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Una prueba de cointegración de los futuros agrícolas de Estados Unidos con el precio del limón mexicano

A cointegration test of the U.S. agricultural futures with the Mexican lemon price

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Resumen

El presente artículo prueba la existencia de una relación a largo plazo entre el precio del limón mexicano #4 y los nueve futuros más negociados en los EE. UU. (maíz, trigo, arroz, avena, cacao, café, azúcar y algodón). Utilizando datos semanales del precio del limón mexicano y de los nueve futuros de interés, junto con la prueba de cointegración de Engle-Granger y pruebas estándar de raíz unitaria, los resultados demostraron que el precio del limón mexicano es estacionario y no tiene una relación de largo plazo con los futuros de interés. En consecuencia, la práctica de cobertura cruzada (para fines de seguridad alimentaria) debe realizarse en un horizonte de corto plazo o mediante otros métodos cuantitativos no lineales.

Palabras Clave: Limón mexicano #4; seguridad alimentaria; futuros agrícolas; cobertura cruzada

Abstract

The present paper tests whether there is a long-term relationship between the #4 Mexican lemon price and the nine most traded futures in the U.S. (corn, wheat, rough rice, oats, cocoa, coffee, sugar, and cotton). Using weekly Mexican lemon price data and the nine futures of interest, and performing Engle-Granger cointegration and standard unit-root tests, the results showed that the Mexican lemon price is stationary and has no long-term relationship with any of these futures. Consequently, the cross-hedging practice (for food security purposes) must be performed in a short-term context or other non-linear quantitative methods.

Keywords: #4 Mexican lemon, food security; agricultural futures; cross-hedging

JEL CODE: Q11; Q18; Q14; G32

INTRODUCTION

The tests in this paper aim to extend the previous literature on the benefits of cross-hedging in non-commodity and niche agricultural products (such as the Mexican lemon) and on its use. No previous works have tested the hedging effectiveness (i.e., long-term relationship) of the main United States (U.S.) agricultural futures and the #4 Mexican lemon.

Testing such a relationship helps understand these prices' dynamics and provides a potential cross-hedging tool in the Mexican lemon market for food security and income risk reduction.

In terms of policy and food security practices, the results of this paper could contribute to the implementation of a Public hedging mechanism, similar to Seguridad Alimentaria de Mexico (SEGALMEX, a public agricultural income risk reduction institution), that could offer a hedging lemon price to reduce the agent's (producer or intermediary) income risk. This result could lead to a more stable lemon offer.

As a related result, the potential use of this paper's results could motivate the Mexican Government and its private financial institutions to offer hedging prices by transferring the hedge risk from taxpayers (as SEGALMEX actually does) to U.S. futures markets. As a result, Mexican agricultural trade practices could evolve from market-protected amber practices, according to the World Trade Organization (1993) classification, to green (more market-friendly) policies.

Among the main challenges that this cross-hedging method faces is basis risk, known as the difference between the underlying's spot price and its strike (buy or sell). Consequently, testing the more stable long-term relationship between the Mexican lemon price and the nine most-traded futures in the U.S. is a necessary step toward assessing the feasibility of the cross-hedging endeavor.

Given the theoretical, policy, and practical motivations, the following section summarizes the main background and motivations of this paper. The third section presents prior work and results that motivate this paper. The fourth section describes the data gathering and processing of the input data, along with the unit root and cointegration tests. Finally, the fifth and last section presents the main conclusions and guidelines for further research.

BACKGROUND

Lemons are one of the most widely used citric staples for human consumption and food production. Its harvested area has increased from 122.75 million hectares (Ha) in 2000 to 210.73 million (Ha). This represents almost a 95% increase in value production, from USD 1.66 billion in 2000 to USD 3.24 billion in 2023. There are two species of lemon to mention for the intended purposes herein: the Persian lime (Citrus latifolia) and Mexican citrus or lemon (Citrus Aurantafolia). The former is consumed in countries like the U.S., China, and most of Europe. The latter is the main species (staple) consumed in Mexico. Following FAO (2024) figures, global lemon and lime production increased from 788.47 million Ha (USD 10.82 billion) in 2000 to 1.38 billion Ha (USD 23.64 billion) in 2023.

