Colegio de Postgraduados

The effect of predictor variables on cherry coffee yield in two regions of the state of Veracruz, Mexico

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ABSTRACT
Objective: To analyze the effect of predictor variables (sown area, harvested area, and production) on cherry coffee yield in the Huatusco and Córdoba regions of the state of Veracruz.
Design/Methodology/Approach: A mixed and correlational method was employed with a representative trial sample of 144 cases. The existing bibliography on cultivation, processing techniques, good practices, commercialization, and yield was subject to a critical analysis.
Results: The results were statistically significant (Pearson correlation=0.983) for the "final production" and "harvested area" variables. The hypotheses were positive, confirmed, and determined to be 95% reliable. The production was 2.532 and the sown area was 0.639. The coffee yield was higher in the Huatusco region, with a value of 1.72.
Study Limitations/Implications: The study was not hindered by any limitations.
Findings/Conclusions: Innovation is of great consequence for the enhancement of coffee productivity. Technified agriculture has the potential to speed up the production process. However, further research is necessary to ensure the optimal care of these crops and to guarantee superior yields of higher quality.

Keywords: predictor variables, yield, coffee, and production process.

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INTRODUCTION

Coffee (*Coffea arabica* L.) is consumed by families around the world. It is enjoyed by many and consumed at any time of the day, even during working hours. Coffee keeps consumers active and relaxed. Many simply prefer it due to its taste and health benefits (Bonilla, 2017). The leading producers and exporters of coffee are Colombia, Brazil, Guatemala, Honduras, Peru, Nicaragua, Costa Rica, and Mexico. Additionally, Vietnam, Indonesia, India, and Uganda make a significant contribution to global coffee production. The United States, Germany, France, and Japan are the primary consumers of coffee (Argoti and Belalcazar, 2017).

The main plantations in Mexico are located in Chiapas, Oaxaca, and Veracruz. Approximately 511,679 producers grow coffee on 697,366.22 hectares (ha), representing 91% of the country's total coffee production (SAGARPA, 2018). As reported by the Mexican Agrifood and Fisheries Information Service (SIAP), the most productive crop varieties were identified and categorized according to their prevalence in large-scale plantations across 15 states (SIAP, 2021). In the state of Veracruz, several varieties of coffee (*Coffea arabica* L.), including *Typica*, *Bourbon*, and *Caturra*, are grown under shade. Most of these plants are grown in areas with varying altitudes to achieve an average production per plant (López-García *et al.*, 2016). The *Typica* variety from Ethiopia was one of the first to be introduced in Mexico in the XVIII century. *Typica* is distinguished by its grain size, although it is highly susceptible to rust (Escamilla Prado *et al.*, 2015). Mexico's abundant biodiversity —resulting from the climate, biogeography, and ecology that characterize some of its tropical regions— accounts for 60-70% of the domestic coffee production (INEGI, 2017).

Interestingly, a quality product requires adequate environmental care, complemented by innovative technical systems to safeguard the product (Flores Vichi, 2014). In some cases, such as in Mexico, coffee is cultivated on plots by small-scale producers who invest very little capital (Calo and Wise, 2005). A study conducted by Medina-Meléndez *et al.* (2016) corroborated that 41.20% of coffee farmers identified climate change as a factor contributing to crop losses. For some farmers, coffee production is a primary source of income (Argoti and Belalcazar, 2017). This is particularly noteworthy, given the experience these farmers have in the management of their production and the commercialization of coffee (Lopes *et al.*, 2020). Verifying the climate, ecological conditions, and productivity is essential for the selection of coffee beans (Monsalve-Vásquez, 2022). The climate in Córdoba, Veracruz, has a wide range of conditions, from tropical to temperate to dry. The latitude ranges from 20° to 36°, while the altitude varies from 600 to 1,500 meters above sea level (Rivera *et al.*, 2013). An assessment was conducted to determine the potential influence of air temperature on the onset of flowering and fruit growth in the Huatusco region (Villers *et al.*, 2009).

According to Thomas *et al.* (2015), innovative production processes are an effective technology for groups with implicit needs. For their part, Sampedro and Díaz (2016) consider that innovation occurs in two distinct spheres: innovation for development (CONCEIÇÃO *et al.*, 2000) and innovation for inclusion (Alzugaray *et al.*, 2012; George *et al.*, 2012; Hall *et al.*, 2012). The former may be defined as new improvement alternatives, while the latter is aimed at groups seeking support for their fields. In Mexico, the implementation of innovative techniques for agricultural products has not been a prevalent practice. For some producers, it entails an additional financial burden, whereas for others, it signifies a major advancement in the development of their crop (Amaro-Rosales and De Gortari-Rabiela, 2016).

There are two types of coffee production processes: artisanal and technified. Artisanal coffee growers have empirical knowledge about cultivation and pest and disease control (Staver *et al.*, 2001). The second process emphasizes the role of technified systems (Egea, 2016).

