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Integrating the ARIMA Model with Sustainable Practices to Forecast Corn Prices in Mexico

Integración del Modelo ARIMA con Prácticas Sostenibles para Pronosticar el Precio del Maíz en México

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Palabras Clave: modelo **ARIMA**, pronósticos de precios, precios del maíz, precios agrícolas, México.

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ABSTRACT

Context. The study addresses Mexico's increasing reliance on corn imports due to inadequate domestic production and analyzes price volatility from 1980 to 2023. This research is of utmost importance, using econometric models, it forecasts prices for 2024-2025, aiming to inform agricultural policies and support farmers amid market uncertainties.

Problem. Corn is crucial to Mexican cuisine and culture, but price volatility challenges farmers, consumers, and policymakers. Addressing this requires exploring its causes, effects, and broader socioeconomic context. How can a multidisciplinary approach enhance agricultural policy, address corn price volatility, and promote sustainability?

Purpose. The research uses econometric models to forecast Mexico's corn prices, integrating economics, agriculture, and sustainability to inform policies, reduce price uncertainty, and support sustainable practices aligned with the United Nations 2030 Sustainable Development Goals (**SDGs**).

Methodology. The study uses **ARIMA models** to forecast 2024-2025 corn prices based on data from 1980 to 2023. **ARIMA** outperforms other techniques for time-series data, which exhibit auto-correlation, such as linear or canonical regression. The reliability of this model is assessed through its parameters **(p), (d)**, and **(q).**

Theoretical and Practical findings. The research uniquely combines economic theory, statistical modeling, and agricultural sciences to analyze Mexico's corn price dynamics, providing actionable insights that support sustainable development goals, including food security (**SDG 2**) and poverty reduction (**SDG 1**).

Multidisciplinary and sustainable innovation originality. The research is valuable and original as it forecasts corn prices, aiding Mexican farmers' planning, reducing income instability, and supporting **SDGs 1** and **2**. This work offers a promising outlook for the future of corn production in Mexico.

Conclusions and limitations. The research shows **that ARIMA** aids in forecasting Mexico's corn prices and mitigating volatility. The most important regions include the northwest and central west. Future studies should explore regional disparities to tailor policies by incorporating spatial analysis of local conditions and practices.

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

RESUMEN

Contexto. El estudio aborda la creciente dependencia de México de las importaciones de maíz debido a la producción interna inadecuada y analiza la volatilidad de los precios de 1980 a 2023. Utilizando modelos econométricos, pronostica los precios para 2024-2025, con el objetivo de informar las políticas agrícolas y apoyar a los agricultores en medio de las incertidumbres del mercado.

Problema. El maíz es un elemento crucial para la cocina y la cultura mexicanas, pero la volatilidad de los precios supone un desafío para los agricultores, los consumidores y los responsables de las políticas. Para abordar este problema es necesario explorar sus causas, sus efectos y su contexto socioeconómico más amplio. ¿Cómo puede un enfoque multidisciplinario mejorar la política agrícola, abordar la volatilidad de los precios del maíz y promover la sostenibilidad?

Objetivo. La investigación utiliza modelos econométricos para pronosticar los precios del maíz en México, integrando la economía, la agricultura y la sostenibilidad para informar políticas, reducir la incertidumbre de los precios y apoyar prácticas sostenibles alineadas con los Objetivos de Desarrollo Sostenible (**ODS**) de las Naciones Unidas para 2030.

Metodología. El estudio utiliza modelos **ARIMA** para pronosticar los precios del maíz en 2024-2025 basándose en datos de 1980 a 2023. **ARIMA** supera otras técnicas para datos de series de tiempo que exhiben autocorrelación, como la regresión lineal o canónica. La confiabilidad de este modelo se evalúa a través de sus parámetros **(p), (d)**, y **(q).**

Hallazgos teóricos y prácticos. La investigación combina de forma única la teoría económica, el modelado estadístico y las ciencias agrícolas para analizar la dinámica de los precios del maíz en México, proporcionando información útil que apoya los objetivos de desarrollo sostenible, incluida la seguridad alimentaria (**ODS 2**) y la reducción de la pobreza (**ODS 1**) .

Originalidad desde el punto de vista Multidisciplinar y de innovación sostenible. La investigación es valiosa y original ya que pronostica los precios del maíz, ayudando a la planificación de los agricultores mexicanos, reduciendo la inestabilidad de los ingresos y apoyando los **ODS 1 y 2**. Este trabajo ofrece un panorama de gran interés para el futuro de la producción de maíz en México.

Conclusiones y limitaciones. La investigación muestra que **ARIMA** ayuda a pronosticar los precios del maíz en México y a mitigar la volatilidad. Las regiones más importantes son las

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

ubicadas en el oeste norte y central. Los estudios futuros deberían explorar las disparidades regionales para adaptar las políticas incorporando un análisis espacial de las condiciones y prácticas locales.

1. INTRODUCTION

The study exemplifies a multidisciplinary approach by integrating economics, agriculture, and sustainability to tackle the issue of corn price volatility in Mexico. By employing econometric models, particularly **ARIMA**, the research addresses the economic aspect by analyzing price trends and forecasts, crucial for informing agricultural policies.