Table 1 summarizes the leading lemon and lime producers as of 2023, and Figure 1 shows the historical production of these since 1961. As noted, India and Mexico are the two leading producers, with Mexico among the most stable producers (in terms of growth) due to its natural conditions and soil quality (mostly volcanic soil and warm, temperate weather most of the time).

As shown in Figure 2, Mexico's global production share, in terms of harvested area, has decreased marginally from 15.57% in 2002 to 15.18% in 2023 (a decrease from 15.35% in 2002 to 13.74% in 2023 in USD value). This is due to the emergence of countries like India and China.

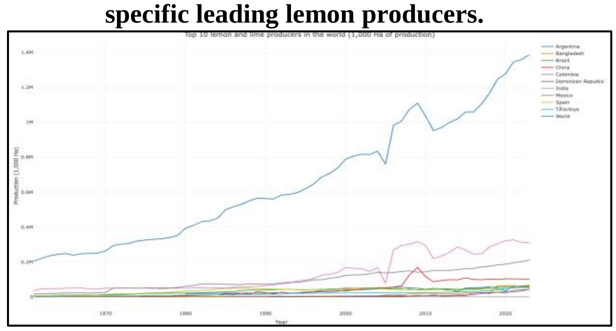
Table 1. Leading lemon and lime producers as of 2023

Country	Harvested area (1,000 Ha)	Value (USD 1,000)
World	1,388,251.00	23,644,474.94
India	312,000.00	3,787,000.00
Mexico	210,735.00	3,249,216.79
China	102,368.00	2,414,248.89
Brazil	66,399.00	2,325,726.00
Bangladesh	63,385.00	1,998,272.53
Argentina	58,368.00	1,724,330.00
Turkey	56,439.00	1,148,870.00
Spain	51,670.00	1,012,420.00
Dominican Republic	44,735.00	809,887.93
Colombia	41,479.00	541,235.62

Source: Own elaboration with data from FAO (2024).

According to production figures from Mexico (SIAP, 2024), 60% of Persian lime is exported to the United States (US) and to European Union members. The main staple of both species is the Mexican lemon, which is consumed in the country. This species is classified into five size categories. From #1 to #5, being the first three the largest size classification. These are primarily consumed in restaurant and delicatessen recipes. Sizes #4 and #5 are more for general home use and are sold in markets and supermarkets. This paper focuses the research effort on the price of #4 Mexican lemons, due to their size and national consumption.

Figure 1. Harvested area by global and country-specific leading lemon producers.



Source: Own elaboration with data from FAO (FAO, 2024).

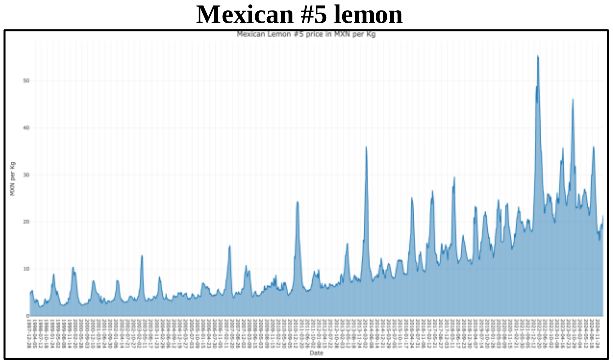
The Mexican lemon (henceforth, lemon) price has increased since its first record, on December 28, 1997, according to the National Information and Integration Market System or SNIIM (Secretary of Economy, 2025)—a public price record system of the Mexican Economy Secretary. Figure 2 shows the historical price increase from December 1997 to February 16, 2025. As noted, the price per kilogram (Kg) has increased from MXN 4.45 to MXN 21.43. Despite this increase (mainly due to inflationary pressures), there are instances where prices have risen due to weather or security issues, followed by significant price corrections.

