia: alex-cg20@hotmail.com

Abstract

Anthropogenic activities have added enough to cause important alterations in the climate at a global level; in the last 20 years, a phenomenon of extreme characteristics called 'climate change' has worsened, which has been responsible for causing climate variability, the level of affectation of which extends to all geographical scales. This research was carried out in 2022 with the aim of knowing the impacts of climate change on the productive system of the corn crop in Mexico, given its great nutritional, cultural, and economic relevance. It describes the climate variability and extreme events that occur in Mexico and that in some way have a direct relationship with corn production, such as precipitation, temperature, frosts, hailstorms, droughts, and floods. Worldwide, Mexico stands out in the first places in production and consumption of corn; the current population exceeds 126 million people, and it is a condition that manifests a great demand, having to make a strong export of the grain year after year, showing the unsustainability of the country's food security. This situation is aggravated when climate change and climate variability directly affect the most important requirements for the establishment of a crop, and that directly affect all stages of growth and development, presenting a decrease in current and future yield.

Keywords:

Zea mays L., extreme events, food security, mitigation and adaptation, vulnerability.

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Introduction

The climate of a geographic region is the most frequent state of the atmosphere in an average or normal time over a long period of time (>30 years); climate change, therefore, is a long-term modification in the typical or average climate of a region (Santos and Bakhshoodeh, 2021). Anthropogenic alterations such as industry, excessive agriculture, deforestation, use of fossil fuels, among others, have led to gradually accelerated changes in the climate, including an increase in the average temperature of the earth's surface, which has been defined as climate change (IPCC, 2021; Abbass *et al*., 2022). This phenomenon not only changes the average state of the climate but also its variability, which is projected to increase towards a greater geographical extension (Frieler *et al*., 2017).

Climate variability refers to variations in the mean state and other statistics of climate at all temporal and spatial scales (IPCC, 2019). This is one of the main phenomena that occur worldwide and has caused important changes in climatic variables such as precipitation, air temperature, relative humidity, and solar radiation (Ochieng *et al*., 2016). Climate variability and extremes are considered one of the main causes of food crises, especially in regions with greater marginalization and food insecurity (Richardson *et al*., 2018).

Recent studies have shown that climate variability is perceived more intensely in productive agricultural regions than in less productive ones; there are also other factors that influence crop yields, such as pests, diseases, type of tillage, low soil fertility, water availability, and increased input prices (Kang *et al*., 2013; Frieler *et al*., 2017; Mills *et al*., 2018).

The occurrence of meteorological events such as frosts, hailstorms, droughts, and floods results in significant damage to agricultural production, impacting for several years the economic and financial recovery of the deterioration caused, in addition to the social problem it triggers (González-Celada *et al*., 2021).

Corn production is highly dependent on climate conditions and extreme weather events; when the normal conditions experienced by crops change, they can significantly impact their yield (Harkness *et al*., 2020; Baum *et al*., 2020). The production of the corn crop, during its different stages of development, such as germination and emergence, vegetative growth, flowering and fertilization, grain filling, and maturity, is very sensitive to extreme weather events; these conditions can severely reduce the yield of the crop and affect its quality (Ureta *et al*., 2020; Noein and Soleymani, 2022).

The aforementioned sensitivity causes modifications in the sowing cycle due to the variability of meteorological conditions and positive and negative changes in yields for different geographical regions (You *et al*., 2017; Leng, 2019; Wang *et al*., 2021). This essay aimed to review the state of the art in the impacts of climate change associated with the production system of the corn crop in Mexico.

Development of the research

This research was obtained from reliable sources, such as the most recent reports from the Intergovernmental Panel on Climate Change (IPCC), the Food and Agriculture Organization (FAO) of the United Nations and the United Nations (UN), reports from state agencies such as the Agri-Food and Fisheries Information Service (SIAP, for its acronym in Spanish), the National Center for Disaster Prevention (CENAPRED, for its acronym in Spanish) and the National Institute of Statistics and Geography (INEGI, for its acronym in Spanish), as well as the scientific platforms Science Direct and Redalyc, consulting research papers focused on climate change and agriculture.