The agricultural dimension is considered in the context of domestic production challenges and the impact on farmers and consumers. Additionally, the study aligns with sustainability principles by supporting policies that contribute to achieving the United Nations 2030 Sustainable Development Goals, specifically those related to food security (**SDG 2**) and poverty reduction (**SDG 1**).

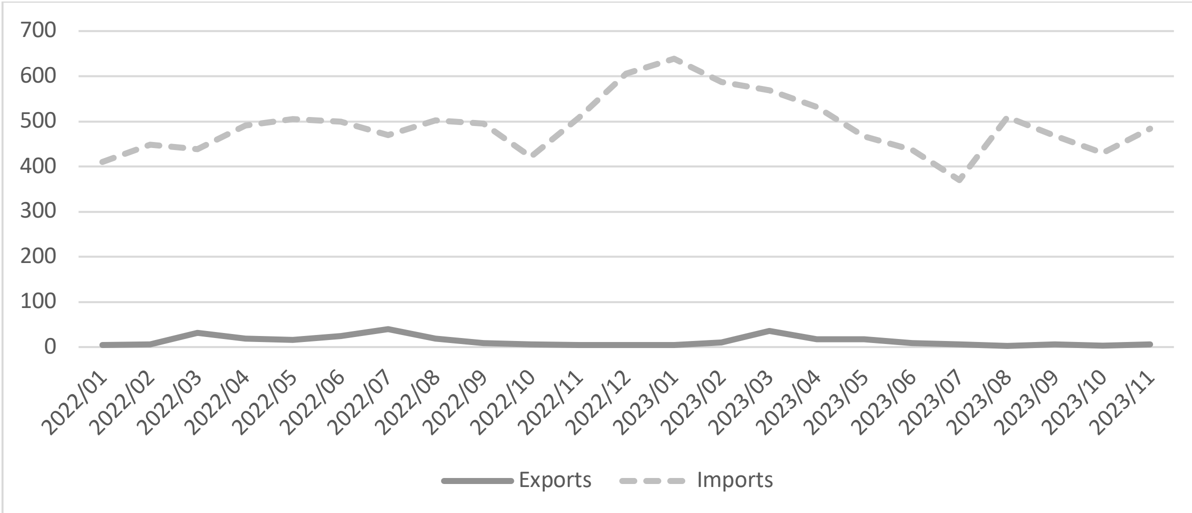
This synthesis of multiple disciplines not only provides a comprehensive understanding of corn price dynamics but also offers actionable insights to support both economic stability and sustainable farming practices in Mexico.

Corn (*Zea mays ssp.mays* [1]) is an essential agricultural product for the diet of Mexicans. During the last decades, Mexico has increased its dependence on imports of this grain. According to INEGI (2024) figures, corn imports from January 2022 to November 2023 totaled 11,283 million dollars, while exports represented only 300 million dollars. This represents a deficit of nearly $11 billion (see **Figure 1**).

[1] *Zea mays ssp mays* corresponds to the maize species of corn found in Mexico.

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

Figure 1. Corn imports and exports in Mexico 2022-2023. Millions of dollars.



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

The same is also reflected in amounts per ton, where **Table 1** shows forecast growth for domestic production, imports, exports, and consumption of corn for 2024. Specifically, forecasts show growth of 2.3% for production, 3.5% for imports, 20% for exports and 5% for consumption. In 2024 Mexico could have a deficit of 900 thousand tons to meet domestic corn consumption (Morales, 2023).

Table 1. Corn imports and exports in Mexico 2022-2023. Millions of dollars.

	Years		
Concept	**2021-2022**	**2022-2023***	**2023-2024***
Production	26762	28000	27400
Imports	17572	18000	18200
Exports	250	200	300
Consumption	44000	45000	46200

Source: Morales (2023).
Notes: Data shown with * indicate forecasts made by the USDA.

The Plan Nacional de Desarrollo (DOF, 2019) for the period 2019-2024 states that "in 2021, the goal of achieving self-sufficiency in corn and beans must be met"; however, it does not specify whether self-sufficiency is in white or yellow corn. In 2021, the Mexican government issued a

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

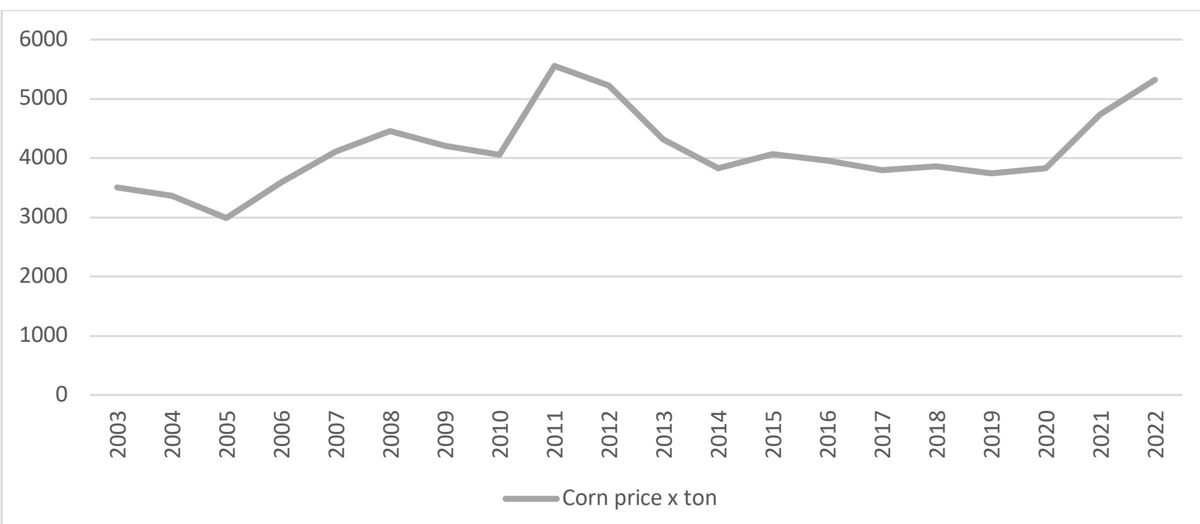
decree to gradually reduce the cultivation and consumption of Genetically Modified (**GM**) corn by 2024. However, no progress is shown to meet the growing domestic demand.

