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PRODUCT PRICE FORECAST FOR BANANA GROWERS IN THE STATE OF COLIMA, MEXICO

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ABSTRACT

Banana (*Musa* spp.) is the fourth most important food in the world, after corn, beans, and rice. It contributes to food security in several countries, and in Mexico, it is the most cultivated tropical fruit. The goal of this work was to project real banana prices for the next 10 years using a non-homogeneous linear second-order difference equation of moving equilibrium, which would serve as a basis for the design of marketing strategies by banana organizations in the state of Colima, Mexico. An autoregressive econometric model was built with real monthly banana prices for the period from January 2014 to February 2020. It was identified that the behavior of the banana market in the state of Colima corresponds to a complex structure, with a cyclical behavior and a duration of nine months. This market tends to converge; therefore, it will reach equilibrium and continue to grow.

Key words: value chain, marketing, dynamic models, *Musa* AAA.

INTRODUCTION

The banana (*Musa* AAA subgroup Cavendish) is native to Southeast Asia, whose cultivation is widely extended in the world. In 2021, bananas were the most produced fruit worldwide, with a total of 125 million Mg (FAO, 2021). The leading banana-producing countries were India (24.1 %), China (23.8 %), and Indonesia (6.4 %) (FAO, 2021). In Mexico, the main cultivated varieties include Dominico, Valery, Pera, Tabasco, Morado, Manzano, Cavendish Gigante or Grand Naine (giant dwarf), and Macho. Due to its availability in the domestic market, bananas are among the most demanded fruits in the country, with a per capita consumption of 14.2 kg (SIAP, 2023). Around 30 % of national production was exported to 43 world markets, with an estimated value of USD 272 million (SIAP, 2023). Mexico's main banana export destinations included the USA, Japan, the United Kingdom, South Korea, Russia, Italy, and New Zealand (SADER, 2020).

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In 2022, Mexico ranked 19th in global banana production with a volume of 2 593 025 Mg. Cultivation took place in 16 states (SADER, 2021), with Chiapas (664 156 Mg), Tabasco (622 175 Mg), Veracruz (335 238 Mg), Colima (324 133 Mg), Jalisco (202 743 Mg), and Michoacán (179 220 Mg) producing the most. The Central-West region contributed 27 % of the national volume. Colima stood out as the fourth largest producer, accounting for 12.5 % of total production. The total value of national banana production was MXN 10 547 million, of which Colima contributed 18.9 %, surpassing Chiapas (15.1 %) and ranking just below Tabasco (21.3 %). Together, these three states contributed 55.3 % of the national production value (SIAP, 2024). At the state level, Colima has a harvested area of 9555.5 ha. The primary producing municipalities are Tecomán (66 %), Manzanillo (29 %), and Armería (4 %) (SIAP, 2024). The banana agri-food chain is the third most important among the priority agricultural chains of the state (SADER, 2019).

The growth rate of the banana plant and the development of its fruit are influenced by ambient temperature, which directly affects physiological processes. Temperature determines the duration of the growth cycle and the weight of the bunch by influencing the leaf emission rate, root development, floral differentiation, and bunch formation (Robinson and Galán-Saúco, 2012). Ramírez *et al*. (2011) pointed out that the environmental conditions directly impact banana productivity, the length of the production cycle, and fruit quality, factors that are crucial for producers in terms of profits, food security, and market supply.

Banana cultivation is characterized by seasonality, with production dependent on ambient temperature. Ramírez *et al*. (2011) noted that higher temperatures increase production, leading to imbalances such as shortages or surpluses at different times of the year. This seasonality also affects Colima, causing fluctuations in field prices. A typical pattern emerges, with higher production volumes that correlate with lower prices, directly impacting producers' incomes. These conditions enable individual banana traders (coyotes) to speculate on both the field price and the market price offered to buyers across national supply chains. Consequently, producer income is negatively affected, and investment in technological improvements is reduced, diminishing the quality of the fruit marketed. According to the State Council of Banana Producers of Colima A.C., producer prices have increased in recent years but remain highly volatile.

