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Article

Analysis of temperature and precipitation in two avocado-growing areas of the state of Morelos: period 1956-2019

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Abstract

Due to its edaphoclimatic conditions, the state of Morelos has a high potential for the development of the avocado industry, however, it faces the threat of the modification of the optimal temperature and precipitation conditions for the production of *Persea americana* Mill., cultivar Hass. The objective of this work was to identify the modifications in temperature and precipitation in three periods in two avocado-growing areas in Morelos in 2019. Two climatological stations were selected, one in Cuernavaca and another in Tetela del Volcán, for the temporal analysis three periods of five years each were established from the year 1956 with a difference of 30 years between periods. An analysis of variance was performed, Fisher's LSD statistical test was used to find differences between the means of the parameter values (0.05). Significant differences were found in the maximum temperature for the municipality of Cuernavaca, as well as in the minimum temperature in Tetela del Volcán, both with a tendency to increase. Precipitation analysis showed a significant increase in the means by period in both localities. It is concluded that the results obtained point towards an increase in temperature in the study sites of importance in the production of avocado. Precipitation shows an increase in annual volume in current years; nonetheless, the main threat to the cultivation of this fruit is the lag of the season and the amount in which the rains occur.

Keywords: avocado, climatic conditions, production.

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Introduction

The observation of alterations in climatological variables as a result of human activity in the last century has aroused a growing concern about the impacts they could cause in different natural and human systems (IPCC, 2014; Molina *et al*., 2017). Agriculture is a sector particularly vulnerable to changes in climatological factors, as they influence crop development directly and indirectly (FAO, 2017). This is because the increase in temperatures ends up reducing the production of the desired crops, while causing the proliferation of weeds, pests and diseases (FAO, 2009; Ojeda *et al*., 2011).

Temperature is a major factor in crop production, as it affects the rate of development and growth (FAO, 2020). Any modification of its values in a certain area will cause the behavior of crops to be different (Jarma-Orozco *et al*., 2012). For its part, precipitation is essential to achieve the success of harvests. However, cultivated areas face extreme problems of gradual changes in this climate element, ranging from fluctuations in their presence (early or late), floods or prolonged droughts that translate into decreases in production (Granados *et al*., 2008).

Regarding the impacts derived from this climate imbalance, Mexico is especially vulnerable since most agricultural and forestry systems are critically dependent on climate, as well as due to its geographical location, topography and socioeconomic aspects (Villafán *et al*., 2007; SEMARNAT-INECC, 2012). Within the agricultural production in Mexico, avocado (*Persea americana* Mill.) is one of the most important fruit crops with a production of 2 300 888.9 Mg.

Mexico is a leader in its cultivation and export with a contribution of 45.95% of the value of world exports (SIAP, 2019). The socioeconomic importance of avocado derives from the benefit to producers, marketers, industrializers and consumers (Téliz, 2015, SAGARPA, 2017).

In the state of Morelos, the avocado industry presents a high potential for development due to the edaphoclimatic and physiographic characteristics. In 2019, the production was 53 347.27 Mg with a value of 795.6 million pesos. Some growing municipalities are Ocuituco, Tetela del Volcán, Yecapixtla, Totolapan and Tlanepantla. The average yield is 9.31 t ha^{-1} (SIAP, 2019). The avocado grown in Morelos meets national and international quality standards, so it becomes attractive for packaging plants and marketers outside the state (Balzadúa, 2018). On the planet there are different races and varieties of avocado, in Mexico the one that is produced in greater volume is 'Hass', due to its characteristics for trade.

The climatic requirements vary according to the race, and the Hass avocado can tolerate temperatures of up to -4 °C for short periods of time and up to 35 °C. For their part, the extreme temperatures for fruit setting are 12 to 17 °C in the lower limit and 28 to 30 °C in the upper limit. For the succession of flowering and fruiting stages, temperatures of 12 to 13 °C are required (Ruiz *et al*., 2013). The precipitation requirements for avocado vary according to the race, in the case of the Mexican race the necessary range is between 650 to 2 200 mm. In general, avocado naturally does not thrive in environments with precipitation less than 650 mm, so irrigation is required when introduced to drier environments (Coria, 2009; Rocha *et al*., 2011; Téliz and Mora, 2015).