The data on corn prices are presented in current terms, which does not make them comparable across time. Therefore, corn prices were converted to constant prices using the Gross Domestic Product (**GDP**) deflator with the base year of 2018. **GDP data** in current and constant prices were obtained from Banco Mundial (2024).

Figure 2 shows the trend of real corn prices between 2002 and 2022. As observed, there has been a price stagnation in corn during the last two decades in Mexico. Maximum real prices were observed in 2012, with a value of $5,555 pesos per ton of corn, and in 2022, with a price of $5,320 pesos per ton.

Given the trends indicated, it is crucial to disaggregate the data to observe patterns at the regional level. This regional-level analysis is essential as it allows us to pinpoint regions with price differentiation in the marketing of corn, thereby providing a more nuanced understanding of the market dynamics.

Figure 2. Real corn prices in Mexico 2002-2021. Pesos per ton.



Source: own elaboration with data from INEGI (2024).

For the regional division, this study follows the classification of the SADER (2021). The classification divides the country into five regions according to their productive vocations seeking

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

to enhance their land, water, and labor force (SADER, 2021). The agri-food regions are divided into:

- Northwest: Baja California, Baja California Sur, Sonora, Sinaloa and Nayarit. Northeast: Chihuahua, Coahuila, Durango, Nuevo León, Tamaulipas and Zacatecas.
- Central West: Aguascalientes, Colima, Guanajuato, Jalisco, Michoacán, Querétaro and San Luis Potosí.
- Center: Mexico City, State of Mexico, Guerrero, Hidalgo, Morelos, Puebla and Tlaxcala. South-Southeast: Campeche, Chiapas, Oaxaca, Quintana Roo, Tabasco, Veracruz and Yucatán.

The data used in the analysis were obtained from the SIACON (2024) database, filtered by crop "corn grain" and by state.

The regional differentiation will allow us to observe possible price divergences. Also, as we observe price stagnation, the study will employ time-series models to forecast the overall price of corn in Mexico for the years 2024 and 2025. This information is helpful for decision-making in the agricultural sector.

The study poses the following research question: *"How can the integration of **ARIMA** models with sustainable agricultural practices enhance the accuracy of corn price forecasts in Mexico, and in what ways can these forecasts reduce price volatility and uncertainty for farmers, thereby informing agricultural policy and promoting sustainable development within the sector?"*

2. CONTEXT DESCRIPTION

This section provides a detailed exploration of corn's significance in global agriculture, particularly on the American continent and within Mexico, addressing not only production statistics but also market dynamics, sustainability efforts, and the broader implications for food security. It is divided into three main sections: Worldwide corn context, American continent corn context and Mexican corn context.

2.1 Worldwide Corn Context

Corn is one of the most significant agricultural products globally, essential for food security, livestock feed, and various industrial applications.

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

Worldwide, corn serves multiple purposes: about 60% is used for animal feed, while the remainder is allocated for food consumption, industrial applications, and biofuel production. The demand for corn is projected to grow due to increasing livestock production and biofuel requirements, with the global consumption expected to reach approximately 1.6 billion metric tons by 2030 (FAO, 2021).

Corn prices have experienced significant fluctuations, driven by factors such as weather conditions, geopolitical tensions, and economic policies. For instance, during the **COVID-19** pandemic, corn prices surged to historic highs. Price volatility affects global food security, especially in developing countries where corn is a staple food and a critical component of food systems.

2.2 American Continent Corn Context

The American continent plays a significant role in global agricultural production, particularly for key staple crops like corn. The region encompasses a vast range of climates, ecosystems, and agricultural practices, from large-scale commercial farming in the United States to smallholder farming in Latin America.

The U.S. is the largest producer of corn in the world. In the 2022-2023 marketing year, U.S. corn production was estimated at approximately 370 million metric tons (USDA, 2023), representing about 36% of global corn production. Production in the U.S. primarily focuses on yellow corn for animal feed and ethanol production.

Climate change presents significant challenges to corn production in the region, affecting yield stability. Studies indicate that a 1°C increase in temperature could reduce corn yields by 10-20% in susceptible regions including the Americas (Lobell et al., 2011).

As agriculture faces increasing scrutiny regarding environmental impact, various sustainability initiatives are being implemented across the Americas. These include:

- Precision Agriculture: Adoption of technology to optimize inputs and reduce resource waste.
- Conservation Practices: Crop rotation and reduced chemical use to promote soil health.