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Climate variability and extreme events in Mexico

Precipitation

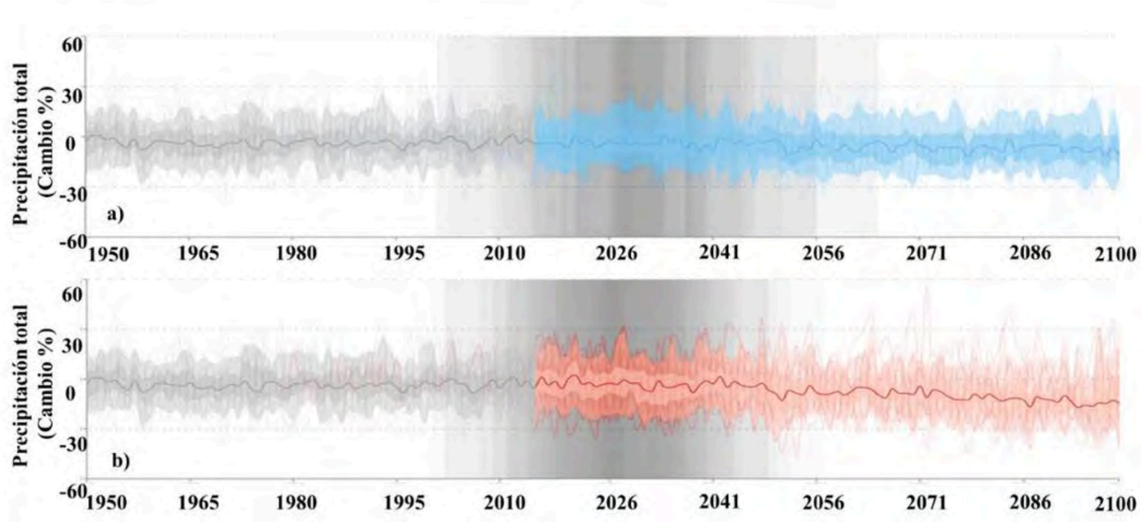
In the Mexican territory during the period 2005-2021, there was an average annual rainfall of 778.2 mm, with an average of 400.4 mm in the northwest, 554.3 mm in the northeast region, 811.2 mm in the east region, 880.5 mm in the center and 1 567 mm for the south (CONAGUA, 2022). The southern and central regions of Mexico are historically the ones with the highest amount of accumulated annual precipitation; this situation is due to the abundance of tropical cyclones, both in the Pacific Ocean and in the Gulf of Mexico; the rainy season corresponds to the months of June, July, August, September, and October (Monterroso and Conde, 2015).

Evidence of Crow-Robayo *et al*. (2020) identified that the Neotropical region of Mexico (provinces of the Pacific Coast, Gulf of Mexico, Balsas Depression, Oaxaca, Chiapas Highlands, and the Yucatán Peninsula) has shown a more pronounced decrease in precipitation during the period 1980-2009. This situation is projected into the future; negative anomalies in precipitation are expected, with an uncertain variability of the El Niño and La Niña phenomena, causing hydrometeorological events with extreme characteristics throughout the country (Zúñiga and Magaña, 2018).

Figure 1 shows projections of total annual precipitation through the end of the year 2100, based on observations from the period 1850 to 1900, using general circulation models (GCMs) from the Coupled Model Intercomparison Project (CMIP6) from https://interactive-atlas.ipcc.ch/. These scenarios are available in the different GCMs of the latest report of the Sixth Report of the Development Plan (IPPC), considering two levels of the shared socioeconomic pathway (ssp), ssp2-4.5 (medium) and ssp5-8.5 (high) (IPCC, 2022).

These values are derived from an average of 32 GCMs, which indicate that, for the ssp2-4.5 scenario by the end of 2100, an overall decrease in precipitation of up to 10% could be expected in the Mexican territory (Figure 1a), while this situation could be of greater impact in the ssp5-8.5 scenario (Figure 1b), with an overall decrease of up to 20% of the accumulated precipitation by the end of the 21st century. This poses a serious problem for rainfed and irrigated corn production.

Figure 1. CMIP6 climate change scenarios for Mexico, variable: annual accumulated precipitation. a) ssp2-4 forcing; and b) ssp5-8.5 forcing (https://interactive-atlas.ipcc.ch/).