This is how the modification of temperature, as a result of climate variability, can alter the thermal threshold necessary for the crop to thrive in certain growing areas. Regarding the relationship with climate change, Howden *et al*. (2005); Putland *et al*. (2010) established that this phenomenon can affect avocado production mainly because of its effect on temperature-sensitive phenological stages, such as flower differentiation, anthesis, fruit setting and development.

Avocado production in the state of Morelos has a high potential for development due to its soil characteristics, geographical location and altitude. However, it can be affected by several factors in its production and one of them by climate variations, which have currently occurred with greater intensity. The objective of the present study was to identify the changes in the climatic variables of temperature and precipitation at the local level in three periods of time that can alter different processes in the production of this fruit in two avocado-growing areas of this state.

Materials and methods

Study site

The study was conducted in two municipalities in the state of Morelos, Cuernavaca and Tetela del Volcán. Cuernavaca is one of the 33 municipalities that make up the state of Morelos, belongs to the northwestern region, is bordered to the north by the municipality of Huitzilac, to the northeast by Tepoztlán, to the east by Jiutepec, to the southeast by Emiliano Zapata, to the south by Temixco and to the west by the State of Mexico. It is located between 18° 50’ and 19° 2’ north latitude and at 99° 11’ and 99° 20’ west longitude of the Greenwich meridian, with an average altitude of 1 831 masl. The area calculated is 205 km^2, a figure that represented 4.9% of the area of the entire state (Programa de Ordenamiento Ecológico del Territorio del Municipio de Cuernavaca, Morelos, 2018). The municipality of Cuernavaca has two agrohabitats: III-C-2 and II-B-2.

The first is characterized by a temperate subhumid climate [C(w2)], a rugged topography (mountainous), acrisol soils, an altitude ranging from 2 000 to 2 800 masl, its precipitation and average annual temperature is 1 300 mm and 16 °C respectively, it covers an area of 39 102 ha, which corresponds to 7.89% of the state. The second has a semi-warm (cool) climate [A(c)], irregular topography (mountainous), Andosol soils, a height masl ranging from 1 400 to 2 000 m. Its precipitation and average annual temperature are 1 000 mm and 21 °C respectively, P/T ratio= 52.3%, it covers an area of 90 713 ha, which corresponds to 18.3% of the state area (Ornelas *et al*., 1990).

Tetela del Volcán is one of the 33 municipalities that make up the state of Morelos, is located in the far northeast and on the slopes of the Popocatépetl volcano, is bordered to the west by the municipality of Ocuituco and to the south by the municipality of Zacualpan de Amilpas, to the north by Ecatzingo and Atlautla, municipalities of the State of Mexico, to the east by Tochimilco and Atzitzihuacán of the state of Puebla. Its location is between 18° 49’ and 19° 01’ north latitude and 98° 47’ west longitude, the altitude varies from 1 700 to 5 000 masl. The total territorial area is 98.5 km^2. The agrohabitats IV-C-5, III-C-1 and III-B-1 are located in Tetela del Volcán.

The first is characterized by a semi-cold climate [C (w2) (b)], rugged topography (ranges), lithosols soils are very thin, susceptible to erosion, so they are not suitable for agricultural activities, they are generally occupied with natural vegetation and their most appropriate use is silvicultural. It corresponds to the highest part of the Sierra del Ajusco, it is bordered by Popocatépetl, at altitudes between 2 800 and 4 000 m above sea level, its precipitation and average annual temperature is 1 500 mm and 12 °C, respectively, P/T ratio= 125, it covers an area of 25 244 ha, which corresponds to 5.09% of the total state area.