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

- Efforts to align agricultural practices with Sustainable Development Goals (**SDGs**) (United Nations, 2015) focus on improving food security (**SDG 2**) and supporting sustainable production processes (**SDG 12**).

2.3 Mexican Corn Context

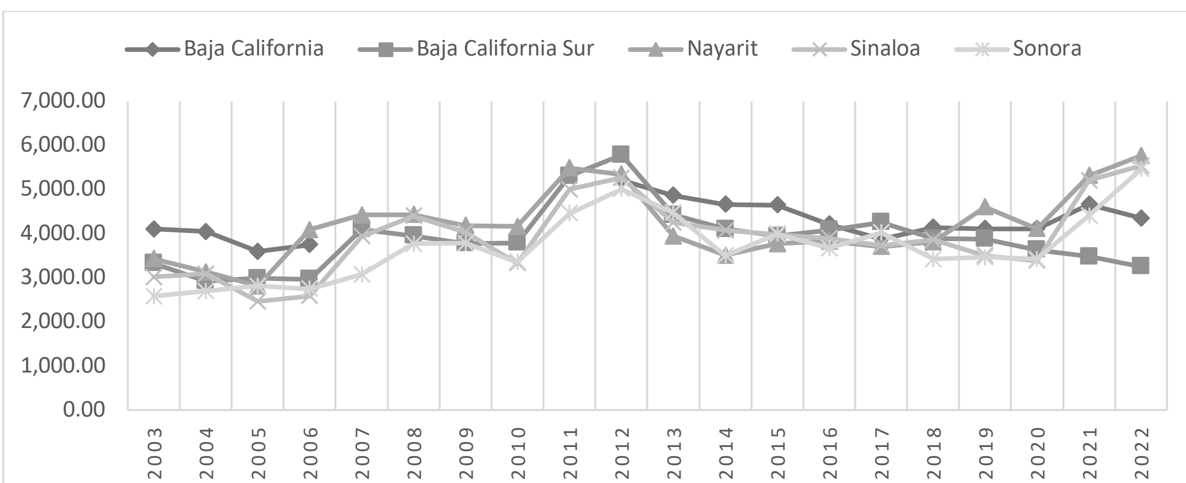
Mexico is one of the world's most significant producers and consumers of corn, Mexico's agricultural landscape is characterized by a rich history and contemporary challenges related to sustainable production, market volatility, and climate change.

The majority of this production is focused on white corn, which is primarily used for human consumption.

The SIACON (2024) presents information regarding rural average prices for corn in Mexico. In this case, monetary values are presented in current prices; so it was convenient to convert them at constant prices using the **GDP** deflator. **GDP** data at current and constant prices were consulted by the World Bank (2024).

Figure 3 shows the evolution of the real price of grain corn in the northwest region in the period 2003 to 2022.

Figure 3. Grain corn price per ton in the northwest region at constant 2018 prices (2003 2022)



Source: Author's elaboration with data from SIACON (2024).

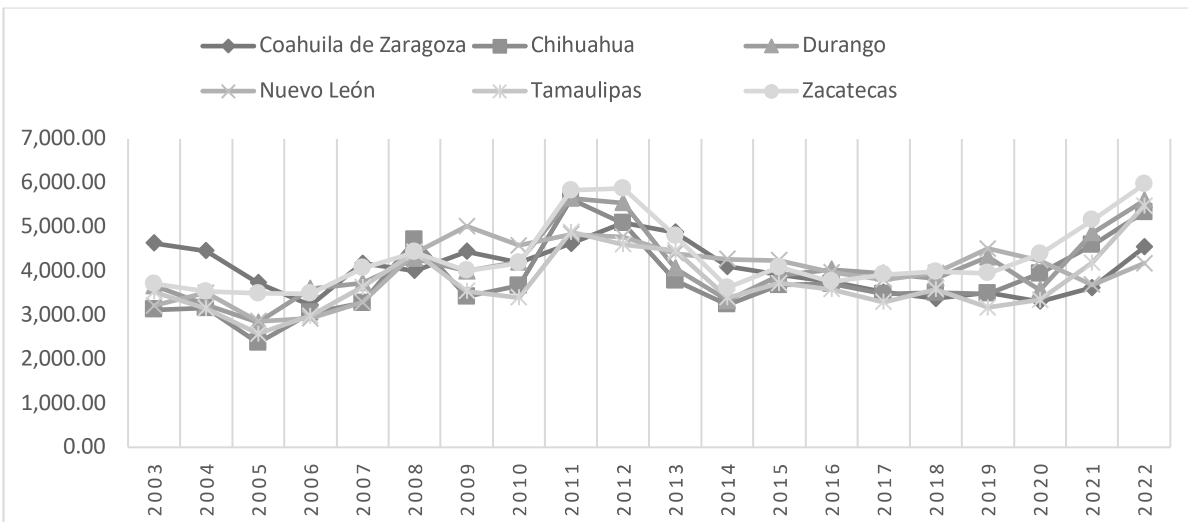
Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

A slight upward trend is observed; but in general prices remain without great variations in real terms. Significant increases were only observed in the region in 2011 and 2012, which could be the result of problems in the harvests of other regions (for example, in the northeast region), as a result of atypical meteorological years that caused damage to the corn crop and affected the prices of its commercialization.