Medina-Meléndez *et al.* (2016) indicated that the coffee-growing region of Veracruz encompasses 82 municipalities (approximately 842 communities) that have implemented various production strategies, including small-scale and large-scale operations, in order to reduce costs and achieve positive results. These strategies have involved the use of diversified and innovative designs (Licona-Vargas *et al.*, 2006).

In the Huatusco region, the Costa Rica cherry coffee variety recorded an efficiency of 277.77 kg, resulting in the production of 55.9 kg of parchment. Meanwhile, the *Garnica* variety had a total yield of 288.94 kg, resulting in 56.5 kg of parchment (Sánchez-Hernández *et al.*, 2018). The expected average yield of coffee was 1.80 kg/plant for the technified system, as reported by Villavicencio-Enríquez (2012). In contrast, Córdoba (located in the central zone of Atoyac) is considered one of the ten best coffee-producing regions (Sánchez *et al.*, 2019). Since 2015, yields have fluctuated between 7.3 and 10.8, in the 18,832 hectares where coffee is grown (López, 2021).These crops are characterized by their aroma, body, and acidity (López-García *et al.*, 2016).

This research is divided into three sections. The first section provides an overview of coffee and its context in the state of Veracruz. The second section focuses on the mixed and correlational method, which involves the use of a representative sample to support the research. The third section presents the statistical analysis of the main results and variables. To support this research, the following hypotheses were proposed: H1: The sown area is directly related to the yield of cherry coffee. H2: The harvested area is positively correlated with the yield of cherry coffee. H3: The final production is closely related to the yield of cherry coffee.

MATERIAL AND METHODS

This research employed a quantitative, mixed, and correlational approach, with a sample selected through judgment method (Delphi) of two groups of coffee farmers in the Córdoba and Huatusco regions of Veracruz. The sample was obtained from a 2018-2023 database, sourced from the Agrifood and Fisheries Information Service (SIAP). In comparison to previous years, the minimal variation in yields was largely attributed to the seasonal cycles established by SIAP and the policies implemented for the benefit of producers. From January to December, a total of 144 cases were observed, with 72 in Córdoba and 72 in Huatusco. Information related to the cherry coffee crop was used, with the independent variables comprising sown area, harvested area, and production. The dependent variable was yield per hectare. The data were then imported into an Excel database and subsequently transferred to the SPSS Statistics 25 software. The Cronbach's alpha statistic was employed to assess the validity of the research instrument, with a confidence level of 95% and a margin of error of 5%. The stepwise regression model was used to correlate the multiple linear regression variables, in the SPSS Statistics 25 software.

RESULTS AND DISCUSSION

Table 1 shows the average data of cherry coffee crop, including sown area, harvested area, and production, as well as the regional yields for Huatusco and Cordoba. This information provided by SIAP covers the period from 2018 to 2023. Both descriptive and

Table 1. Average data of the cherry coffee crop.

State	Municipality	Year	Crop	Area sown (ha)	Area harvested (ha)	Production	Yield (udm ha^{-1})
Veracruz	Cordoba	2018	Café cereza	1900	1109.17	1160.71	1.15
		2019	Café cereza	1900	1055.00	1371.50	1.30
		2020	Café cereza	1990	539.88	631.16	1.17
		2021	Café cereza	1990	580.00	681.36	1.18
		2022	Café cereza	1826	531.67	696.48	1.20
		2023	Café cereza	1992	1341	1756.71	1.31
	Huatusco	2018	Café cereza	7495	5458.33	9997.75	1.83
		2019	Café cereza	7470	5637.50	10255.50	1.82
		2020	Café cereza	7465	6100.00	10405.53	1.71
		2021	Café cereza	1990	580.00	681.36	1.18
		2022	Café cereza	7467	6101	11530.89	1.89
		2023	Café cereza	7467	6826	12901.16	1.89

inferential statistics were calculated, supporting the information resulting from the study variables.

Descriptive statistics

As suggested by Hernández-Samipieri *et al.* (2014), the internal consistency of the instrument was validated using the Cronbach's Alpha statistic (Cronbach, 1951): a >0.7 value for this parameter is considered significant (Table 2).

Table 3 presents the descriptive statistics. The mean of each variable was calculated and the dependent variable (yield per hectare) showed an average value of 1.5151. The independent variables included the following values: sown area (4,716.08), harvested area (3,412), and production (5,889.63). These values were used to formulate the multiple linear regression model:

$$\textit{Average value}\left(X_1\right) = 4{,}716.08, X_2 = 3{,}412 = \left(X_3\right) = 5{,}889.63, \text{ and } Y = 1.5151$$

Table 2. Cronbach's Alpha statistic values

N of elements	Cronbach's Alpha based on the typed items
144	.972

Table 3. Descriptive statistics.

	Mean	Standard deviation	N
Yield (udm/ha)	1.5151	.33065	144
Area Sown(ha)	4716.08	2765.212	144
Harvested Area(ha)	3412.00	2646.411	144
Production	5889.63	5095.927	144

Source: Developed by the authors.

