Journal of Agricultural Sciences Research

ISSN 2764-0973 vol. 5, n. 7, 2025

ARTICLE 1

Data de Aceite: 30/10/2025

ECONOMIC VALUATION OF CORN *(ZEA MAYS L.)* AND COFFEE CHERRIES *(COFFEA ARABICA L.)* IN THREE MUNICIPALITIES OF THE LOWER LAXAXALPAN BASIN, PUEBLA, MEXICO, IN THE PERIOD 2003–2022

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Abstract: Study analyzing the economic importance of three representative municipalities in the lower Laxaxalpan River basin, Puebla, Mexico, highlighting an economic assessment of the importance of two representative crops in the region: corn and cherry coffee. The variables analyzed are harvested area (ha), average yield per hectare (tons/ha), and production value, both at current prices and deflated to 2018 prices. The average growth rates for each of the variables for both crops are determined, and in the case of corn, based on per capita consumption in the state, it is determined whether or not it contributes to the food sovereignty of the most consumed product in Mexico.

Keywords: planted area, average annual growth rate, average yield per hectare, production value.

INTRODUCTION

According to the Water Institute (IA, 2024), a hydrological basin is an area geographically defined by the boundaries of a series of mountains or other natural formations, in which all precipitation (rain, snow) that falls within it accumulates and flows toward a single outlet, which may be a river, lake, or sea. This allows us to understand and analyze how water is distributed and moves on our planet. According to the National Water Commission (CONAGUA, 2025), there are 1,471 watersheds in Mexico, which vary in size due to the country's geological and topographical diversity.

According to the UACH (2025), the Laxaxalpan basin originates with the river of the same name in the state of Tlaxcala at an altitude of 3,250 meters above sea level on the Peñon del Rosario hill, 11 km from Tlaxco, Tlax. It passes 20 km west of Chignahuapan. This stream originates under the name Tecoyuca and flows south of Chignahuapan, where it changes its name to Laxaxalpan. The river continues its course northeast through mountainous areas and valleys, passing east of Zacatlán and five km from Chiconautla, where four rivers join on its left side: Hueyapan, Pepeixco, Tlaxco, and Zempola. It then changes course to the east-northeast to cross the border of the state of Veracruz. According to SEMARNAT, there have been changes in primary activity due to the expansion of coffee cultivation at the expense of natural forest vegetation.

METHODOLOGY

The methodological process used is divided into two phases:

I) Conducting an analysis of land use and vegetation change can be a tool that gives us a general idea of the impacts of national strategies on natural resources. For this study, series III to VII were used, covering a time span from 2002 to 2022. To compare land use, INEGI vector data from the aforementioned series was used and processed with ArcMap 10.8.1 in the Geomatics Laboratory of the National Center for Disciplinary Research in Forest Ecosystem Conservation and Improvement (CENID COMEF) of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP).

II) Five-stage documentary:

First: selection of the topic to be studied. For the socioeconomic research, the topic chosen was the evolution of the harvested area of two plant species: a grass (corn) and a fruit tree (coffee cherry) in the lower Laxaxalpan River basin in three

municipalities in the state of Puebla selected because they had statistical data available: Hermenegildo Galenaa, Olintla, and San Felipe Tepatlán.

Second: gathering information from secondary documentary sources, with the aim of quantifying, organizing, and classifying it in order to measure and assess the importance of the variables. A bibliographic review is carried out in official information centers ( ), libraries, as well as articles and abstracts from national and international seminars and conferences. During this phase, an Excel spreadsheet is designed and developed, which is fed with information generated by the Agrifood and Fisheries Information System (SIAP) of the Ministry of Agriculture and Rural Development (SADER) in periodic documents that serve to organize the documentary sequence. The study period is defined according to the national accounts published by the aforementioned source over a 22-year period (2003–2022), with 2018 as the base year, in order to use constant prices so that the data can be compared when analyzing the production value of the selected species.

Third: preparation of the research plan, which systematizes and prioritizes the indicators of: harvested area (hectares), average yield (tons per hectare), production (tons), and production value (Mexican pesos at current and constant values). It also considers data on total population (TP) and economically active population (EAP).

Fourth: organization of information by indexing the content of secondary sources of information by species to visualize the contribution of each to the local economy.