This behavior suggests that even if the Mexican lemon price shows an upward trend, its market fluctuations are volatile. This result indicates that Mexican lemon producers face a significant level of income risk. If volatility levels are related to the low level of technological development in Mexican lemon production, the reader could conclude that income risk is a significant concern for Mexican producers.

Following the 2023 data of the Agricultural, food, and fisheries program or SIAP (2024), the total MXN value of the Mexican lemon production was MXN 31,201,428,470.00. The figure for the 2023 Mexican gross domestic product (GDP) at current prices was approximately MXN 30 trillion, according to the National Statistics, Geography and Informatics Institute, INEGI (2025).

By assuming an average marginal consumption propensity of 0.8, the estimated added value of Mexican lemon production was approximately MXN 156,007,142,350.00. This added value represents 0.51% of Mexican GDP as of 2023. Table 2 summarizes these calculations. In this exhibit, the authors also estimated the contribution of lemon production to Mexican agricultural GDP (21.42%).

Figure 2. Historical national average price of the Mexican #5 lemon



Source: Own elaboration with data from SNIIM (2025).

Following previous works like those of Villar-Luna et al. (2024), Mellado-Vázquez et al. (2023), Espinosa-Zaragoza et al. (2021), Vargas-Canales et al. (2020), and Fernández et al. (2014), the lemon production generated income for 69,000 families in Mexico with about 28 million workdays a year. The five leading producing states are Michoacan, Colima, Veracruz, Oaxaca, and Tamaulipas. Table 3 summarizes the National lemon production and the ten leading states in lemon production in 2023. Table 3 displays the cropped, harvested, and lost areas, along with the tons produced, the yield in tons per hectare (Ha), the average MXN value per ton, and the total production value in thousands of MXN.

Table 3 depicts the nine futures of interest that are among the nine most traded futures, according to the United States Commodities and Futures Trading Commission (US CFTC, 2009).

Table 2. Mexican lemon production's GDP contribution

Variable	Value
Mexican GDP (MXN)	30,497,488,360,000.00
Mexican agricultural GDP (MXN)	728,327,621,000.00
Mexican lemon production value (MXN)	31,201,428,470.00
Mexican lemon added value (MXN)	156,007,142,350.00
Lemon added value share of GDP (%)	0.51
Lemon added value share of agricultural GDP (%)	21.42

Source: Own elaboration with data from SIAP (2024) and INEGI (2025).

Table 3. The futures used in the backtests, their general contract specifics.

Future	contract unit	Future's exchange
1-month corn	Bushel	CME
1-month wheat	Bushel	CME
1-month rough rice	Hundred weight (cental)	CME
1-month soybean	Bushel	CME
1-month oats	Bushel	CME
1-month cocoa	Metric ton	NYMEX
1-month coffee	Pounds	NYMEX
1-month no.11 sugar	Pounds	NYMEX
1-month cotton	Pounds	NYMEX

Source: Own elaboration with data from CME (2025).

If, by using the Engle and Granger (1987) cointegration test, there is proof that there is a long-term relationship between each future and the Mexican lemon price, the conclusions could lead to suggesting their use for food security hedging schemes provided either by the Mexican government or the private financial institutions.

Consequently, the hypothesis to be tested in this paper is that these nine futures have a long-term relationship (as measured by a cointegration test).

Based on this brief economic and social impact review of lemon production in Mexico, this paper tests whether any of the nine most traded Agricultural futures in the United States (U.S.) exhibit a long-term relationship and could be useful for cross-hedging. Cross hedging is a practice used to hedge the price of a product or underlying with the futures of a similar underlying, for example, using 1-month futures in the Chicago Mercantile Exchange (CME) to hedge the price of the #4 lemon, or the 1-month cocoa of the New York Mercantile Exchange (NYMEX).

The following section summarizes prior work on cross-hedging and the use of cointegration tests in futures-based cross-hedging.

LITERATURE REVIEW

There is no test of the long-term relationship between Mexican lemon prices and the main agricultural U.S. futures. Testing the long-term relationship (cointegration) and the hedging effectiveness of each of these nine futures contracts could be used by practitioners and Academics to develop practical applications for any of these futures to hedge lemon prices. The evidence of a long-term relationship between each of the nine most traded agricultural futures in the U.S. and the Mexican lemon price, along with a high hedging effectiveness (a value close to 1), will suggest the potential benefits of cross-hedging with these futures.