The second and third agrohabitats have a temperate subhumid climate [C (w2)], acrisol soils which are very acidic, so they are generally not exploited agriculturally, are of low fertility, are in rugged topography (ranges and hills) and are easily erodible, their most appropriate use is forestry. An altitude ranging from 2 000 to 2 800 m, its precipitation and average annual temperature is 1 300 mm and 16 °C respectively, P/T ratio= 81.3%, it covers an area of 39 102 ha, which corresponds to 7.89% of the state. A topography of mountain ranges and hills, respectively (Ornelas *et al*., 1990).

Data and analysis

A meteorological station was selected in each municipality, from which, through the Comisión Nacional del Agua (CONAGUA), databases of the variables of interest were obtained. In the case of Cuernavaca, the station was the 17004, located at coordinates 18.9186 latitude and -99.2342 longitude and at a height above sea level of 1 510 m, the maximum temperature, minimum temperature and daily precipitation of the period 1956 to 1960, 1986 to 1990 and 2016 to 2019 were considered. The station of Tetela del Volcán corresponds to the 17046, located at coordinates 18.8850 latitude and -98.6903 longitude and at 2 285 masl, the daily information of the variable's maximum temperature, minimum temperature and precipitation of the period 1986-1990 and 2016-2019 was taken.

Temperature and precipitation

The following variables were analyzed: temperature (minimum and maximum) and precipitation to determine the presence of climate variability and evaluate the variation in temperature behavior, as well as significant changes in the amount of rainfall in the areas selected for the study in the different periods.

To carry out this analysis, an adaptation of the methodology proposed by Tapia *et al*. (2011) was used, for which five-year periods of daily records of the variables were established. Time intervals were established every 25 years so that they appropriately represent climate behavior in the local context.

According to the availability of the historical data recorded at the study sites, they correspond to three periods: the first from 1956 to 1960, the second to the years from 1986 to 1990 and the current one from 2016 to 2019. Subsequently, they were compared to know the differences between these three time periods (Table 1).

Table 1. Periods for the analysis of the modifications of the climatic variables.

Period	Cuernavaca	Tetela del Volcán
A	1956-1960	Not available
B	1986-1990	1986-1990
C	2016-2018	2016-2018

Data analysis

The daily data of each of the years of analysis were recorded in individual spreadsheets and a control of the data from the climatological stations was applied, for this the complete series were reviewed, in such a way that there were no anomalous data such as inconsistent temperature values, for example, maximum temperature less than the minimum temperature or precipitation values less than zero. To make the spatiotemporal analysis of the data obtained, they were grouped by locality, period, year, month, precipitation, maximum temperature, minimum temperature. Subsequently, an analysis of variance was performed with the Statistical Analysis System (SAS 9.0) program to determine the existence of interaction and significant differences in the two meteorological stations of Cuernavaca and Tetela del Volcán.

The method of Fisher's least significant difference (LSD) was applied to determine differences between the means of the parameter values ($p \leq 0.05$). The two localities (Cuernavaca and Tetela) were analyzed separately, the years as treatments and the months were taken as blocks. Subsequently, the localities were analyzed separately, taking the periods as treatments and the months as blocks. Finally, a combined temporal analysis was performed.

Results and discussion

Table 2 shows the annual averages by period of the maximum and minimum temperatures of the two avocado-growing areas of Cuernavaca and Tetela del Volcán, Morelos. Increases in temperatures reported by the meteorological stations studied are observed.

Table 2. Annual average of the maximum and minimum temperatures of the two study localities.