Fifth: selection of the statistical indicator. The mathematical formula that best reflects annual growth is considered to be the average annual growth rate (AAGR), as it best reflects the growth of an activity over the medium and long term. Its mathematical expression is:

$$AGR = ((FV / PI) \wedge (1 / n) - 1) * 100.$$

Where Vf is the final value at the end of the period; Vi is the initial value at the beginning of the period; and n is the number of years in the period. Similarly, the percentage growth of the initial year is taken into account, which is compared with the immediately preceding year, to facilitate and identify the sizes of positive and negative increases that result throughout the period (Addin Technology, 2018). In addition, a trend line is included to observe the evolution of the indicators.

RESULTS AND DISCUSSION

Figure 1 shows the Laxaxalpan watershed, identifying the municipalities considered as case studies: Hermenegildo Galeana, Olintla, and San Felipe Tepatlán, which cover part of the lower watershed area and are located between the geographic coordinates of latitude 19^0 55´ 00¨ and 20^0 18´ 00¨ North and latitude 98^0 20´ 05¨ and 97^0 33´ 00¨ West. There are a total of 31 municipalities, including the three in the case study, distributed across four states: six in Veracruz de Ignacio de la Llave, one in Hidalgo, one in Tlaxcala, and 23 in Puebla de Zaragoza (UACH, 2025).

Overall, we can observe a trend in land use and vegetation cover in the case of forests, which increased from 37.12% in 2002 to 41.02% in 2022, representing an increase in forest cover of 6,293.9 hectares. Meanwhile, agriculture decreased by 3.75%,

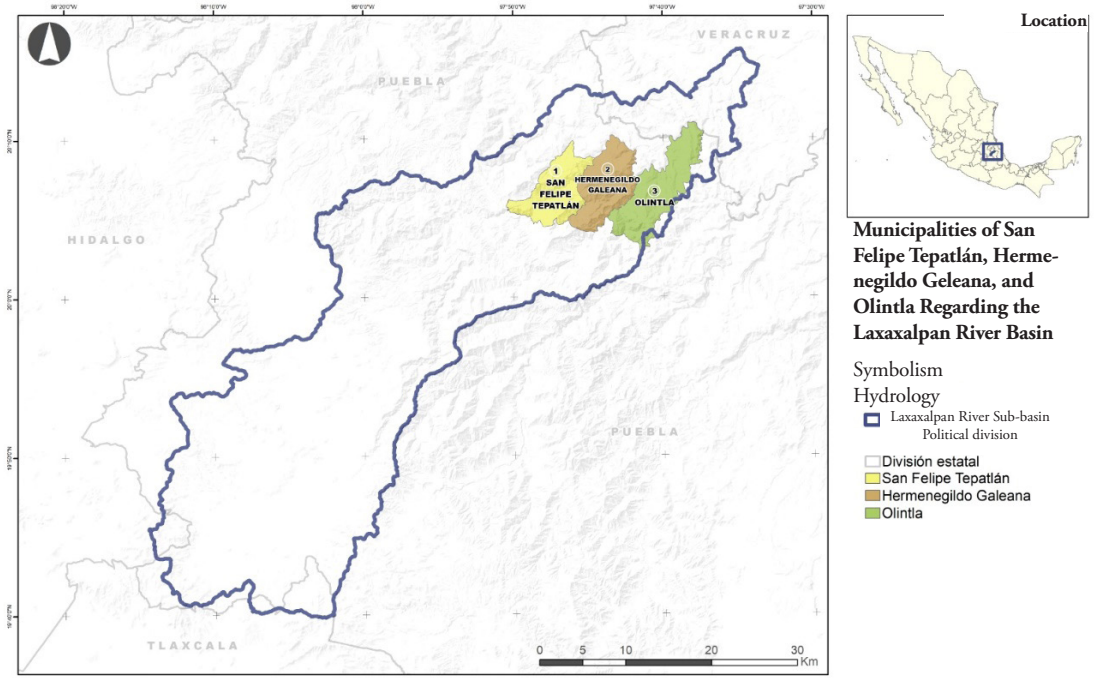

Figure 1. Laxaxalpan Basin. Source: INEGI. Prepared by the Geomatics Laboratory of Cenid – Comef. INIFAP