The theoretical basis for cross-hedging with futures dates back to the works of Working (1953), Ederington (1979), and Anderson and Danthine (1981), who tested the mean-variance efficiency of hedging a given underlying (primarily a financial one). These tests lay the groundwork for what is known as the Futures hedging theory, a framework for modelling the agent's hedging and futures trading decisions.

The work of Ederington (1979) departs from Working's hypothesis and the hedging hypothesis (hedging exists for risk avoidance). This author is the first to mention the concept of basis. Basis is defined as the difference between the spot price and the opposite future prices. The variance of the difference of the spot and future's price percentage change is known as basis risk. Consequently, this author proposed the concept of hedging effectiveness of a future (or futures portfolio), given the percentage price change of the spot price $\Delta\%P_t$, and the future's $\Delta\%F_t$:

$$HE_{i,t} = 1 - \frac{\sigma^2(\Delta\%P_t - \Delta\%F_t)}{\sigma^2(\Delta\%P_t)} \quad (1)$$

If the future or futures are a proper hedge, the value of the HE must be close to one.

The work of Anderson and Danthine (1981) focuses on several aspects of hedging, like the correlation between the spot price $P_{s,t}$ and the future $P_{f,t}$. When such a correlation is neither perfect nor high, basis risk increases. Consequently, the authors suggest using a portfolio of direct futures to hedge the spot position, plus other futures that, given their correlation matrix, could reduce basis risk. This could motivate, as a primary goal, to find a futures weight vector $\mathbf{w}$ that solves the following optimal selection, assuming that the investment weights must be positive and add to 1 (100%):

$$\mathbf{w}^* = \arg\min \sigma^2(r_{s,t} - \mathbf{Rw}) \quad (2)$$

Subject to:

1. $\mathbf{w}'\mathbf{1} = 1$
2. $\mathbf{w} \geq 0$

In the previous expression $\mathbf{R}$ is a $n \times T$ futures return (percentage price variation $r_{f,t}$), being n the number of futures and t the length of the time series. $\mathbf{w}$ is the futures weights vector in the hedging portfolio. The core idea is finding the optimal investment level such that $\sigma^2(r_{s,t} - \mathbf{Rw})$ tends to zero. That is, the basis risk is at its lowest.

A first study supporting the use of cross-hedging in agricultural products is that of Kumar and Pandey (2011). These authors made a historical review of several commodity markets in India, along with their relationship with the Indian futures markets. The authors tested de hedging effectiveness of agricultural products such as soybeans, corn, castor, and guar seeds. In their results, the authors found that agricultural futures exhibit hedging effectiveness between 0.3 and 0.7.

Ortiz-Arango and Montiel-Guzmán (2017) tested the dynamic short- and long-term (cointegration) relationship between Mexican white corn prices and the CME yellow corn futures. Their tests found no significant long-term relationship between the Mexican price of almost all the origins.

In a related review, Gupta et al. (2017) tested the effectiveness of Indian Agricultural and energy futures in hedging Indian agricultural products. Using vector error correction (VEC) models, they found that metals' futures exhibit the best hedging effectiveness (HE).

To incorporate the effect of weather on agricultural prices, Barrera et al. (2020) tested the cross-hedge between Colombian electricity derivatives and several Colombian agricultural products. Only nine of these products showed a significant relationship between the product's price and the futures. These reduced the price risk by only 32%.

The work of Penone et al. (Penone et al., 2021) tested the hedging effectiveness of the Euronext futures exchange and the Chicago Board of Trade (CBOT) with the Italian soybean, corn, and milling wheat prices. Their primary motivation was to test the hedging effectiveness of the European and US markets. By testing a naïve and optimal hedge ratio HR of the futures with the spot price. The authors found three key results:

1. European futures are superior to US futures.
2. With hedging periods like t+4, the hedging effectiveness HE rises.
3. The correlation between future and spot prices is relevant to hedging effectiveness.