Period	Year	Cuernavaca		Tetela del Volcán	
		T° max (°C)	T° min (°C)	T° max (°C)	T° min (°C)
A	1956	26.46 ef	13.67 b	-	-
	1957	27.8 cd	14.89 a	-	-
	1958	26.7 e	14.9 a	-	-
	1959	26.78 e	15.08 a	-	-
	1960	27.52 d	15.34 a	-	-
B	1986	25.76 g	15.01 a	22.77 cd	6.21 de
	1987	26.14 efg	15.01 a	23.07 c	5.94 de
	1988	26.23 efg	15.21 a	24.29 b	5.75 e
	1989	26.02 fg	14.88 a	26.07 a	6.39 d

Period	Year	Cuernavaca		Tetela del Volcán	
		T° max (°C)	T° min (°C)	T° max (°C)	T° min (°C)
C	1990	26.48 ef	15.07 a	22.8 cd	10.11 bc
	2016	28.38 bc	15.05 a	21.69 d	10.9 a
	2017	28.26 bc	14.73 a	24.49 b	10.43 ab
	2018	28.63 b	15.31 a	24.47 b	10.53 ab
	2019	29.36 a	15.07 a	22.95 cd	9.78 c

Means with the same letter are statistically equal (by locality) according to the LSD test (0.05).

In Cuernavaca, the average maximum monthly temperatures show a similar behavior in the three periods, that is, the highest temperatures are recorded in April and May, while the least hot months are December and January (Figure 1). However, it is possible to observe that, in Cuernavaca, the temperatures of the most recent period of records are above the other two, which may indicate that maximum temperatures are slightly higher in recent years than in 1956-1960 and in 1986-1990. In the case of Tetela del Volcán, the record of the highest temperatures occurred in April for period B, while for period C it was in March. The least hot months September, October and January (Figure 2).

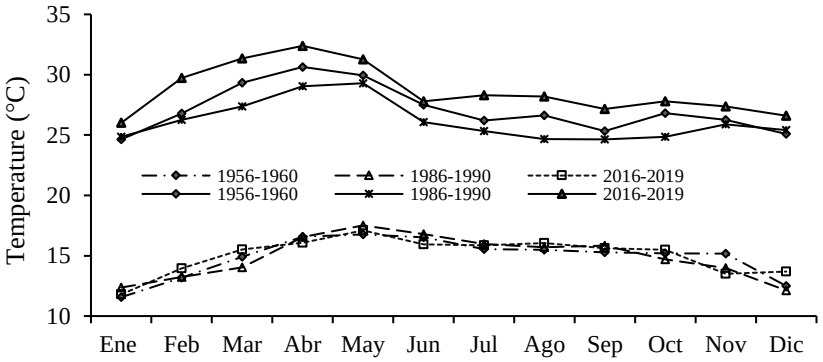

Figure 1. Behavior of the maximum and minimum monthly temperatures by period in the locality of Cuernavaca, Morelos.

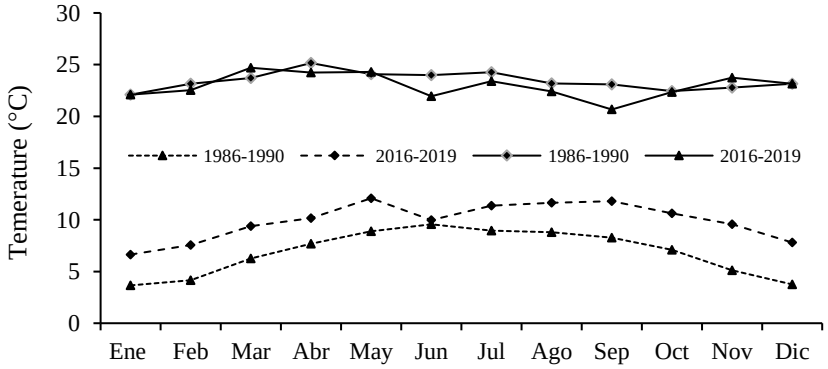

Figure 2. Behavior of the maximum and minimum monthly temperatures by period in the locality of Tetela del Volcán, Morelos.