The central hypothesis of this research is that the price paid to banana producers will continue to rise over the next 10 years and that it will be influenced by temperature-driven changes in production. Specifically, prices will tend to be lower in warmer months when production increases and higher in cooler months when production decreases. Therefore, the objective of this study is to project real banana prices for the next 10 years using a non-homogeneous linear second-order difference equation of moving equilibrium. This projection aims to provide a basis for designing effective marketing strategies for banana organizations in the state of Colima.

MATERIALS AND METHODS

The research study is quantitative, prospective, and longitudinal. A database with monthly product prices paid to the producer in the field during the period from January 2015 to February 2020 was provided by the State Council of Banana Producers of Colima A.C. based on field surveys by González-Rodríguez (2025). Nominal prices were deflated with the National Consumer Price Index (INPC) (based on February 2020) (INEGI, 2022) to place them in real terms according to Brambila-Paz (2011).

Actual prices

The actual prices were calculated according to the following expression (Equation 1):

$$p_r = \frac{Pn}{INPCb} \times 100 \quad (1)$$

where *Pr* is the actual price (in MXN); *Pn* is the nominal price (in MXN); and *INPCb* is the National Consumer Price Index, based on February 2020 (= 100).

The Dickey Fuller (DF) test was used on the data to test the statistical presence of stochastic trend behavior in the time series of the variables using a hypothesis test (Lizarazu-Alanez and Villaseñor-Alva, 2007), which met with an asymptotic *p* value of 0.000697, which is less than the significance value of the model ($p = 0.05$).

Econometric model

For this study, an econometric model was formulated using real monthly banana prices (*Pt*). As exploratory variables, two-time lags of the price variable (p_{t-1}, p_{t-2}), a dummy variable, and a discrete time variable were introduced. The dummy variable was considered since the production cycle is affected by climate throughout the year. At higher temperatures, plants and fruit ripen and grow faster, resulting in an oversupply of the product (Ramírez *et al*., 2011). As a result, producer prices decrease. For this purpose, the value D = 1 was assigned to the cold months (January, February, March, October, November, and December) and D = 0 to the warm months (April, May, June, July, August, and September). a_1 y a_2 are the coefficients of the model, as shown in the following expression (Equation 2).

$$P_t = \beta + a_1 P_{t-1} + a_2 P_{t-2} + \beta_1 D + t \quad (2)$$

A trend variable (*t*) was added to the model, which was considered a discrete time variable, since the value of the variable y_i changes only when *t* goes from one integer value to the next, such as *t* = 1 to *t* = 2. The values of *t* are known as "periods," where *t* = 1 denotes period 1 and *t* = 2 denotes period 2, then y_i is considered to have a unique value for each period (Chiang and Wainwright, 2006).

The model was estimated using the ordinary least squares methodology to obtain the intercept and the coefficients (Equation 3).

$$y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \ldots + \beta_k x_k + \varepsilon_i \qquad (3)$$

where y_i is the explained variable, x_k is the explanatory variable, β_k is the parameter that quantifies the relationship between the explained variable and each explanatory variable, and ε_i is the error (Gujarati and Porter, 2010).

The model is based on a second-order difference equation, which was analyzed dynamically using the difference equation techniques described by Chiang and Wainwright (2006). This model was used to determine the projection of future banana prices for the next 10 years (scenario 1). A second scenario was also estimated, where the minimum price acceptable to producers was taken as the banana production cost (MXN 3.19 kg^{-1}), corresponding to November 2022 (González-Rodríguez *et al*., 2025); this value was added as a restriction to the model. The Gretel software was used to calculate the model.

Dynamic analysis

The starting point was a second-order difference equation (Equation 4), expressed by the general model (Equation 1).

$$y_{t+2} + a_1 y_{t+1} + a_2 y_t = c \qquad (4)$$

The variable p_t was renamed by y_t. The y_t variables were cleared and pre-multiplied by y_2 which is the order of the equation, and c is a constant variable. It was assumed that the market tends to reach balance eventually; therefore, $y^* = y_{t+1} = y_{t+2} = y_t$. The y^* variable was factored and cleared to obtain the particular solution from the general model (Equation 5), then it was equaled to zero to start with the calculation of the complementary equation (Equation 6).