Rout et al. (2021) examined price formation between futures and spot markets in India. By using cointegration and the Engle-Granger (1987) causality tests, the authors found low HE and an insignificant cointegrating relationship. They attribute this result to market liquidity and futures contract specs.

The work of Erasmus and Geyser (2024) tested the benefits of hedging soy prices in South Africa using related local futures. The authors found significant hedge ratios. They also noted that the South African futures hedging effectiveness is high when the hedged price is close to the export price.

The work of Goswami et al. (Goswami et al., 2023) tested non-convergence. This phenomenon happens when the spot and future prices do not converge at the futures redemption rate. This leads to different settlement and delivery prices that the hedger must consider in the hedging strategy. The authors also found that the optimal (minimum) hedge ratio method for hedging agricultural spot prices with their related futures is ineffective in the presence of non-convergence. This paper uses this result as a theoretical motivation to test the long-term relationship between U.S. futures and the Mexican lemon price.

In some regions and agricultural products, the industry's gross profit margins receive little attention, as Haarstad et al. (2022) have shown. In some sectors, such as salmon or shrimp, the development of new futures exchanges with limited demand led to limited hedging tools and the closure of the newly created exchanges (Sanders et al., 2010; Sanders & Manfredo, 2002).

Despite these two issues, using futures in cross-hedging could reduce income risk (even with high profit margins), enhancing profitability and generating added value. Consequently, the core motivation of this paper is to test a portfolio of agricultural (liquid) futures to hedge a niche product, such as Mexican lemons.

To support the use of the cointegration test between future contracts and the non-commodity hedged, Working (Working, 1953), Ederington (Ederington, 1979), Overdahl and Starleaf (Overdahl & Starleaf, 1986), Pennings and Meulenberg (Pennings & Meulenberg, 1997), and Stein (Stein, 1961) are among the authors to test and suggest the use of ordinary least squares (OLS) methods in different functional forms to determine the optimal hedging ratio (β). With different functional forms, all these depart from a minimum tracking error (basis risk reduction) rationale and use the following OLS (or variants with price increments, prices at a level, or the use of other regressors) functional form:

$$r_{s,t} = \alpha + \beta r_{f,t} + \varepsilon_t \qquad (3)$$

The optimal hedging ratio (HR) in the previous expression (β) is the proportion of how many future contracts are necessary to hedge with the lowest basis risk. Also in (3), $r_{s,t}$ is the percentage price change ($r_{s,t} = \Delta\% P_{s,t}$) of the spot (lemon) price, and $r_{f,t}$ the one of the tested future.

Consequently, testing the presence of a long-term relationship between the nine futures of interest and the Mexican lemon price could lead to supporting the use of each future to hedge the lemon price, due to a time-stable hedge ratio of β in (3) or the long-term cointegrating relationship version of (3):

$$P_{s,t} = \alpha + \beta P + \varepsilon_t \quad (4)$$

If the long-term (cointegrating relationship) holds, (4) could be good enough to estimate how many contracts β of the future of interest must be bought (sold) to hedge a potential price increase (reduction)

Another related perspective for future hedging is the use of vector error-correction models VECs; (Alexander, 1999; Alexander & Dimitriu, 2005). The general functional form of such models departs from one of (4) and could be extended to a portfolio of two or more futures:

$$P_{s,t} = \alpha + \sum_{f=1}^{n} \beta_f \cdot P_{f,t} + \sum_{p=1}^{P} \gamma_p \cdot \varepsilon_{t-p} + \nu_t \quad (5)$$

The first two terms are the long-term relationship between the future and spot prices (the cointegrating or long-term relationship of interest), and the third is the error correction terms, given P number of lags:

The rationale for VEC models is that the regressors have a long-term relationship given by β_f. The third term models the correction of short-term price divergences because of shocks or new information in the markets of interest.