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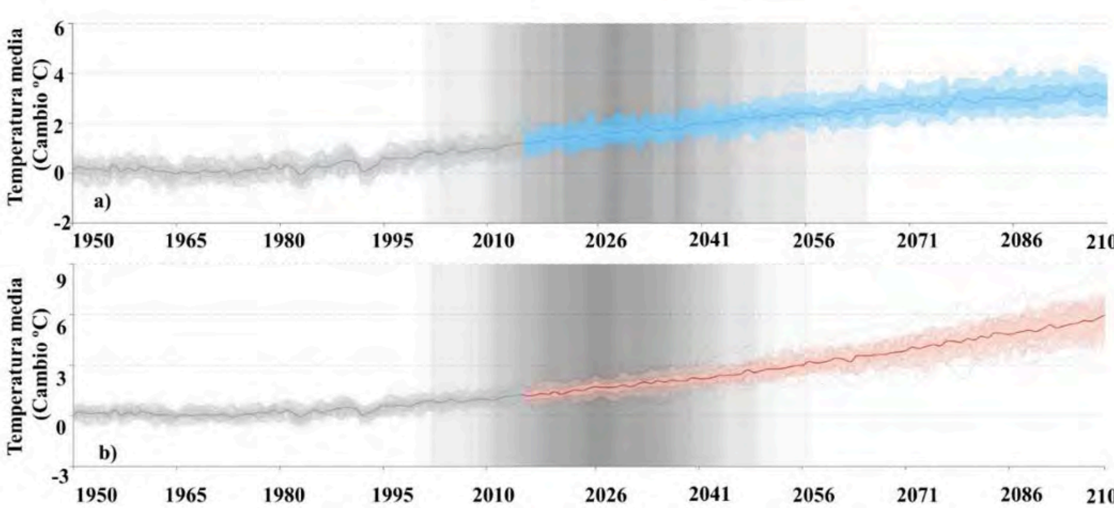
Temperature

CONAGUA (2022) reported that during the period 2005-2021, the average annual temperature for Mexico was 22 °C, with averages ranging from 25.2 °C in the southern region to the lowest temperatures with 17.6 °C in the central region. Lobato-Sanchez *et al*. (2017) analyzed the anomaly of 112 meteorological stations distributed throughout the country during a period of 64 years (1950-2013); of these, 84 correspond to positive anomalies (warming) and 28 to negative (cooling), the greatest change in temperature, with values between 1 and 3 °C, occurred in the north and northwest, being the most affected regions, followed by the Central and Pacific regions, with ranges of increase between 1 and 2 °C, and with the smallest changes on the Coast of the Gulf of Mexico, being less than 1 °C.

The Climate Change Research Program of the National Autonomous University of Mexico (UNAM, for its acronym in Spanish) has identified an anomaly in the annual average temperature, indicating that, until 2021, there has been an increase of 1.31 °C in the average temperature in the country since 1910 (PINCC, 2022). According to the IPCC, the future projections obtained through the simulation of the CMIP6 GCMs to model the average temperature of Mexico indicate that from the ssp2-4.5 pathway (Figure 2a), an increase in the average temperature of up to 3 °C is expected by the year 2100, while in the forcing to the ssp5-8.5 pathway (Figure 2b), an increase of up to 6°C is projected by the end of this century, putting at risk the life of multiple ecosystems in addition to agricultural production (IPCC, 2022).

Figure 2. CMIP6 climate change scenarios for Mexico, variable= average temperature. a) ssp2-4.5 pathway; and b) ssp5-8.5 pathway (https://interactive-atlas.ipcc.ch/).



Extreme events

In Mexico, it is common for hydrometeorological events to occur; floods, droughts, frosts, and hailstorms are the ones with the most significant impact on corn production; these events have been perceived with greater intensity and recurrence in the last 20 years, having effects in different regions where they are very common and in some others, they are considered as atypical phenomena or extreme events (Monterroso and Conde, 2015; CENAPRED, 2020).

Extreme events, when they impact corn production, imply a considerable decrease in the quantity and quality of the product, even total losses, which causes a reduction in industrial activity due to the scarcity of inputs, a rise in agricultural prices, and an increase in grain imports, in addition to conditioning food security and the socioeconomic well-being of producers and consumers (CENAPRED, 2014).