$$y^* = \beta + \beta_1 D + \beta_2 t \qquad (5)$$

$$y_{t+2} + a y_{t+1} + a_2 y_t = 0 \qquad (6)$$

$Y_t = A(b)^t$ was renamed by $Y_{t+n} = A(b)^{t+n}$, therefore, for $Y_{t+n} = A(b)^{t+n}$, A is the initial condition of the banana price when $t = 0$; the common factor Ab^t (different from 0) was cancelled to obtain the following expression:

$$b^2 + a_1 b + a = 0 \qquad (7)$$

The quadratic function (Equation 7) has two characteristic roots (b). The value of b was determined using the general formula, where the complex roots correspond to the next expressions:

$$b_1 = h \pm v_i \qquad (8)$$

$$b_2 = h \pm v_i \qquad (9)$$

The cyclic behavior of the function is presented by a complex number. When plotted in an Argand diagram (Brambila-Paz, 2011) (Figure 1), the real values (*h*) are located on the horizontal axis and the imaginary values (v_i) on the vertical axis, and *M* is the modulus or absolute value of the complex number $h + v_i$.

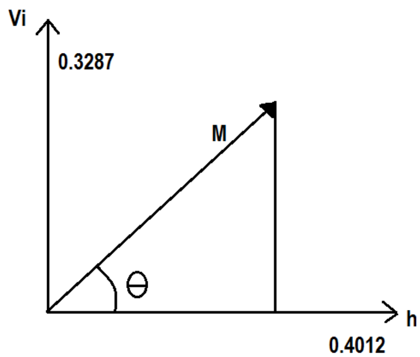


Figure 1. Argand diagram

To determine the modulus of Equations 8 and 9 and define market behavior, the Pythagorean theorem was used (Equation 10), which indicates a market is cyclical but convergent when $M < 1$, cyclical but convergent when M > 1, and cyclical but convergent when M = 1.

$$M = \sqrt{h^2 + vi^2} \qquad (10)$$

To calculate the angle θ, the following (Equations 11 and 12) were used to estimate the cycle length, which is equivalent to 360° / θ.

$$cos\ \theta = \frac{h}{M};\ \theta = cos^{-1}\left(\frac{h}{M}\right) \qquad (11)$$

$$sen\ \theta = \frac{h}{M};\ \theta = sin^{-1}\left(\frac{h}{M}\right) \qquad (12)$$

where *M* is the modulus, and *h* is the real part of the complex number.

Using Moivre's theorem (Chiang and Wainwright, 2006), the complementary solution was obtained (Equation 13).

$$Y_t = r^t[A1\ cos(\theta_t) + A2\ sen(\theta_t)] \tag{13}$$

where Y_t is the projected price, r^t equals module *M*, *A1* is the first long-run multiplier, θ_t is the angle, and *A2* is the second long-run multiplier.

The total solution (Equation 14) was obtained from the sum of the particular solution (Equation 5) and the complementary solution (Equation 13). This expression made it possible to project prices for the next 10 years.

$$Y_t = M^t[A1\ cos(\theta_t) + A2\ sen(\theta_t)] + \beta + \beta_1 D + \beta_2 t \tag{14}$$

where *Yt* is the projected future price; M^t is the modulus of the equation that defines the behavior of the banana market; *A1* is the first long-term multiplier; $\cos(\theta^t)$ is the cosine of angle θ; *A2* is the second long-term multiplier; $\sin(\theta^t)$ is the sine of the angle θ; β is the intercept of the econometric model; β_1 is the intercept that relates the dummy variable to the model; *D* is the dummy variable that relates the influence of temperature on price at different times of the year; β_2 is the intercept that relates the time variable to the model; and *t* is the discrete time trend variable.

RESULTS AND DISCUSSION

The second order difference equation (Equation 15) was formulated to understand the structure and behavior of the banana market. The statistic results of the variables used in this dynamic model (Table 1) were used to determine the trajectory and projection of future banana prices for the next 10 years.

$$P_t = 1.1373 + 0.8025P_{t-1} - 0.2691P_{t-2} + 0.4888D + 0.0150t \tag{15}$$

Table 1. Statistical results of the econometric model (Equation 15) for real banana prices projection from January 2015 to February 2020.