According to the analysis of Fisher's LSD, Cuernavaca presented significant differences in its maximum temperatures, between the periods 1956-1960, 1986-1990 and 2016-2019, with 27.08 °C, 26.13 °C and 28.68 °C respectively, with the most recent period being the warmest with an increase of 2.55 °C, which shows that, in recent years, temperatures have been higher than in previous periods. However, it was identified that Tetela del Volcán did not have significant differences between the analysis periods (Figure 3).

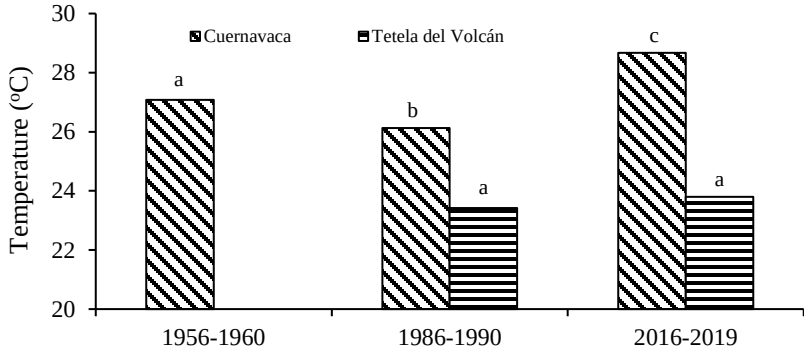

Figure 3. Maximum temperature by period in the localities of Cuernavaca and Tetela del Volcán. Means with the same letter are statistically equal (by locality) according to the LSD test (0.05).

Regarding the minimum temperatures in Cuernavaca, in the three periods the lowest was recorded in January, being 11.56 °C, 12.35 °C and 11. 79 °C for periods A, B and C, respectively. In the locality of Tetela del Volcán, the average minimum temperatures, it coincides that the lowest occurred in January with 3.6 °C and 6.6 °C for periods B and C, respectively.

The minimum monthly temperature of Cuernavaca analyzed by period shows a minimum variation, indicating the months of December, January and February as the coldest months, with temperatures below 15 °C (Figure 1). While the minimum monthly temperature by period in Tetela del Volcán has increased between 1 to 4.5 °C, the coldest months were December and January. The annual behavior of the minimum temperature for the municipality of Cuernavaca presented significant differences, the coldest year was recorded in 1956 (Table 1). The increases in the minimum temperature are more marked in Tetela del Volcán, it is highlighted that the minimum temperatures of the years of the period 2016-2019 increased considerably compared to those of the period 1986-1990 (LSD, α= 0.05) (Table 1).

When performing the analysis by period, it does not indicate significant differences of the minimum temperature in Cuernavaca. On the other hand, in Tetela del Volcán, a significant difference was identified in the means between periods, which were 6.88 °C and 10.41 °C for periods B and C respectively, which represents an increase of 3.45 °C (Figure 4).

It was identified that, according to the limit requirements of the crop, the orchards that are located in Cuernavaca are more vulnerable to temperature changes, especially to an increase in it, which has been shown to be the trend with Climate Change (IPCC, 2014), therefore, the importance and need for conducting this type of studies in the state of Morelos is reflected. Based on the historical records of temperature and precipitation obtained from CONAGUA, it was possible to carry out an analysis of the variations that have occurred over the years. It was identified that there have

been modifications in the maximum temperature in the locality of Cuernavaca (station 17004) as it shows significant differences (LSD 0.05) in the increase of this climatic element from period C with respect to B.