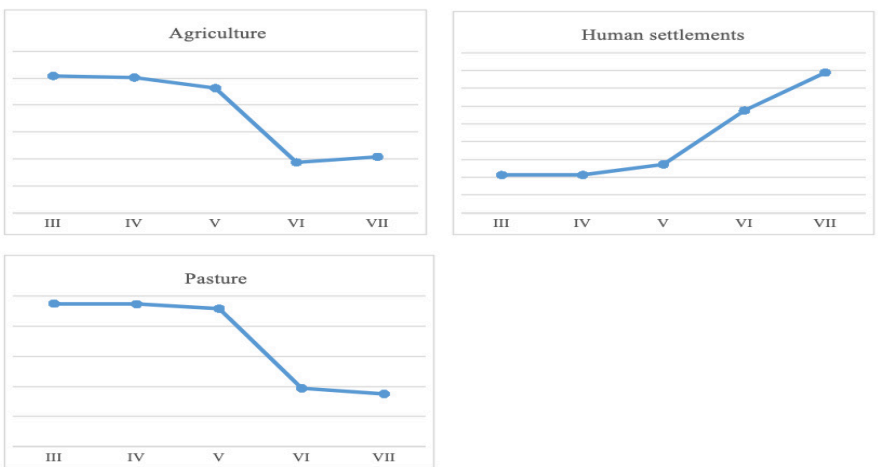

Figure 2. Evolution of agriculture, human settlements, and grasslands from 2002 to 2022. Source: INEGI land use and vegetation series III to VII. Prepared by the Geomatics Laboratory.

DOI https://doi.org/10.22533/at.ed.973572529101

equivalent to 6,003 ha, for the same period. Human settlements increased by 0.51%, or 1,152 ha. Grasslands decreased from 5.61% to 4.79%, meaning their coverage decreased by 1,501 ha, according to vegetation series III to VII INEGI

However, this dynamic does not follow a linear pattern but rather responds to economic and social changes over time. Figure 2 shows the behavior of agriculture, grasslands, and human settlements as an example.

In general, population growth is always associated with agriculture and livestock (represented by pastures), but we can see that this is not the case with land use in the basin.

One of the variables selected to focus on economic development during the study period is the area harvested for corn and coffee cherries. Table 1 shows the evolution of these areas in the three selected municipalities: Hermenegildo Galeana, Olintla, and San Felipe Tepatlán in the state of Puebla.

Table 1 shows that cherry coffee made the largest contribution to the harvested area in all years of the study. In the case of corn cultivation, the main producing municipality was Olintla, followed in order of importance by the municipalities of , and Hermenegildo Galeana, with San Felipe Tepatlán making the smallest contribution. In the case of cherry coffee, until 2010, the municipality of Hermenegildo Galeana was the main producer, but from that year until 2024, Olintla has been the main producer of this perennial crop, and San Felipe Tepatlán has contributed the least harvested area for both corn and cherry coffee. Figure 3 shows the total harvested area of corn and cherry coffee per year in the selected municipalities, as well as its evolution and trend.

Figure 3 also shows the best curves explaining the behavior of harvested corn and cherry coffee areas. In both cases, they were polynomial curves. For corn, the curve is: $y = -10.928x^2 + 239.744x + 1137.9$ with an $R^2 = 0.4725$, which is considered a medium correlation; for cherry coffee, the mathematical expression is: $y = 9.5744x^2 - 289.26x + 4828.5$ and with an $R^2 = 0.6985$, which is considered a medium correlation. Based on the above curves, the corn area shows an upward trend from 2003 to 2013 and a downward trend from then until 2024. Coffee cherry production trended downward until 2016, with three marked reductions between 2009 and 2011, mainly due to adverse weather conditions and lower international prices. Starting in 2015, the harvested area began to recover.

The second variable analyzed is the average yield per hectare of corn and coffee cherries. Table 2 shows its evolution over the years covered by the project.

Table 2 shows that the best corn yield was in 2005 with 2.36 tons/ha in the municipality of Olintla, and six years later, in the same municipality, the lowest yield was 0.72 tons/ha. With regard to cherry coffee, the highest yield was achieved in Hermenegildo Galeana in 2012 with 6 tons/ha, which was 2.54 times higher than that of corn. The lowest yield occurred a year later in Olintla with 0.96 tons/ha, which was 1.33 times higher than that of corn. Figure 4 shows the average yields per hectare for corn and cherry coffee during the study period in the three municipalities of the lower Laxaxalpan basin.