Variable	Coefficient	Standard deviation	*t* statistic	*p* value	
Intercept	1.1373	0.6219	1.829	0.0729	*
$P_{(t-1)}$	0.8025	0.1321	6.077	<0.0001	***
$P_{(t-2)}$	-0.2691	0.1378	-1.954	0.0558	*
D	0.4888	0.4445	1.100	0.2762	
t	0.0150	0.01223	1.229	0.2243	

D: dummy variable; *t*: time variable; $P_{(t-1)}$: lagged price variable on the first period; $P_{(t-2)}$: the lagged price variable on the second periods; *not statistically significant, **** statistically significant.

Market structure

From the mathematical transformations described in methodology and applied to Equation 15, Equation 16 was obtained, which has two characteristic roots. The value of b was determined using the general formula, where the complex roots correspond to the values b_1 and b_2.

$$b^2 - 0.8025b + 0.2691 = 0 \tag{16}$$

where:

$$b_1 = 0.4012 + 0.3287i$$

$$b_2 = 0.4012 - 0.3287i$$

The module value (Equation 10) is $M = 0.5186$; therefore, since the model has a negative root, the market has a complex structure. As $M < 1$, the market behaves cyclically and tends to converge, allowing long-term projections (Brambila-Paz, 2011).

The following expressions were used to calculate the angle θ (Equations 17 and 18). The cycle length equals 360° / θ.

$$cos\ \theta = \frac{h}{M}; \theta = cos^{-1}\frac{0.4012}{0.5186};\ \theta = 39.3217 \tag{17}$$

$$sen\ \theta = \frac{h}{M}; \theta = sin^{-1}\frac{0.3287}{0.5186};\ \theta = 39.3310 \tag{18}$$

360° / 39.321 = 9.153 months; the prices used in the model were presented on a monthly basis, which means that the cycle of price increases and decreases was estimated in nine months.

The most important variables involved in banana price consolidation are related to supply and demand, which in turn are defined by external and internal factors, such as weather conditions and resource allocation in the case of supply. In terms of demand, the most important factors affecting the price of fruit are the tastes and preferences of consumers, who are looking for a better-quality product and are willing to pay a higher price. For this reason, the quality of the fruit is very important for the international market.

In regions where seasonal transitions are well defined, the trend in banana consumption is generally of a seasonal nature, with drops in consumption occurring during the summer and at the end of the year, which coincides the prices observed in the field by González-Rodríguez (2025). This coincides with an increase in the supply and demand of seasonal fruits, since temperature attracts consumers to other products, coupled with the low school activity due to holiday periods. On the other hand, banana consumption peaks in autumn and early spring (April, May, and October), thanks to favorable temperatures for the production and consumption of this fruit (Martínez-Solórzano and Rey-Brina, 2021).

The increase or decrease in the price depends on the amount of fruit harvested, although this often does not correspond to actual production. In addition, there is the variability in market prices of products used as inputs for production, transportation, and even exchange rate fluctuations (Erazo-Berrú *et al*., 2021).

Price projections

The price projection for the first scenario was calculated using Equation 14, and the multipliers *A1* and *A2* of the equation were estimated when *D* = 1 and *D* = 0. Y_0 = 5.2 (first real price of the data series) and Y_1 = 4.61 (second real price of the data series) were considered (Table 2 y 3). Also, a non-negativity restriction was established for the model so that in case of a negative value in the price estimation, the previous

Table 2. Calculation of multipliers A1 and A2, when D = 1.

$Y_t = 0.5186^t[A1\ cos(39.3217t) + A2\ sen(39.3310t)] + 2.4374 + 1.0475D + 0.0321t$			
Variable	Value	Variable	Value
Y_0	5.20	Y_1	4.61
t	0	*t*	1
D	1	*D*	1
A1	1.7151	*A2*	1.2321

D: dummy variable; *t*: time variable; Y_0: first real price of the data series; A1: first long-term multiplier; Y_1: second real price of the data series; A1: second long-term multiplier. D = 1 when estimating prices during the cold months (January, February, March, October, November, and December).

Table 3. Calculation of multipliers A1 and A2, when *D* = 0.