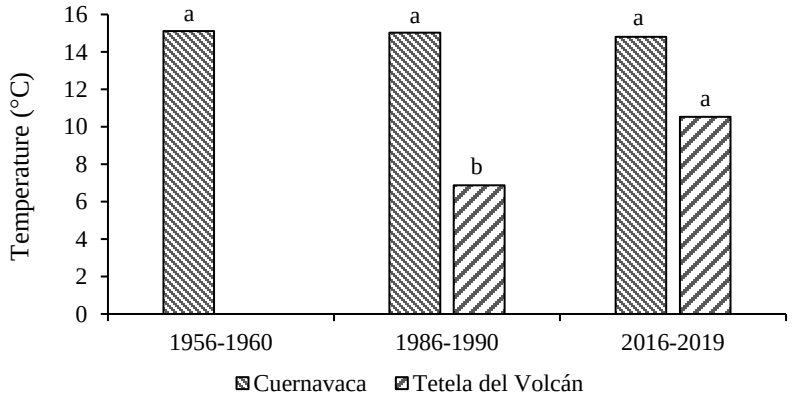

Figure 4. Average minimum temperature by period in the localities of Cuernavaca and Tetela del Volcán. Means with the same letter are statistically equal according to the LSD test (0.05).

As can be seen during the period 2016-2019 of the producing area of Cuernavaca, the general trend is an increase of 2.5 °C in the average maximum temperature; while in Tetela del Volcán, the maximum temperature remains stable during the two periods studied (Figure 3). This coincides with what was reported by Bolongaro *et al*. (2013), who, after analyzing the temperature records of various meteorological stations in the state of Morelos in the period 1961 to 2008, found that the data show a behavior of increase in the maximum temperature and in the number of warm periods in the state, although the present study was broader.

The temperature is closely related to the productivity of avocado since it governs the succession of the phenological stages, influences numerous physiological processes. It has been documented that any change in its values in a given agroecological zone affects production (FAO, 2009; Rocha-Arroyo *et al*., 2011; FAO, 2017). Avocado has very specific ecophysiological characteristics, its climatic and edaphic requirements vary depending on its phenology. In Morelos, there are two important flowering seasons, the normal one which occurs from September to November (70%) and the crazy flowering which takes place during January and February (30%) and which is the one that reaches the best prices.

It requires temperatures of 12.7 to 17 °C, so this process would not be affected by the changes in temperature observed in the last study period, the fruit setting stage will be compromised in the area of Cuernavaca and Tetela del Volcán, since the maximum temperatures are above 25 °C during the rest of the year (Figures 2 and 3) (Ruíz *et al*., 2013; Téliz and Mora, 2015; Castro-Acosta *et al*., 2022).

Studies such as those carried out by Ortíz and Ortega (2015) calculated the indices of vulnerability to climate change in the avocado-growing area of Michoacán and their results show that the projections of temperature increase show values above the average. In addition, temperature indices in the regions under study provide clear evidence of an increasing trend in the frequency of hot

days. For their part, Álvarez *et al*. (2017) mention that an increase in the maximum temperature could represent a limiting factor for the Hass cultivar in Michoacán, since high temperatures (33 °C) during flowering not only shorten the period of flower opening, but also reduce the number of flowers that open.

This can pose a threat to the cultivation of avocado in Morelos, since an increase in temperatures over time was demonstrated and in localities such as Cuernavaca and Tetela del Volcán, they are already close to the critical temperature threshold, especially for the crazy flowering that represents 30% of the annual flowering and is the harvest that reaches the best price in the market. Regarding the minimum temperature, the municipality of Tetela del Volcán (station 17046) showed an increase in all months of the current period, except for June, compared to the period of 1986-1990. This increase in minimum temperatures was significant from period B to C.

In the analysis of precipitation in both meteorological stations, it was observed that Cuernavaca has a greater volume of rain than Tetela del Volcán and in general, there have been increases in the amount of precipitation in both sites as the periods are more recent (Table 3).

Table 3. Accumulated precipitation by year in the municipalities of Cuernavaca and Tetela del Volcán.