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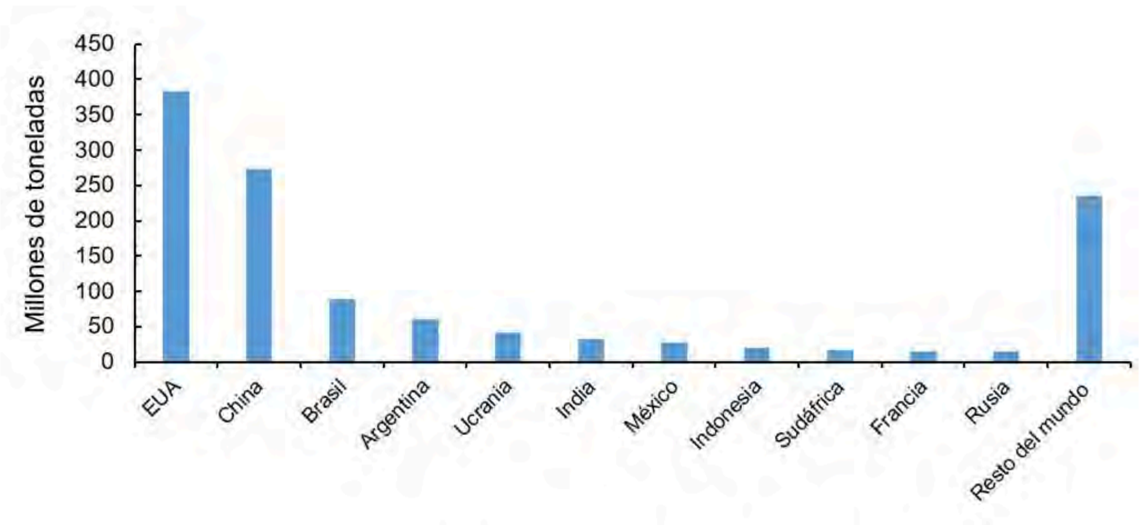
Corn production in the world and Mexico

Corn is one of the most important food crops in the world; in 2021, it represented 40% of the world's cereal production; it is considered the most important crop in terms of production volume and human consumption; in the same year, the cultivated area in the world was more than 1 600 million hectares, of which 50.9% was destined for the sowing of cereals, with corn and wheat being the two most important with 29.7% and 29.1%, respectively; Mexico ranked seventh in the largest corn producers, as shown in Figure 3 (Ureta *et al*., 2020; FAO, 2023).

Figure 3. World corn production 2021 (FAO, 2023).



The statistical records of the Agri-Food and Fisheries Information Service (SIAP, for its acronym in Spanish) indicate that, in 2020, a production of 21 885 170 t of grain corn was reached in Mexico, with a planted area of 7 481 137 ha; Figure 4 shows the leading producing states, Sinaloa (28.6%), Jalisco (9.7%), Guanajuato (7.1%), Michoacán (6.6%) and the State of Mexico (5.6%) (SIAP, 2020). During the period from 2005 to 2020, an average area of 7.3 million hectares of corn was sown, of which 20.4% (1.5 million ha) correspond to irrigation, while 79.6% (5.8 million hectares) was developed under rainfed conditions (Figure 5), with an average yield of 7.7 t ha^{-1} and 2 t ha^{-1}, respectively, resulting in an average production of 18.1 million tonnes (SIAP, 2020).

In this same period of time, the average consumption of white corn was 22 million tonnes, and that of yellow corn was 14 million tonnes, so an average deficit of 17.9 million tonnes is identified, which were imported annually to meet the demand in the country (Reyes *et al*., 2022).

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Figure 4. Leading corn producers in Mexico (SIAP, 2020).