Year	Corn (ha)			Coffee cherries (ha)		
	H. Galeana	Olintla	S. F. Tepatlán	H. Galeana	Olintla	S. F. Tepatlán
2003	453.00	270.00	290.00	2,061.00	1,050.00	972.00
2004	450.00	132.00	290.00	2,061.00	1,050.00	972.00
2005	450.00	1,075.00	290.00	2,061.00	1,050.00	972.00
2006	450.00	1,465.00	290.00	2,061.00	1,050.00	972.00
2007	327.75	1,273.78	290.00	2,061.00	1,145.00	972.00
2008	445.00	2,100.00	330.00	2,070.00	980.00	980.00
2009	449.00	2,170.00	334.00	2,070.00	980.00	980.00
2010	442.00	2,600.00	334.00	1,136.00	1,150.00	542.00
2011	448.00	1,680.00	318.00	518.00	1,150.00	542.00
2012	442.00	1,300.00	318.00	1,136.00	1,149.00	542.00
2013	440.30	1,420.00	318.00	518.00	1,149.00	542.00
2014	802.10	931.00	383.10	518.00	1,149.00	739.00
2015	441.40	1,550.00	320.50	597.21	1,157.00	803.00
2016	450.10	1,568.00	322.20	709.00	1,149.00	819.00
2017	460.00	1,499.00	335.00	910.00	1,150.00	750.00
2018	470.00	$895.00	345.00	915.00	1,150.00	750.00
2019	465.13	895.00	337.45	930.00	1,155.00	770.00
2020	460.20	890.00	331.00	932.00	1,152.00	768.00
2021	481.00	861.00	94.00	961.80	1,154.30	796.00
2022	456.00	883.00	305.50	960.00	1,178.50	795.00
2023	479.50	882.50	275.68	958.00	1,180.00	797.00
2024	462.00	917.00	281.50	953.00	1,182.00	785.00

Table 1. Evolution of harvested areas (hectares) of corn and coffee cherries in the three municipalities of the lower Laxaxalpan basin in the period 2003–2024

Source: SIAP. Agricultural, Food, and Fisheries Information System.

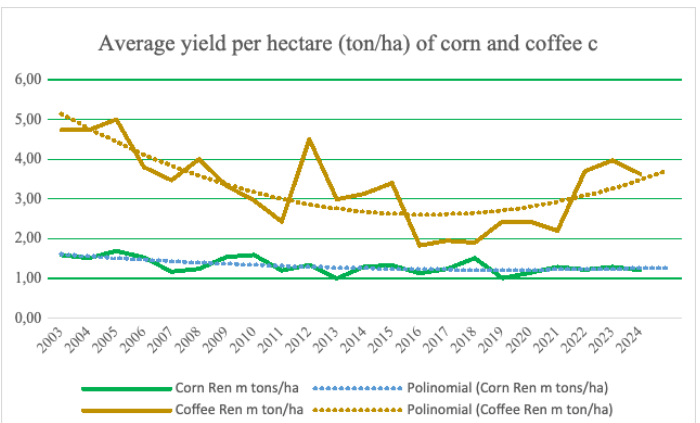

Figure 3. Behavior and trend of planted areas of corn and cherry coffee (ha) in three municipalities in the lower Laxaxalpan basin. Source: Prepared by the authors using data from the Agricultural, Livestock, and Fisheries Information System (SIAP) of SADER.

Year	Corn (tons/ha)			Coffee cherries (tons/ha)		
	H. Galeana	Olintla	S. F. Tepatlán	H. Galeana	Olintla	S. F. Tepatlán
2003	1.46	2.00	1.32	5.20	5.00	4.00
2004	1.32	2.00	1.32	5.20	5.00	4.20
2005	1.40	2.36	1.30	5.00	5.00	5.00
2006	1.34	2.00	1.24	3.20	4.50	3.70
2007	1.12	1.38	1.00	3.20	4.00	3.20
2008	1.20	1.29	1.22	4.80	2.50	4.70
2009	1.48	1.66	1.47	4.00	1.50	4.50
2010	1.85	1.11	1.81	3.64	1.60	3.63
2011	1.44	0.72	1.45	3.00	1.30	3.00
2012	1.52	0.97	1.52	6.00	1.50	6.00
2013	1.13	0.82	1.05	4.00	0.96	4.00
2014	0.79	1.50	1.60	4.00	1.18	4.00
2015	1.50	1.06	1.44	4.50	1.29	4.20
2016	1.12	1.04	1.22	1.87	1.30	2.31
2017	1.21	1.29	1.24	1.90	1.60	2.35
2018	1.54	1.40	1.58	1.88	1.61	2.20
2019	0.93	1.25	0.85	2.88	1.82	2.60
2020	1.01	1.38	1.03	2.57	2.16	2.56
2021	1.22	1.35	1.29	2.09	2.00	2.50
2022	1.05	1.40	1.22	4.58	2.30	4.23
2023	1.27	1.35	1.25	4.80	2.31	4.80
2024	1.14	1.37	1.12	4.27	2.30	4.43

Table 2. Evolution of average yields per hectare (ton/ha) of corn and cherry coffee in three municipalities of the lower Laxaxalpan basin in the period 2003–2024

Source: SIAP.