In 2022, in the northwest region, the state with the best real marketing price was Nayarit with $5,678 real pesos per ton; Baja California Sur showed the lowest price, with $3,256 real pesos per ton.

In the northeast region, there was also a real increase in the price of corn in 2011 and 2012. Especially in Zacatecas and Durango (see **Figure 4**).

Figure 4. Grain corn price per ton in the Northeast region at constant 2018 prices (2003 2022)



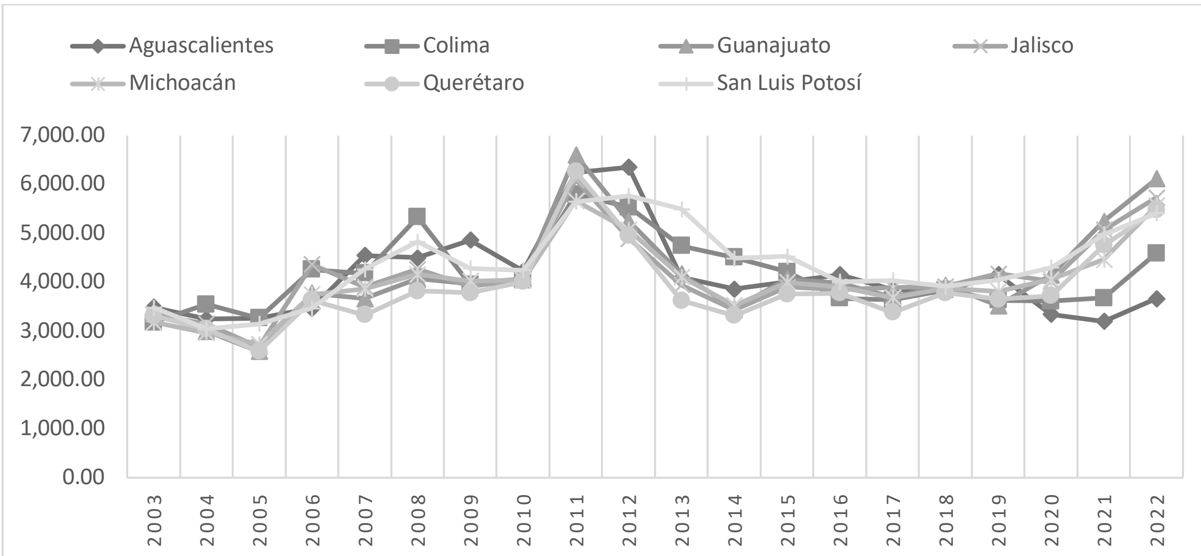
Source: Author's elaboration with data from SIACON (2024).

The state that has observed a real growth in the price of corn is Zacatecas; this had a real price per ton of $3,712 in 2012; for 2022 the real price increases to $5,970 constant pesos. The lowest prices observed in the region were recorded in Nuevo León, with a price per ton of $4,174 pesos at constant 2018 prices.

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

In the western region, the increase in real prices in 2011 and 2012 is also observed (**Figure 5**). In addition, as of 2020, real price growth trends are recorded for most states; the one that registers the highest real price in 2022 was Guanajuato, with $6,115 real, in constant pesos; the entity with the lowest price that year was observed in Aguascalientes with $3,662 constant pesos.

Figure 5. Grain corn price per ton in the Central-West region at constant 2018 prices (2003-2022)



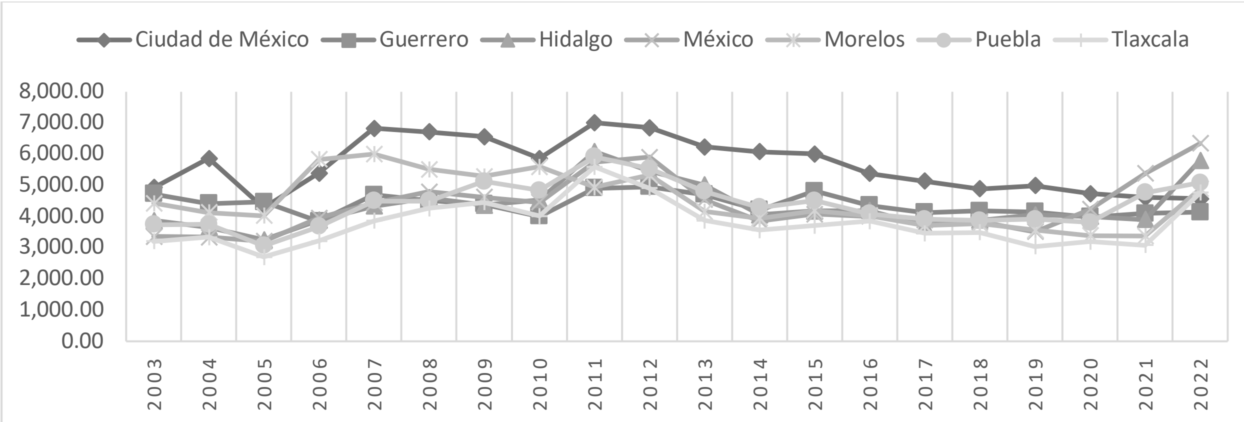
Source: Author's elaboration with data from SIACON (2024).