$Y_t = 0.5186^t[A1\ cos(39.3217t) + A2\ sen(39.3310t)] + 2.4374 + 1.0475D + 0.0321t$			
Variable	Value	Variable	Value
Y_0	5.20	Y_1	4.61
t	0	*t*	1
D	0	*D*	0
A1	2.7626	*A2*	3.1412

D: dummy variable; *t*: time variable; Y_0: first real price of the data series; A1: first long-term multiplier; Y_1: second real price of the data series; A1: second long-term multiplier. D = 0 when estimating prices during the warm months (April, May, June, July, August, and September).

positive value is taken. This restriction is based on the commercial strategy taken by the producers in the area, who stop the banana harvest when the price is very low, with the purpose of pressuring the marketers. This allows the producer to obtain a better sale price.

The total solution expression (Equation 14) was used to estimate real monthly banana prices for the next 10 years (Table 4).

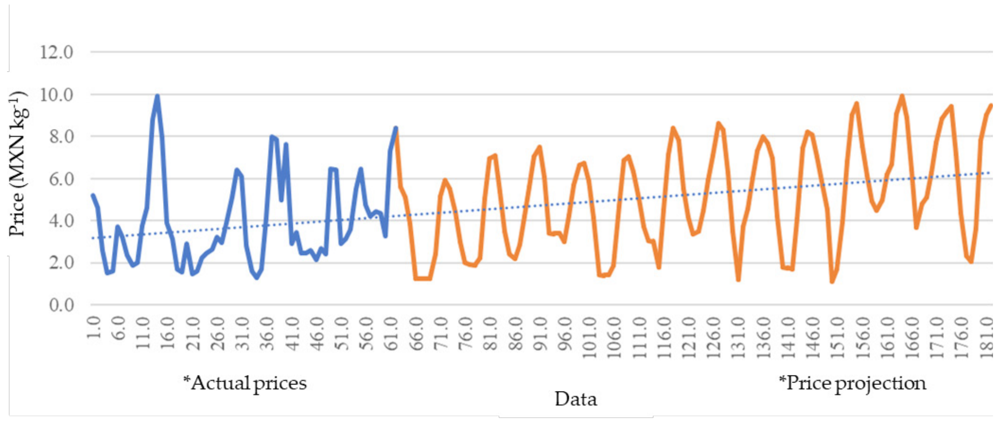
Table 4. Real banana prices for the years 2021–2030 (MXN kg^{-1}).

Month	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
January	5.62	2.99	2.86	6.65	5.01	3.49	7.33	7.05	4.47	7.74
February	5.10	2.02	4.20	6.71	3.71	4.49	7.97	5.65	4.96	8.86
March	3.87	1.92	5.60	5.86	3.03	5.94	7.66	4.52	6.20	9.15
April	1.23	1.92	7.05	4.13	3.03	7.10	6.97	1.09	6.67	9.45
May	1.23	2.25	7.47	1.42	1.77	8.63	4.21	1.70	9.06	7.14
June	1.23	5.06	6.03	1.42	4.54	8.31	1.77	3.94	9.92	4.34
July	1.23	6.95	3.40	1.42	7.14	6.28	1.77	6.81	8.88	2.34
August	2.40	7.07	3.40	1.86	8.41	3.49	1.66	9.02	6.41	2.05
September	5.14	5.38	3.40	4.69	7.79	1.21	4.08	9.59	3.66	3.63
October	5.92	3.49	2.99	6.85	5.53	3.70	7.45	7.54	4.78	7.81
November	5.53	2.41	4.27	7.06	4.18	4.59	8.23	6.16	5.12	9.03
December	4.37	2.16	5.70	6.33	3.37	6.01	8.07	4.95	6.27	9.46
Annual Average	3.57	3.64	4.70	4.53	4.79	5.27	5.60	5.67	6.37	6.75

For the analysis and price projection for the period from January 2021 to December 2030, the dummy variable (D = 1 cold months and D = 0 hot months) explains the projected prices. This is due to the fact that the average prices for the cold months were higher than the hot months, which coincides with the amount of fruit harvested during these two periods of the year. The hot months are the peak season for fruit production (more supply). Therefore, the selling price is lower, while during the cold months, the supply of fruit decreases and the price increases.