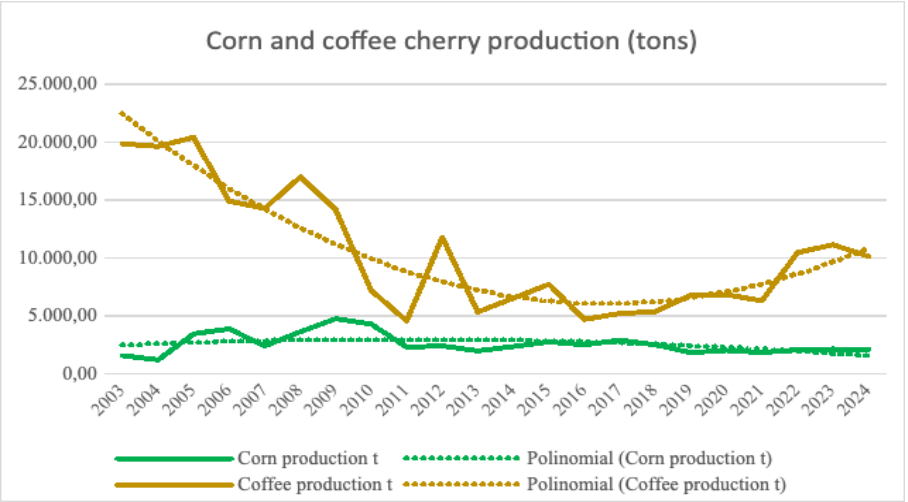

Figure 4. Behavior and trend of average yields per hectare (tons/ha) of corn and coffee cherries in three municipalities of Puebla in the lower Laxaxalpan basin. Source: Prepared by the authors using data from SIAP.

Year	Corn (tons)			Coffee cherries (tons)		
	H. Galeana	Olintla	S. F. Tepatlán	H. Galeana	Olintla	S. F. Tepatlán
2003	660.85	540.00	383.00	10,717.20	5,250.00	3,888.00
2004	593.00	264.00	354.00	10,305.00	5,250.00	4,082.00
2005	630.00	2,537.80	290.00	10,305.00	5,250.00	4,860.00
2006	601.00	2,930.00	360.00	6,595.20	4,725.00	3,596.40
2007	367.75	1,754.27	291.00	6,595.20	4,580.00	3,110.40
2008	534.00	2,700.00	402.00	9,936.00	2,450.00	4,606.00
2009	665.00	3,612.00	490.00	8,280.00	1,470.00	4,410.00
2010	817.21	2,877.85	603.20	4,138.00	1,840.45	1,230.00
2011	644.80	1,206.00	460.8	1,554.00	1,494.66	1,526.00
2012	671.00	1,265.00	483.00	6,816.00	1,723.37	3,252.00
2013	496.30	1,157.50	334.20	2,072.00	1,103.32	2,168.00
2014	633.56	1,393.05	613.00	2,072.00	1,356.12	3,103.80
2015	662.10	1,639.10	461.50	2,686.50	1,495.07	3,553.20
2016	506.02	1,623.40	392.30	1,325.83	1,493.71	1,887.70
2017	555.85	1,938.37	413.70	1,729.00	1,840.00	1,725.60
2018	772.64	1,252.65	545.00	1,720.00	1,865.20	1,782.50
2019	433.36	1,120.85	287.06	2,678.40	2,102.10	2,002.00
2020	465.57	1,225.70	342.27	2,395.20	2,488.32	1,966.08
2021	570.38	1,158.71	122.38	2,010.16	2,308.60	1,990.00
2022	477.60	1,235.70	373.36	4,394.32	2,710.64	3,362.85
2023	611.32	1,192.28	344.98	4,598.40	2,775.80	3,825.60
2024	524.52	1,252.20	316.29	4,069.31	2,600.40	3,477.55

Table 3. Evolution of corn and coffee cherry production (tons) in three municipalities of the lower Laxaxalpan basin in the period 2003–2024.

Source: SIAP.