In the central region, during the period, Mexico City stands out with prices above the other entities. However, as of 2012, the real price in Mexico City has been decreasing until it is below all the states in the region, except Guerrero.

It also highlights the case of the State of Mexico, an entity where an accelerated increase in real prices is observed as of 2019. Specifically, in 2019 the real price per ton was $3,512; for 2022 the figure increased to $6,344, which represents a real price growth between the two years of 80% (**Figure 6**).

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

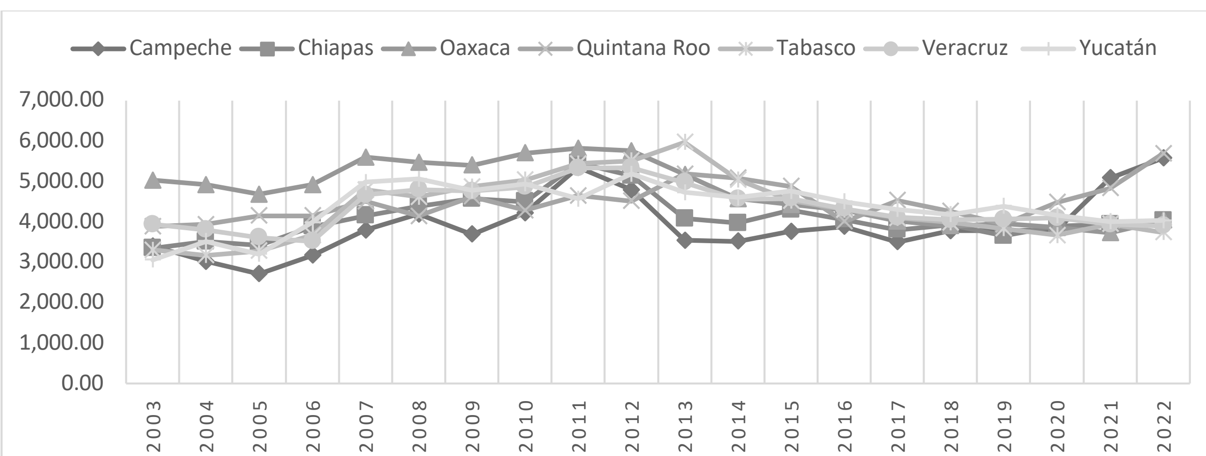
Figure 6. Grain corn price per ton in the central region at constant 2018 prices (2003-2022)



Source: Author's elaboration with data from SIACON (2024).

In the southern and southeastern regions, **Figure 7** shows the evolution of real prices per ton of grain corn. Unlike other regions, there are no drastic changes in prices and for most states in the region levels between $3,000 and $4,000 pesos remain constant. Only Campeche and Quintana Roo stand out, which as of 2021 show price increases above the average for the region, reaching levels above $5,000 constant pesos per ton in 2022.

Figure 7. Grain corn price per ton in the South & Southeast region at constant 2018 prices (2003-2022)



Source: Author's elaboration with data from SIACON (2024).

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

The price analysis shows in the previous sections, important divergences in corn prices between different regions and Mexican entities. This can generate uncertainty for producers, since, despite the hectares planted, harvested or production levels reached, the final marketing price determines the profitability of the crops. In recent years, the Mexican federal government has introduced guaranteed price programs for basic food products, seeking to reduce this uncertainty. In the case of corn, in 2021 the guarantee price was recorded at $6,060 per ton with a limit of 20 hectares per producer. In the spring-summer 2020 cycle, SAM (2022) reported having supported 65,578 producers with guaranteed prices, totaling 703,976 tons. In that year, the production of grain corn in Mexico was 27.4 million tons, so the amount of corn stockpiling with a guaranteed price represented 2.6% of the national production.

3. LITERATURE REVIEW

The previous sections present information regarding prices of grain corn in different regions of Mexico. The data show us variability in prices in different regions. This can generate uncertainty for farmers when facing price volatility. This section seeks to propose a maize price forecasting model using an integrated autoregressive moving average model (**ARIMA**) or also known as Box-Jenkins (Box et al., 2015).

This section begins by presenting the relationship between corn price forecasts and SDGs, it later highlights the multidisciplinary and innovative contribution as well as the relevance for policy makers. It later discusses the innovation for sustainable development contributions of the research. Finally, it presents the **ARIMA** model used for forecast purposes.

The section emphasizes the ongoing need for innovative approaches to enhance resilience in agriculture and how the study's conclusions bridge theoretical contributions with practical applications for sustainable agricultural practices in Mexico.

3.1. Addressing critical Sustainable Development Goals

The research on integrating the **ARIMA** model with sustainable practices to forecast corn prices in Mexico is both valuable and original, particularly in relation to the Sustainable

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

Development Goals (**SDGs**) (United Nations, 2015). Here are several key points highlighting its significance:

Goal 1: No Poverty. By providing reliable forecasts of corn prices, the research empowers smallholder farmers with essential information for better planning, potentially mitigating risks associated with income instability and market volatility. This helps farmers adapt to changing market conditions, reducing vulnerability to poverty.