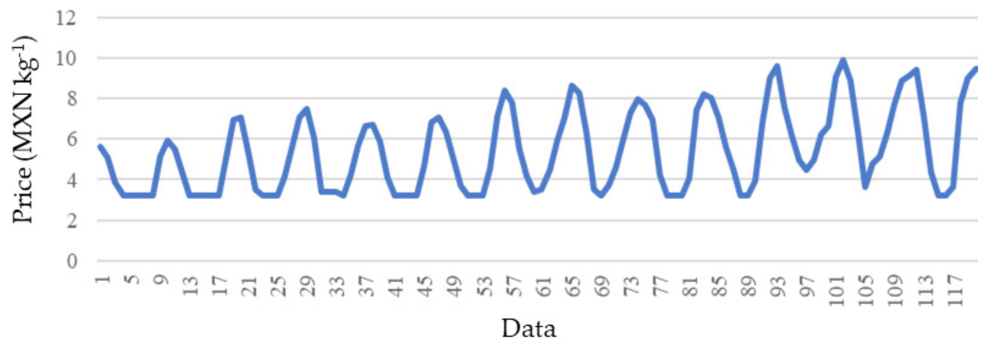
The projected average annual price was estimated to increase by 68.32 % over the entire period (January 2021 to December 2030). Regardless of the fact that the banana market behaves in cycles of highs and lows (Figure 2), prices showed an upward trend for the following years.

For the second scenario, the production cost was taken as a reference, which was calculated for November 2022 and is equivalent to MXN 3.19 kg^{-1}. This value was added as a constraint to the model. It was assumed that producers would implement a commercial strategy that would allow them to obtain a minimum price at the time of sale equivalent to this production cost (Figure 3).



Data 1 to 62 = observed price.
Data 61 to 181 = projected price within the analyzed period.

Figure 2. Projected real banana prices, 2021–2030 (MXN kg^{-1}).



Data 1 to 62 = observed price.
Data 61 to 181 = projected price within the analyzed period.

Figure 3. Projection of real banana prices for 2021–2030, with the assumption of receiving the cost of production (MXN kg^{-1}).

In Ecuador, an analysis of banana price variation was conducted for the period 2015-2020. Erazo-Berrú *et al*. (2021) conclude that the variation of the price has mostly been increasing. However, between 2017 and 2018, there was a decrease of six cents in its price, corresponding to -0.96 %. In 2020, the highest price was USD 6.4 per box, despite the fact that it was a year with high risks in the world economy due to the COVID-19 pandemic, which paralyzed many industries.

In addition to the limitations derived from the pandemic, factors such as increases in the price of production inputs (fertilizers and packaging materials) and transportation costs, shortages of refrigerated containers, low production due to adverse weather conditions and plant diseases, strict limitations on maximum residue levels in some important markets, and slightly lower demand in import markets affected world trade in bananas (FAO, 2022). All of the above hinder prices and profit margins along the value chain, as well as the ability of producers and exporters to supply bananas in adequate quantities and meet the quality requirements of export markets. In most of the main import markets, banana prices have shown an upward trend. The European Commission (2022) notes that prices for this fruit produced in the European Union grew by 33 % over the 2018–2021 period. Meanwhile, import prices from African, Caribbean, and Pacific countries increased by 13.6 % from 2012 to 2021.

So far, no studies provide a previous reference of the use of this dynamic economic analysis tool in price projection for banana cultivation as in the present article. However, Mendoza-Rodríguez *et al*. (2016) implemented this methodology of using superior difference equations to analyze the egg market in Mexico and estimate the amount of egg per capita to be consumed for 2013–2020. The egg market did not behave cyclically like the banana market; however, both markets tend to converge.

Brambila-Paz *et al*. (2015) also used this methodology to measure the technological effort required and increase the yields of different agricultural products such as corn, lemon, wheat, avocado, potato, egg, and milk, to cover the demand of the Mexican population and its projected trend for the year 2025.

CONCLUSIONS

Real banana price projections showed an upward trend, with a cumulative growth rate of 89 % over the period from January 2021 to December 2030. This validates the hypothesis that the product price paid to the producer will continue to rise over the next 10 years, influenced by the effect of ambient temperature on plant production. The structure of the banana market is complex, cyclical, and convergent. The cycle period has a duration of 9 months. This implies that the market will reach equilibrium and is expected to continue growing.

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