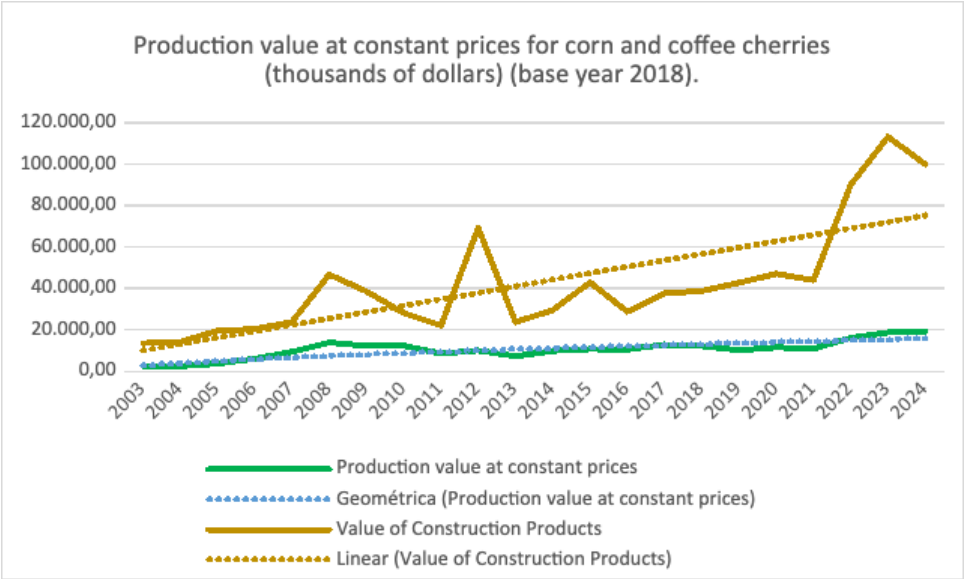

Figure 5. Behavior and trend in the production (tons) of corn and coffee cherries in three municipalities in the lower Laxaxalpan basin.

Source: SIAP.

Figure 4 shows the best curves explaining the behavior of average yields per hectare for corn and cherry coffee, both of which are polynomial in nature. For corn, the curve is: $y = 0.00016x^2 - 0.0523x + 1.6543$ with an $R^2 = 0.3962$, which is a medium-low correlation; for coffee cherries, the mathematical expression is: $y = 0.0145x^2 – 0.4132x + 5.5441$ and with $R^2 = 0.5886$, which is a medium correlation. Based on the trends in the curves, corn acreage showed a downward trend from 2003 to 2024, while cherry coffee showed a downward trend until 2016, due to unfavorable weather conditions. Since then, there has been a recovery in average yields, without reaching the peak recorded in 2005.

Another variable is the production in tons of corn and coffee cherries, which is shown in Table 3.

Table 3 shows that, with the exception of the first two years, the municipality with the highest corn production was Olintla, Hermenegildo Galeana was the largest producer for the period mentioned, and the smallest producer for the entire study period was San Felipe Tepatlán. In terms of cherry coffee production, the municipality of Hermenegildo Galeana dominated production during the period 2003–2013. Subsequently, Olintla and San Felipe Tepatlán alternated as the main producers, and during the final three-year period, the municipality of H. Galeana regained its position as the main supplier of cherry coffee.

Figure 5 shows the total corn and cherry coffee production of the three municipalities selected from the lower Laxaxalpan basin in Puebla, as well as their behavior and trends.

Figure 5 above shows that, in the case of corn, from 2011 to 2024, production of this staple food product remained virtually constant, unlike in the early years

(2003–2009), when it showed an upward trend, reaching a peak of around 5,000 tons. Coffee cherry production shows a downward trend from the beginning of the period until 2016, followed by a recovery, without reaching the peak production level of 2005. The best-fit curves in both cases are polynomial; for corn, it is: $y = -8.6486x^{(2)} + 155.27x + 2314.6$ with $R^2 = 0.2258$, which is considered low correlation, while for cherry coffee, the best equation is also polynomial $y = 88.153x^2 - 2578x + 24921$ with $R^2 = 0.8306$, which is classified as high correlation.

The variable that shows importance within the economy is the value of production, which is expressed in constant prices in order to make the data comparable throughout the period. Table 4 shows the data reporting the sum of the value of production at current and constant prices for the three municipalities.

Table 4 shows that, for the value of corn production, the lowest amount of money contributed to the economy, both at current and constant prices, was in 2004, and the highest monetary contribution at current prices was in 2009. In the case of constant prices, the highest contribution was in 2024. In the case of coffee cherries, the lowest economic impact at current prices was in 2004 and at constant prices in 2003, while the highest contribution at current prices was in 2012 and at constant prices in 2023.

Figure 6 shows the behavior and trend of the value of production at constant prices for corn and cherry coffee over 22 years of analysis.