Goal 2: Zero Hunger. Understanding price dynamics and forecasting future prices promotes food security for consumers and farmers alike. When farmers are aware of expected price trends, they can make informed decisions regarding production, storage, and distribution, which ultimately stabilizes food supplies.

Goal 12: Responsible Consumption and Production. The research fosters sustainable agricultural practices by integrating econometric analysis with agricultural policies. Forecasting tools can help inform strategies that optimize resource use, reduce waste, and encourage responsible production methods that align with sustainable practices.

3.2. Multidisciplinarity and innovation

The original contribution of the research stems from its multidisciplinarity. By combining conceptions and methodologies from agricultural economics, statistical modeling, and sustainability science, the study breaks down traditional disciplinary silos. This collaborative approach generates new insights that are more holistic and relevant to real-world agricultural challenges.

Innovative Application of the ARIMA Model. The application of the **ARIMA** model—a statistical method predominantly used in finance—to the agricultural sector represents an innovative methodology that enhances the understanding of price volatility. This cross-disciplinary strategy sets a precedent for future studies and applications in similar contexts, emphasizing the potential benefits of diverse disciplinary contributions to problem-solving.

3.3 Relevance for Policymaking

The research's findings have practical implications that make it especially relevant in a policy context.

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

Evidence-Based Decision-Making. By equipping policymakers with reliable and innovative forecasting tools, the research provides the empirical evidence necessary for developing informed policies that support agricultural sustainability. This evidence-based approach fosters accountability and adaptability in policy frameworks aimed at meeting **SDG** targets (United Nations, 2015).

Fostering Public and Private Sector Collaboration. The study encourages collaboration between public institutions, agricultural producers, and researchers. Such partnerships are crucial for implementing sustainable practices in agriculture and addressing the pressing challenges associated with agriculture and climate change.

3.4. Contribution to Innovation for Sustainable Development

The originality of the research lies in its innovation, which can lead to transformative changes in agricultural practices:

Promoting Innovative Solutions. By employing econometric modeling in agriculture, the research facilitates the development of innovative solutions to traditional agricultural problems.This not only enhances productivity but also promotes sustainable practices that can withstand adverse economic conditions.

Handling Complex Systems. The complexity of agricultural markets demands sophisticated tools for analysis and forecasting. This research provides a template for how innovative modeling approaches can be applied to similar issues within the agricultural sector while keeping in view environmental sustainability.

3.5 The ARIMA model as a forecast instrument

ARIMA models are univariate time series techniques that are used to generate forecasts. They have been used in the literature for agricultural forecasting under different perspectives. For example, to forecast production yields. Yasmin & Moniruzzaman (2024) employ **ARIMA** models to forecast the jute production in Bangladesh. The overall trend found in the model showed an increasing trend in area cultivated but a decreasing trend in production which can be valuable for policy makers to guide initiatives. Similarly, time-series analysis has been employed for the production forecasts of cereal crops including maize. Bezabih et al. (2023), forecast cereal crop

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

production in Ethiopia. The findings suggest increasing trends in all crops analyzed, where corn is expected to transit from 11 to 14 tons between 2020 and 2030.

For price forecasts using **ARIMA** models, studies have focused on agricultural crops that exhibit price volatility. Agbo (2023) employs **ARIMA** models to forecast export crops in Egypt such as green beans, tomatoes, onions, oranges, grapes and strawberries. Developing countries depend of agricultural exports as a crucial part of their economies, therefore predicting price volatility in export crops is important in designing economic plans in regarding agricultural production, consumption, marketing and trade.

For the case of maize, Yadav et al. (2023) forecast maize production in South Asian countries. The countries included in the analysis were Afghanistan, Bangladesh, Bhutan, China, India, Nepal, Pakistan, and Sri Lanka during the time-span from 1961 to 2027. The results indicate an expectation of maize production increase for these nations where India is expected to lead corn production in the region in 2027. Similarly, Jadhav, et al. (2017) employ **ARIMA** models to forecast maize prices in India. The results show that the models exhibit powerful forecasting abilities marked by the precision indicators. Similarly, Maiga (2024) explores the use of **ARIMA** models to forecast corn production in Tanzania. The results indicate a ten year forecast with an intermittent pattern which may be valuable in anticipating trends.

For the case of maize in Mexico, López-García et al. (2021) estimate **ARIMA** and autoregressive vector (**VAR**) models for corn price predictions in the states of Sinaloa and Mexico from 2000 to 2018. The results indicate that multivariate models are not necessarily decisive to obtain forecasts close to the observed values, which indicates that **ARIMA** models can be good agricultural price forecasting tools. Martínez-Damián & Brambila-Paz (2023) mention that nominal or real prices is indifferent in the construction of maize forecast prices in Mexico.

Previous evidence show that **ARIMA** models outperform other forecast techniques such as regression analysis when dealing with time series data. The primary reason is that time-series data is auto-correlated between periods, so the no auto-correlation assumption in linear regression is regularly broken. Also, in regression analysis, often the independence assumption is also violated as variables exhibit autocorrelation among them. The limitations of linear regression are accounted for in **ARIMA** models.

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

The literature review shows that use of advanced inferential statistical methods may increase our understanding of agricultural production and price levels. Understanding these dynamics result in powerful data valuable to policymakers, agricultural stakeholders and researchers which in turn may use them to guide policy, programs and projects aimed to enhancing agricultural productivity and food security particularly in developing nations.