Following (4) and (5) β_f is the hedge ratio. Given its long-term nature, this hedge ratio is more stable and results in fewer trades in the portfolio. Alexander (Alexander, 1999) and Alexander and Dimitriu (Alexander & Dimitriu, 2005) are the first to suggest VEC models for index tracking and, potentially, futures hedging as in (4) or (5). These two authors suggest estimating β_f with a quadratic programming problem, given the restriction that $\sum \beta_f = 1$.

This model was initially designed for stock index tracking with a few stocks, minimizing trades, and used β_f for long-term investment weights. Despite the simplicity and flexibility of (5) for the lemon price replication purposes, it is essential to test if a long-term relationship between the lemon price and the futures holds (without exception). As noted, this is the main goal and motivation of this paper. As mentioned, the Engle-Granger (1987) cointegration test will be the core quantitative method of the working hypothesis that the nine futures of interest exhibit a long-term (potentially hedging) relationship with the Mexican lemon price.

Based on the theory, model, and related research, the data gathering methods and cointegration test process are detailed in the following section.

METHODOLOGY

To perform the cointegration and hedging effectiveness tests, the historical Mexican #4 lemon prices were retrieved from the databases of the National Markets Information and Integration System (SNIIM) (Secretary of Economy, 2025), a market price database of the Mexican Secretary of Economy. Because the SNIIM provides daily records of the minimum, maximum, and median lemon price of the main markets in each state, the authors estimated a national lemon price ($P_{lemon,t}$) with the average of the median price in each state at date t and transformed the daily time series to weekly, by using the price of last labor day each week.

Similarly, from the databases of tradingView (2025), Refinitiv (2021) and the Chicago Mercantile Exchange (2025), the historical weekly futures prices were retrieved. With these prices ($P_{i,t} = P_{s,t}, P_{f,t}$) (lemon and futures), the continuous-time returns were estimated as follows:

$$r_{i,t} = \ln(P_{i,t}) - \ln(P_{i,t-1}) \quad (6)$$

For the cointegration test, the authors examined whether the time series of lemon prices and futures prices are non-stationary. That is, if they are either increasing in values or the current realisation ($P_{i,t}$) shows a dependence or autocorrelation with previous periods ($P_{i,t-n}$) and the value of $P_{i,t}$ is not random (could be explained with an equation). If this property holds in the price's time series, the cointegration test could be performed in the following cointegrating relationship, a single-future version of (5):

$$P_{s,t} = \alpha + \beta \cdot P_{f,t} + \nu_t \qquad (7)$$

For this purpose, the third term (7) is the short-term, error correction. If the cointegrating relationship (7) holds, the price of the future of interest ($P_{f,t}$) moves closer to that of the Mexican lemon ($P_{s,t}$), plus a random, short-term value that must be stationary. That is, it must be practically random.

Consequently, and following the time series analysis procedure, if both time series in (7) are non-random or non-stationary, they should be tested with a unit-root test like the ones of Dickey and Fuller (1981; 1979), Phillips and Perron (1988), or the KPSS of Kwiatkowski et al. (1992). For this paper, the first two tests assume a null of non-stationarity (unit root) versus the alternative of stationarity (no unit root). The third believes that the time series follows a stationary stochastic process, rather than a stationary trend process. Consequently, to prove that the ten time series of prices are non-stationary, the results of the first two tests must show high p-values, and the third, a low one.

Once the unit-root test indicated non-stationarity, the cointegrating relationship (7) was estimated for the Mexican lemon, with the spot price as the dependent variable and each of the nine futures in Table 3 as the regressor. To test whether the two time series in (7) are cointegrated (i.e., they exhibit a long-term relationship), the residuals must be non-stationary. That is, the p-value in the Dickey-Fuller test must be high (the KPSS test p-value must be low).

To test for the long-term (cointegrating) relationship, the Engle-Granger test was performed by using only the Dickey-Fuller test in the residuals of (7)

Now that the quantitative method for testing the long-term relationship was described, along with the data-gathering process, the following section presents the results review.

RESULTS DISCUSSION

To test whether the ten time series of interest are non-stationary, Table 4 shows the results of the Augmented Dickey-Fuller test, Table 5 those of the Phillips-Perron, and Table 6 the p-values of the KPSS. As noted for the first two tests, except for the lemon, rough rice, and wheat future prices, all the time series exhibit a unit root. That is, they are non-stationary. Consequently, the long-term relationship between the Mexican lemon price and any of the other futures does not hold.