Figure 6 shows that the production value of corn, at constant 2018 base year prices, has an upward trend with an exponential equation: $y = 2578.1x^{0.5851}$ and with $R^2 = 0.7548$, which is considered a good correlation. For cherry coffee, the best fit equation is exponential, with the formula: $y = 15533e^{(0.0728x)}$ and $R^{(2)} = 0.6592$, which is considered a medium correlation.

The gap in the value of production at constant prices (base year 2018) between 2003 and 2024 between corn and cherry coffee is 7.34 times greater for coffee. This situation indicates the economic importance of coffee in the area; however, corn is essential for feeding the population.

Average annual growth rates (AAGR %). In order to determine the growth (positive or negative) of the variables for the 22 years of the study, Table 5 shows the AAGR values.

Variables	**Average annual growth rate (%)**	
	Corn	Coffee cherries
Harvested area	2.27	-1.51
Average yield per hectare	-1.24	-1.19
Production	1.28	-3.01
Value of production at current prices	4.40	4.34
Value of production at constant prices, base year 2018	9.56	9.50

Table 5. Average annual growth rates (%) of the variables considered in the study for each crop.

Source: Own elaboration.

Table 5 above shows the growth rates for corn and coffee cherries in the three municipalities studied over the 22-year period. It can be seen that corn reports higher growth rates than coffee cherries, with the exception of average yields per hectare. In terms of harvested area, corn showed positive growth and coffee cherries declined. In terms of production, corn performed positively, while coffee cherries declined. In ter-

Year	Corn (thousands of $)		Coffee cherries ($ thousands)	
	Current prices	Constant prices	Current prices	Constant prices
2003	5,591.84	2,577.84	29,433.20	13,568.71
2004	4,965.10	2,477.58	28,456.11	14,199.60
2005	7,012.57	3,702.64	37,068.46	19,557.43
2006	10,844.20	6,083.60	36,337.14	20,385.14
2007	9,389.87	5,605.75	39,906.06	23,823.92
2008	13,912.60	8,792.76	73,903.14	46,706.78
2009	18,389.60	12,247.47	57,914.00	38,570.72
2010	17,841.77	12,400.03	40,446.45	28,110.28
2011	11,657.65	8,556.72	30,058.96	22,063.28
2012	13,095.11	10,043.95	90,203.18	69,184.84
2013	9,310.73	7,262.37	30,447.01	23,748.67
2014	12,092.40	9,855.31	36,198.08	29,501.44
2015	12,754.28	10,726.35	51,034.18	42,919.75
2016	11,783.92	10,511.26	37,271.41	28,760.10
2017	13,549.64	12,885.71	39,551.92	36,613.88
2018	12,237.66	12,237.66	38,810.62	38,810.62
2019	9,728.54	10,146.87	40,992.87	42,755.56
2020	10,565.72	11,548.33	43,059.51	47,064.48
2021	9,815.40	10,936.32	39,480.90	43,989.63
2022	13,225.52	16,608.68	73,979.23	90,106.70
2023	14,765.59	18,731.63	89,250.34	113,222.98
2024	14,433.06	19,224.84	74,998.36	99,987.87

Table 4 Evolution of the value of production in current and constant pesos (base year 2018) of corn and coffee cherries in the three municipalities of the lower Laxaxalpan basin in the period 2003–2024.

Source: SIAP.

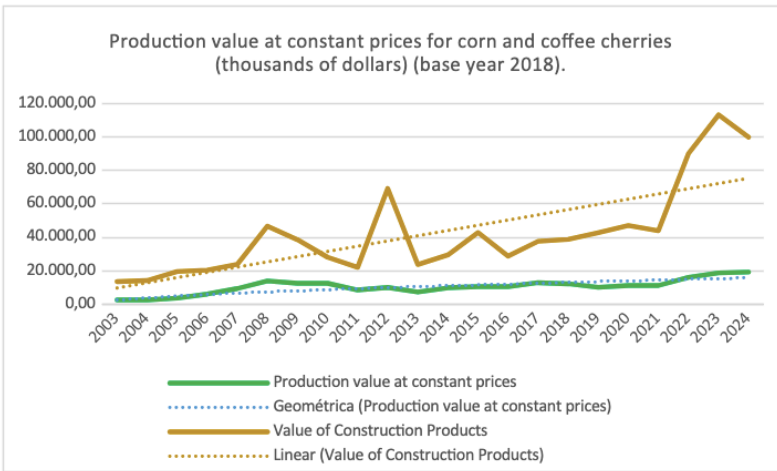

Figure 6. Behavior and trend in the value of production (thousands of pesos) of corn and coffee cherries in the three municipalities of the lower Laxaxalpan basin, Pue. Source: Prepared by the authors using data from SIAP. Agri-Food and Fisheries Information System of SADER.

ms of production value at both current and constant prices with a base year of 2018, corn was higher than coffee cherries.