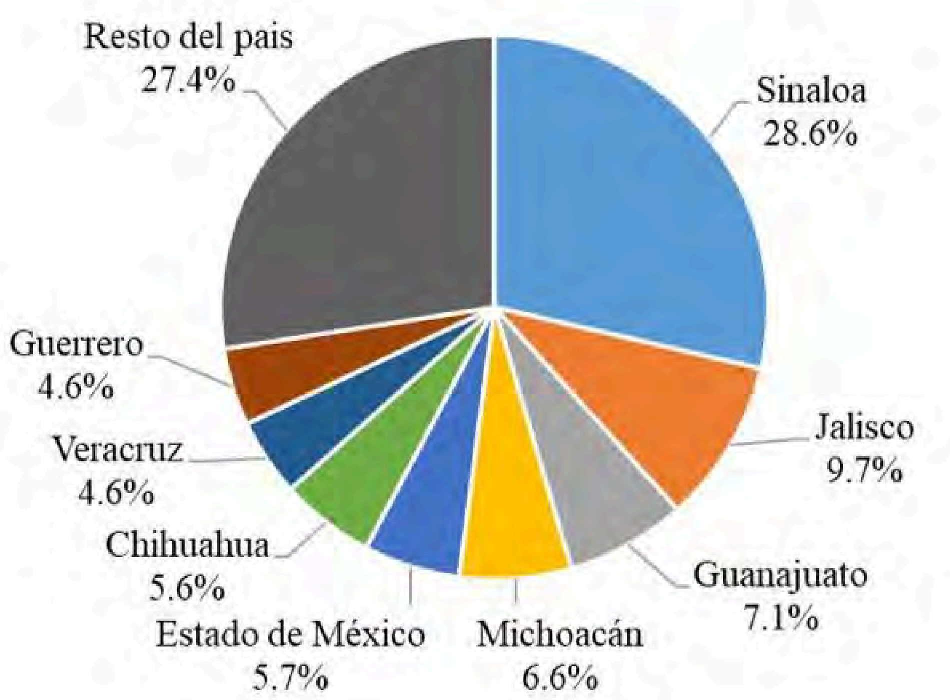
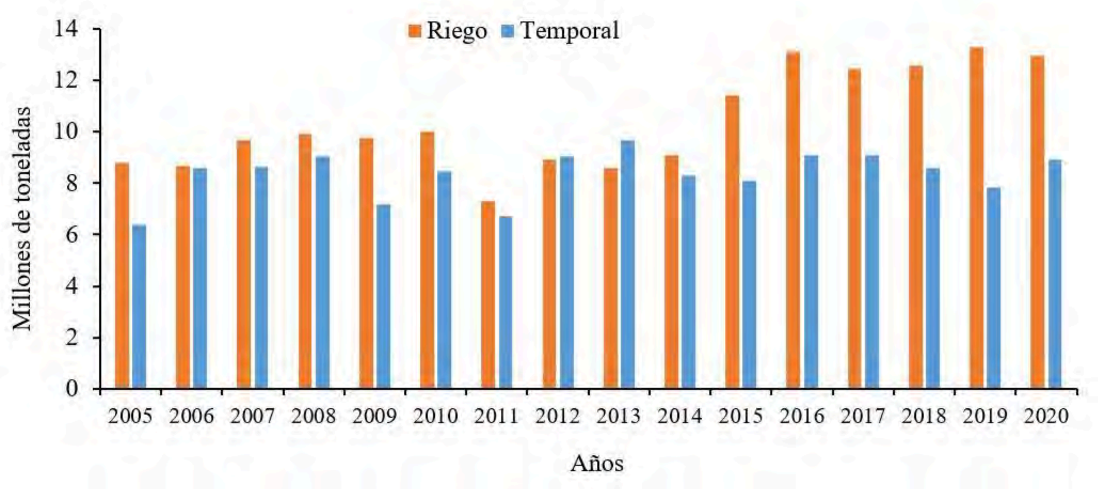


Figure 5. Historical corn production in Mexico, a comparison between irrigation and rainfed conditions (SIAP, 2020).



Effects of climate change on corn cultivation

At a global level, it has been identified that climate change and climate variability directly influence the most important requirements for the establishment of a crop and that directly affect all phenological stages; it has been identified that the growth and flowering phases of plants are the most vulnerable to extreme weather events (Mastachi-Loza *et al*., 2016).

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This situation considerably impacts corn production as this crop is sensitive to adverse weather conditions such as water stress, heat, frost, hailstorms, and drought, which can potentially reduce yields and even condition production. Sustained increases in temperature and the decrease in soil water can modify the phenological cycle of corn, negatively impacting grain yields (Leng, 2019; Lv *et al*., 2020; Baum *et al*., 2020; Noein and Soleymani, 2022).