Table 4. The Dickey-Fuller test p-values.

Time series	Dickey-Fuller test
Mexican lemon price	0.01
Corn future	0.129572
Wheat future	0.108623
Rough rice future	0.01
Soy bean future	0.07488
Oats future	0.035097
Cocoa future	0.99
Coffee future	0.966337
Suggar future	0.045963
Cotton future	0.477227

Source: Own elaboration with data from CME (Chicago Mercantile Exchange, 2025) and SNIIM (2025).

The KPSS test confirms the absence of a stationary trend.

Table 5. The Phillips-Perron test p-values.

Time series	Phillips-Perron test
Mexican lemon price	0.01
Corn future	0.089139
Wheat future	0.01
Rough rice future	0.01
Soy bean future	0.086741
Oats future	0.028318
Cocoa future	0.982196
Coffee future	0.99
Suggar future	0.017014
Cotton future	0.557448

Source: Own elaboration with data from CME (Chicago Mercantile Exchange, 2025) and SNIIM (2025).

Despite these results, the Engle-Granger test was still performed, resulting in stationarity of the residuals in (7). Because the lemon price and two of the futures are not stationary, the residuals in (7) show stationarity (as expected) due to the stationarity of the lemon price. Consequently, there is evidence of no long-term relationship between the Mexican lemon price and the nine futures tested herein.

Table 6. The KPSS test p-values.

Time series	KPSS test
Mexican lemon price	0.01
Corn future	0.01
Wheat future	0.01
Rough rice future	0.01
Soy bean future	0.01
Oats future	0.01
Cocoa future	0.01
Coffee future	0.01
Suggar future	0.01
Cotton future	0.01

Source: Own elaboration with data from CME (Chicago Mercantile Exchange, 2025) and SNIIM (2025).

CONCLUSIONS

Food security is an important research line for the Mexican government, mainly because it helps stabilize food prices for consumers and reduce income risk for producers. Mexican lemon production is among the leading agricultural activities with a global impact, due to the relevance of this fruit in U.S. and European consumption. More importantly, #4 lemon is a fundamental fruit in the Mexican diet. Consequently, finding effective price hedging mechanisms is essential. Nowadays, there is no hedging mechanism for this fruit, leading to the need for solutions such as public minimum-buy prices. The Mexican Government has implemented several mechanisms, but these have focused on four staples: white corn, rice, beans, and milk. Also, this hedging mechanism is financed with taxpayers' income.

A current policy and economic need in Mexico is to have an effective price hedging mechanism for these four staples and other fruits, without cost to taxpayers. A potential solution is cross-hedging using the futures prices of different commodities, such as corn, wheat, rough rice, soybeans, cocoa, coffee, sugar, or cotton. One limitation of such an approach is the presence of basis risk. That is, in simple terms, the future and spot prices move on different paths. To check whether cross-hedging is appropriate for the Mexican lemon price, this paper used long-term or cointegration tests to determine whether the nine most-traded futures in the U.S. are suitable for cross-hedging with the lemon price.

Following the unit-root and cointegration tests, the results indicated that the Mexican lemon price is stationary (i.e., has no unit root). Consequently, there is no long-term relationship between this fruit's price and the futures of interest. In conclusion, cross-hedging of Mexican lemon prices should not be done with a single future position, but with a portfolio of futures, as de la Torre-Torres et al. (2024; 2025) found for Hass avocado and White corn. This potential short-term tracking approach (minimum tracking error portfolios instead of VEC or cointegration) could be more feasible for lemon prices.

Consequently, a guideline for further research could be to test several portfolios or combinations of futures, using their correlations to enhance hedging effectiveness. Another guideline for further research could be to test the non-stationarity by filtering with the presence of structural breaks or regimes.

Finally, estimating short-term statistical relationships (such as vector autoregressive models or neural networks) with a single future hedging position could be a task of interest for the food security purposes intended herein.

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