Total Population (TP) and Economically Active Population (EAP). Table 6 shows the total population and economically active population data for the three municipalities in the lower basin that were selected, according to CONAPO censuses (2000-2020).

The table above shows that the most populous municipality in 2020 was Olintla, while the municipality with the largest economically active population was San Felipe Tepatlán ( ); and the municipality with the highest PT/PEA ratio was Hermengildo Galeana, with a percentage of 42.72%.

Figures 7a and 7b show the evolution of the data series (2000–2010–2020) for the total population and the economically active population of the municipalities.

In Figure 7 a and b above, we can see in the first case a parallelism between the three municipalities in terms of their behavior and population growth trends, with Olintla having the highest TP and, in the case of the EAP, from 2010 to 2020, its growth is more pronounced, with the municipality of San Felipe Tepatlán standing out, rising from third to first place in the EAP.

CONCLUSIONS

The harvested area for corn and coffee cherries throughout the analysis period showed that the former grew until 2010 and then declined until the end of the period (2024). The situation was similar for coffee cultivation, as the harvested area peaked in 2007, fell sharply in 2011, and then began to recover, without reaching the initial area.

In the case of average yield per hectare, both corn and coffee cherry decreased, indicating little development and technological innovation.

Production in the case of corn was similar throughout the period studied, with a slight upturn in the final years. For cherry coffee, the production situation was not favorable, as the figure at the end of the period was negative, despite the fact that during the last 10 years of the period there was an upturn, although without reaching the production levels of the initial years.

The value of production is influenced by market or current prices, which are generally on the rise. In order to compare prices, an analysis was carried out at constant or deflated prices, resulting in positive average growth rates for both corn and coffee cherries. For the latter, the trend fluctuated throughout the period (sixteen increases and six decreases) due to international fluctuations. For corn, guaranteed prices were a palliative measure to prevent sharp drops in price.

In relation to the Total Population (TP) and the Economically Active Population (EAP) in 2020, the largest TP is located in Olintla, and the municipality with the highest TP/EAP ratio was Hermenegildo Galeana.

Acknowledgments

To the National Institute of Forestry, Agricultural, and Livestock Research for providing funding for the Strategic Project: Integrated Management of Forest Resources for the Sustainability of Ecosystem Resources in the Face of Climate Change.

	PT				EAP		
Municipalities/ year	2000	2010	2020	Municipalities/year	2000	2010	2020
H. Galeana	8,194	7,718	7,011	H. Galeana	2,802	2,159	2,995
Olintla	12,609	11,641	11,003	Olintla	4,103	3,202	3,554
S. F. Tepatlán	8,632	9,426	11,063	S. F. Tepatlán	1,288	3,623	4,664
Total	29,435	28,785	30,067	Total	8,193	8,984	11,213

Table 6 Total Population and Economically Active Population in the municipalities of Hermenegildo Galeana, Olintla, and San Felipe Tepatlán.

Source: CONAPO 2000, 2010, 2020

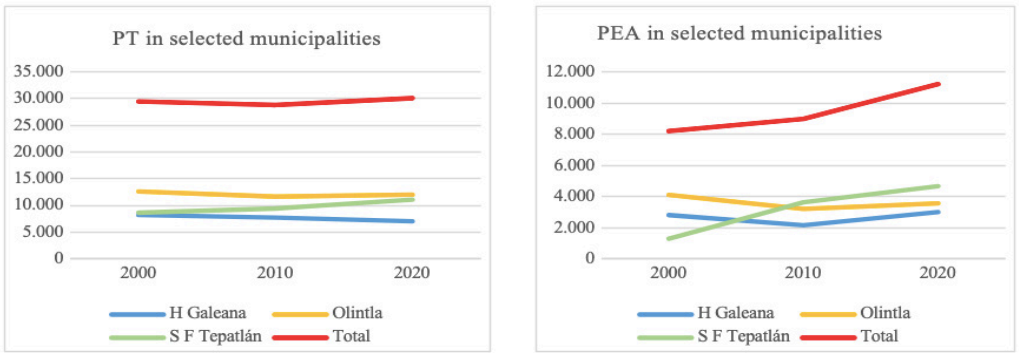

Figure 7-a and b. Total Population and Economically Active Population (2000–2010–2020) in three municipalities of Puebla in the lower Laxaxalpan basin, Pue. Source: (CONAPO) 2000, 2010, and 2020.

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