Period	Year	Cuernavaca		Tetela del Volcán	
		Accumulated	Mean	Accumulated	Mean
A	1956	994.2	21.17 bc		-
	1957	591.8	17.27 c		-
	1958	1 813.5	37.59 a		-
	1959	1 027.3	21.4 bc		-
	1960	1 037.9	21.62 bc		-
	1986	1 263.8	27.26 abc	1 006.4	20.3 a
B	1987	1 291.7	26.91 abc	812.8	16.93 a
	1988	1 084.3	22.42 bc	1 188.9	24.73 a
	1989	1 062.6	22.14 bc	895.9	18.66 a
	1990	1 496.1	31.17 abc	1 250.5	25.51 a
C	2015	1 330.2	34.74 a	1 133.8	25.13 a
	2016	1 751.7	29.15 abc	1 366.2	25.44 a
	2017	1 410.8	35.78 a	1 221.2	25.52 a
	2018	1 717.5	30.65 ab	1 221.2	22.82a
	2019	1 407.53	27.26 abc	1 096.14	20.3 a

Means with the same letter are statistically equal (by locality) according to the LSD test (0.05).

The averages of the accumulated precipitation of the three periods studied allow evidencing this increase in precipitation in the different periods, being that for Cuernavaca in period A the average was 1092.9 mm, in B it was 1 239.7 and finally in period C, which corresponds to the

last five years, the average was 1 532.4 mm, that is, a difference of 439 mm between period A and C. The same happens in Tetela del Volcán, where in the years from 1986 to 1990 the average of precipitations was 1 030.9 mm and for 2015 to 2019 it was 1 207.7 mm, with an increase of 177 mm.

Table 3 shows the annual behavior of precipitation in each of the localities, in which, through statistical analysis, significant differences were found between the years of study in the municipality of Cuernavaca, with the years 1956, 2016 and 2018 obtaining the highest values. In the case of Tetela del Volcán, despite reporting variations in annual accumulated precipitation, statistically it does not represent a significant difference by year, as can be seen in Figure 5.

Regarding the analysis by periods, in Cuernavaca for B it was 25.98 mm and finally in period C, which corresponds to the last five years, the average was 33.65 mm, which indicated a significant difference. Although the means of precipitation in the annual analysis do not show significant differences for Tetela del Volcán, in the comparison by period, the increase in rainfall was significant as observed in Figure 5.

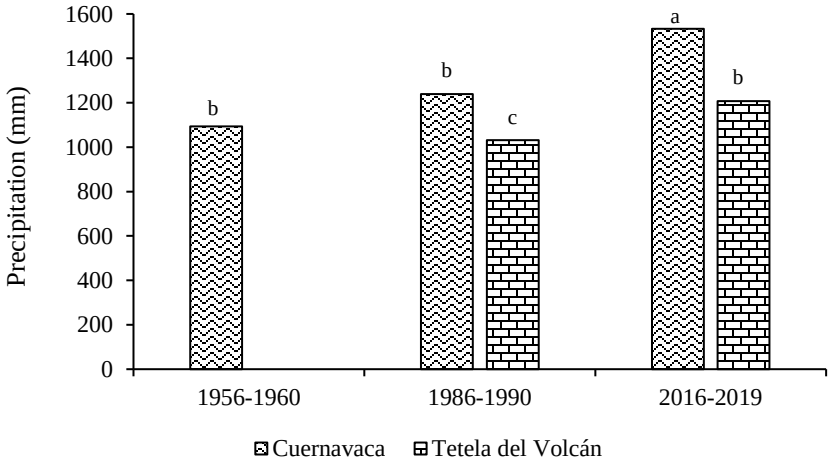

Figure 5. Behavior of annual precipitation in the localities of Cuernavaca and Tetela del Volcán by period. Means with the same letter are statistically equal according to the LSD test (0.05).

Conclusions

The results obtained point to an increasing trend in temperatures in the producing areas of Cuernavaca and Tetela del Volcán, Morelos. Precipitation presents an increase in the annual volume in current years, however, the main threat to the cultivation of this fruit is the possible lag of the season and the amount in which the rains occur. The avocado crop is vulnerable to the effects of climatic alterations, since its phenological stages are sensitive to the alteration of temperatures and the availability of water, therefore, it is essential to look for alternatives to face these changing conditions that could bring consequences, especially due to the socioeconomic importance that this crop has in the state.

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