Climate variability advances or delays the sowing season of corn, postpones harvest time, and generally shortens the vegetative growth phase, lengthening the reproductive growth phase, and it has also been identified that the crop presents changes in times of germination, emergence, panicle formation, and plant maturity (Lizaso *et al*., 2018; Lv *et al*., 2020).

Specialized software has been used to simulate corn cultivation based on climate change scenarios, in which it has been possible to demonstrate that the increase in temperature and changes in precipitation patterns are the main factors that influence the phenological cycle of corn, which impacts according to the geographical latitude in which it develops since at high latitudes, longer and more beneficial growth cycles have been observed, while at low latitudes, there is a shorter production cycle with lower yields (Welikhe *et al*., 2016; Nandan *et al*., 2021; Wilson *et al*., 2022). Temperature increases would translate into increases in Growing Degrees Days (GDDs) for corn; an increase in GDD accumulation impacts the rapid development of corn phenology, reducing its life cycle (Ruiz *et al*., 2011).

This situation has an important impact as the corn crop reduces its time to use the available resources for the maximum growth, development, and yield of its genetic potential (Welikhe *et al*., 2016).

The thesis of Ruiz *et al*. (2011) mentions that an increase in the ambient temperature affects the phenology of corn and its yield since, as the time of the maturity cycle decreases, the life phases shorten, the leaf area decreases, the production of photosynthates, the production of biomass and grain filling are limited. In addition to the above situation, in general, an increase in temperature and precipitation levels favors the growth and distribution of pest and weed species by providing a warm and humid environment, which enriches the necessary conditions for their development and adaptation (Skendži# *et al*., 2021).

Considering the water aspect, Villalobos-González *et al*. (2017) mention that the water deficit in corn causes a reduction in the expansion of the leaf area, a delay in the anthesis and female flowering stages, a reduction in grain yield and the number of grains per ear of corn. Çakir (2004) found that water deficits during the vegetative growth period can cause losses of 28% to 32% of the final dry matter weight, while during tassel formation, these effects could be greater.

Impacts of corn yields in the face of climate change

Results from Ureta *et al*. (2020) identified that the effects of climate change on corn cultivation will have negative impacts on yield (t ha^{-1}) in rainfed fields, while in irrigated fields, it will remain stable, as long as the water condition is not limited. A very important impact on the future modeling of corn is the increase in GDDs due to temperature increases; thus, the GDDs accumulated during May-October in the subtropical region, which currently hosts the most productive rainfed corn-growing areas in the country (Jalisco, Guanajuato, and Michoacán), will go from 2061 GDDs of the historical period 1961-2003 to 2190, 2163, and 2410 GDDs on average in the decades 2011-2020, 2031-2040, and 2051-2060, respectively (Ruiz *et al*., 2011).

Murray-Tortarolo *et al*. (2018) modeled the relationship between climate and rainfed agriculture based on four representative concentration pathways (RCPs), in which rainfall throughout the country was projected to decrease slightly through RCPs 2.6 and 4.5, while with RCPs 6.0 and 8.5, the reduction is expected to be severe; as a result, rainfed corn yields were predicted to decline nationwide by up to -10% under RCP 2.6, with regional reductions of up to -80% under RCP 8.5, although in some regions they could be maintained or even increase by up to 1.5% by 2100.

Ruiz *et al*. (2011) identified, through a future projection to 2050, that of five corn-growing areas in Mexico, three will show a negative impact on corn production; in the agricultural areas of the tropics

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(< 1 200 masl) and subtropics (1 200 to 1 900 masl), this is due to an increase in temperature; in the transition zone (1 900 to 2 200 masl), this is due to a negative water balance, while in the areas of high valleys (2 200 to 2 600 masl) and very high valleys (> 2 600 masl), optimal conditions are predicted for corn, as the variables that favor the crop (precipitation, evapotranspiration and moisture index) will increase.

Using climate projections, Arce-Romero *et al*. (2018) estimated corn yields for central Mexico, a higher yield was identified towards the near horizon (2020-2039) with the RCP 8.5 scenario, so the increase in temperature could be beneficial in the short term; with the RCPs 4.5 and 8.5, it is expected that for the medium horizon (2045-2069), there will be a reduction in yield of up to -1.5 t ha^{-1} compared to the reference production, which leads to a decrease of 46.7%, while for the distant horizon (2075-2099), crop yields of up to 1.6 t ha^{-1} are expected with RCP 8.5.