Inferential statistics

Inferential statistical data are calculated by determining significant associations according to Pearson's Correlation. Values lower than 1, with a 95% reliability and $p \leq 0.05$, indicate a significantly positive correlation between the data. The following results were obtained when the variables were crossed with yield: 0.848 (sown area), 0.840 (harvested area), and 0.899 (production). Production had a higher positive correlation. In summary, the four variables had positive correlations (>0.840). These findings are the closest to the results obtained by Reyna (2022) for the Amazonas region. The correlation of coffee production calculated for that region reached a score of 0.878, indicating a positive association with the variables shown (Table 4). Although there are some differences both obtained similar results.

The correlation was determined using the stepwise regression model and included the selected variables: production, harvested area, and sown area. The F-test results ranged from 2.70 to 3.84. Subsequently, the variables that had the greatest influence on the dependent variable (*i.e.*, yield per hectare) are presented. Model 1 in R resulted in the highest predictor variable (0.954), a corrected R-squared of 0.907 accounted for a data reliability of 90.7%, and 1.016 with Durbin-Watson, indicating that the residuals are dependent. These data corroborate a range of 0 to 4, which is predominantly associated with a positive autocorrelation. According to Belts (2011), the estimated model offers first-order evidence (Table 5).

In relation to the ANOVA of Model 1, the F-test yielded a result of 468.584, with a significance of 0.000, indicating a statistically positive result. To test the hypotheses, the typified coefficients with the following β values were provided as reference. The results of the analysis indicate that β_1 production has a value of 2.579, β_2 harvested area has a value of -2.237, and β_3 sown area has a value of 0.554. These values are significant at the 95% level, which supports the acceptance of the hypotheses. The t-value for production was 16.803, while the values for harvested and sown area were -12.459 and 5.777, respectively.

Tabla 4. Correlations

		Yield (udm/ha)	Area Sown (ha)	Harvested Area (ha)	Production
Pearson correlation	Yield (udm/ha)	1.000	.848	.840	.899
	Area Sown(ha)	.848	1.000	.964	.951
	Harvested Area(ha)	.840	.964	1.000	.986
	Production	.899	.951	.986	1.000

Source: Developed by the authors.

Table 5. Summary of model[b].

Model	R	R square	R square co-regulated	Standard error of estimation	Durbin-Watson
1	.954[a]	.909	.907	.10057	1.016

a. Predictor variables: (Constant), Production, Area Sown (ha), Area Co-harvested (ha).
b. Dependent variable: Yield (udm/ha).

Source: Developed by the authors.

These variables were found to be significant at the 0.000 level, with positive results. The collinearity statistics met the <1 tolerances (Table 6).

Table 6. Coefficients[a].

Model	Unstandardised coefficients	Typified coefficients	T	Sig.	Collinearity statistics	
	B	Beta			Tolerance	FIV
(Constant)	1.171		56.060	.000		
Area sown (ha)	.0000730	.554	5.777	.000	.070	14.210
Harvested area (ha)	.000	−2.237	−12.459	.000	.020	49.838
Production	.0000734	2.579	16.803	.000	.027	36.410

Source: Developed by the authors.

The mathematical equation of the multiple linear regression with the unstandardized coefficients and with the values of β is shown below. The constant is equivalent to $\beta_0 = 1.71$, production $\beta_1 = 0.0000734$, sown area $\beta_2 = 0.000$, and harvested area $\beta_3 = 0.000$. Therefore, the mathematical equation is proven according to the model that was proposed from the beginning (Table 5):

$$Y = \beta_0 + \beta_1(X_1) + \beta_2(X_2) + \beta_3(X_3) =$$

$$Y = 1.171 + .0000730(4{,}716.08) + .000(3{,}412) + .000(5{,}889.63) = 1.5151$$

Finally, both municipalities were compared using the Kolmogorov-Smirnov test for independent samples. This comparison proves the hypotheses, indicating that both are symmetrical, with a normal distribution and a positive significance (0.000). The test result for the Córdoba zone was 2.444, with an average yield of 1.21. In contrast, the test result for the Huatusco zone was 2.992, with an average yield of 1.72. According to Castillo (2013), in other states (such as Puebla), yields were higher and even reached 1.92, which is considered one of the highest national averages.

The results clearly demonstrate the crucial role and the high profitability of coffee production in these states. The Huatusco region has benefited from its central location, which has led to increased crop yields. This zone has been developed and conserved thanks to the effective management of its technified system. However, Cordoba, located in the south, still needs to improve its cultivation methods. Therefore, the farmers' experiences must be reorganized to enhance their local, regional, state, and international competitiveness.

CONCLUSIONS

The agriculture sector is of great importance to producers who are fully devoted to farming activities. Specialty crops, such as cherry coffee, are an essential component of the food supply of Mexico and the rest of the world. The cultivation-to-harvest relationship is essential, as evidenced by the SIAP database, which shows that coffee yields in Córdoba and Huatusco, Veracruz, increased from 2018 to 2023. The variables under study have positive correlations, interrelated with the yield of the cherry coffee crop. In this regard, innovation is of great importance to enhance coffee productivity. Technified agriculture facilitates accelerated production processes. However, further studies are necessary to ensure optimal crop care and yield quality.

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