Climate change adaptation and mitigation measures

The adoption of climate change adaptation and mitigation strategies has as its main focus to increase agricultural productivity, as well as develop the resilience of farmers to this phenomenon; it is an important and necessary task to preserve this activity in the future, with the purpose of guaranteeing the food sustainability of a people (Bedeke *et al*., 2019).

Studies such as those by Adeagbo *et al*. (2021) recommend some practices to minimize the impact of climate change on corn production: intercropping, crop rotation, early sowing, using drought-tolerant varieties, changing chemical to organic fertilization, incorporation of organic matter, minimum or conservation tillage, agroforestry, irrigation systems, and water and soil conservation practices. These strategies are applied at the plot level and can be interrelated simultaneously or sequentially (Bedeke *et al*., 2019). In Mexico, depending on their experience, peasants have a variable capacity to adapt and respond to the effects of climate change through different culturally inherited practices (Mastachi-Loza *et al*., 2016).

To minimize losses in corn production, programs to improve current production technology could be implemented, the regions with the greatest impact could be prepared through strategies such as regional and exotic-adapted germplasm management, change of sowing date, application or increase of organic covers, migration to new areas of opportunity to carry out this activity and maintain investment costs (Ruiz-Corral *et al*., 2011; Arce-Romero *et al*., 2018; Ureta *et al*., 2020).

Authors such as Ruiz-Corral *et al*. (2011) developed a dendrogram of 48 Mexican varieties of landrace corn, considering four agroclimatic variables, in which it was determined that corn production in the face of climate change will be concentrated in the future in environments with high temperatures and deficient moisture, for which it is recommended to work with the genetics of the races: Chapalote, Blando de Sonora, Tuxpeño Norteño, Onaveño, Ratón, Dulcillo del Noroeste, Dzit Bacal and Elotero de Sinaloa, which present a better response and adaptation to these natural conditions in each producing area.

Future uncertainties in food security

Total or partial losses in corn crops severely affect the farmer's economy as it is often their only source of income or, as the case may be, their only source of livelihood (FAO, 2017). This phenomenon will increase the gap in achieving some goals of the Sustainable Development Agenda, no poverty, zero hunger, health, and well-being (ONU, 2016). FAO (2017) mentions that the food security of a region is compromised by the scarcity or decrease of basic crops; INEGI (2020) reported that the population of Mexico was 126 014 024 people, who stock up on the corn that is grown and harvested in the country. The annual per capita consumption of corn is 120.5 kg per year; it is considered that 94% of the population consumes it in tortillas; it is a basic element on the table of all families and a pillar in Mexican livestock farming (Ortiz-Rosales and Ramírez-Abarca, 2017).

CONAPO (2019) reports that population growth in Mexico by 2050 will reach 148.2 million inhabitants, which will significantly increase the demand for food, including corn. During the period

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2015-2020, an annual average of 15 193 750 t of corn was imported, mainly from the United States of America and Brazil; this figure is projected to increase in the future, possibly generating a crisis due to national and global shortages (FAO, 2022).

Important factors such as investment costs, low yields (t ha^{-1}), and corn prices do not guarantee a livelihood for small-scale farmers; investment capital is under latent risk, and in the event of a disaster, it is likely that they will not have the resilience to be able to reinvest; therefore, they decide to change their land use or, where appropriate, abandon agricultural activities (Giller *et al*., 2021).

Conclusions

From the literature consulted in this essay, it is found that climate is one of the most important factors in agricultural productivity, which can influence directly or indirectly since it is linked to physiological processes that occur in the plant. The impact of climate change and climate variability on corn production is an unavoidable condition at a global level, the repercussions of which trigger multiple effects on different sectors; this activity is highly vulnerable and with little resilience, which indicates a serious risk to food security in the country and the economy it supports.

Knowing the danger associated with climate change and the relationship with the corn crop, which turns out to be highly sensitive to fluctuations in temperature and precipitation, resulting in low yields (due to frosts, droughts, floods, and other disasters), allows managing the different hydrometeorological risks from an integrated management and agricultural decision-making perspective. Adopting adaptation and mitigation measures will guarantee the productivity of corn in the country, as well as the cushioning of the impacts on the productive and economic processes involved, resulting in better resilience for farmers.

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