3.6 The Design of the final instrument

The Autoregressive, Integrated Moving Average (**ARIMA**) univariate model is a statistical analysis model which suggests that the variable {Yt} follows an **ARIMA** process (p, d, q), where p denotes the autoregressive terms, q is the order of moving averages and d the number of differences in the series required for the process to be stationary.

Its representation is as presented in **Equation 3.1**:

Equation 3.1. ARIMA General model

$$Y_t = \varphi_1 y_{t-1} + \varphi_2 y_{t-2} + \cdots + \varphi_p y_{t-p} + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \cdots - \theta_q \varepsilon_{t-q}$$

Where ε denotes the random error term of white noise, distributed independently with zero mean and variance θ^2. The fit of the model follows the Box-Jenkins methodology, where the stationarity conditions of the series are first verified, afterwards, we identify the values of the **ARIMA** process (**p, d, q**), we review diagnoses, fit tests and prognoses, following the principle of parsimony (Box et al., 2015)

3.7 Conceptual Model/Experimental Model

The **ARIMA** model extends the **ARIMA** perspective (**see Equation 3.2**) assuming that time-series data is non-stationary and may exhibit systematic changes in trends. Therefore, trends must be eliminated by a difference operator.

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

Equation 3.2. ARIMA model description.

$$X_t = Noise + AutoRegressive\ Part + Moving\ Average\ Part$$

$$X_t = Z_t + \phi_1 X_{t-1} + \cdots + \phi_p X_{t-p} + \theta_1 Z_{t-1} + \cdots + \theta_q Z_{t-q}$$

Source: Thistleton & Sadigov (2023).

The study poses the following **hypothesis** (**H**):

H: "*Given the current volatility and uncertainty in corn prices in Mexico, the integration of the* ***ARIMA*** *(Autoregressive Integrated Moving Average) model with sustainable agricultural practices will effectively forecast corn prices, thereby providing valuable insights for reducing price volatility and uncertainty faced by farmers. This will ultimately contribute to more informed decision-making in agricultural policy and practice, promoting sustainable development within the agricultural sector"*.

This hypothesis reflects the study's aim to analyze the effectiveness of the **ARIMA** model in providing accurate price forecasts, which can help mitigate the challenges associated with price fluctuations in the context of sustainable agricultural practices in Mexico.

4. METHODOLOGY

The data on the average rural price of grain corn were obtained from SIACON (2024), expressed in pesos per ton at current prices. The data are annual with a period from 1980 to 2023.

The statistical software used was R and R-Studio in its version "2023.06.0 Build 421".

The stages for applying the **ARIMA** model were the following:

- First, after a literature review, the previous findings suggest the use of **ARIMA** estimation techniques to deal with data that exhibits a time-series component. Previous evidence show that **ARIMA** models outperform other forecast techniques such as regression analysis or canonical regressions when dealing with time series data.
- Second, the price data on corn was analyzed and after a visual inspection, one can conclude that the data is non-stationary. This was confirmed by the Dickey-Fuller test (Dickey & Fuller, 1979).

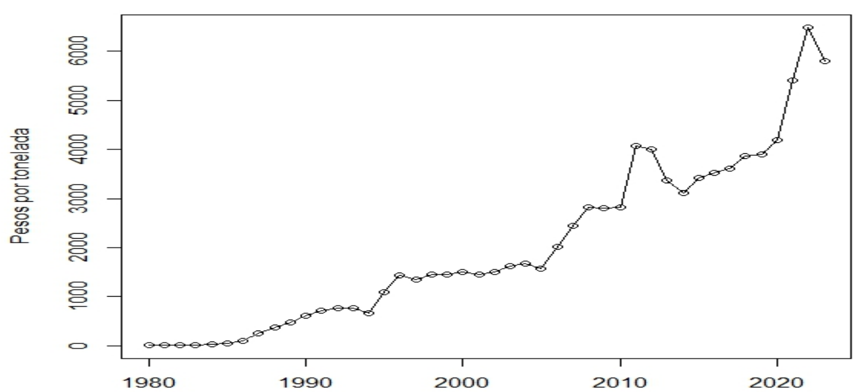
Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

- Third, since data is non-stationary and a trend is observed, the data was differentiated to eliminate the trend. The Dickey-Fuller test was conducted again to confirm that data is stationary.
- Fourth, the autocorrelation function (**ACF**) and partial autocorrelation (**PACF**) tests were performed to indicate the possible **ARIMA** models to estimate.
- Fifth, the **ACF** and **PACF** indicate the **p, d, q** parameters to include in the estimation of the **ARIMA** model. Several models were estimated, including one suggested by the auto.arima function in R software.
- Sixth, following the principle of parsimony and a residual analysis, the model **ARIMA** (1,1,0) was elected as the one that best fits the data. This model was employed for the forecasting of corn prices.
- Seventh, using the **ARIMA**(1,1,0) model, a two-period forecast is estimated. Also, spot forecasts and confidence intervals are calculated at the 90% and 95% levels.

5. RESULTS

The time series of the price of grain corn shows an upward trend as shown in **Figure 8**.

Figure 8. Time series of the rural average price of grain corn (1980-2023)



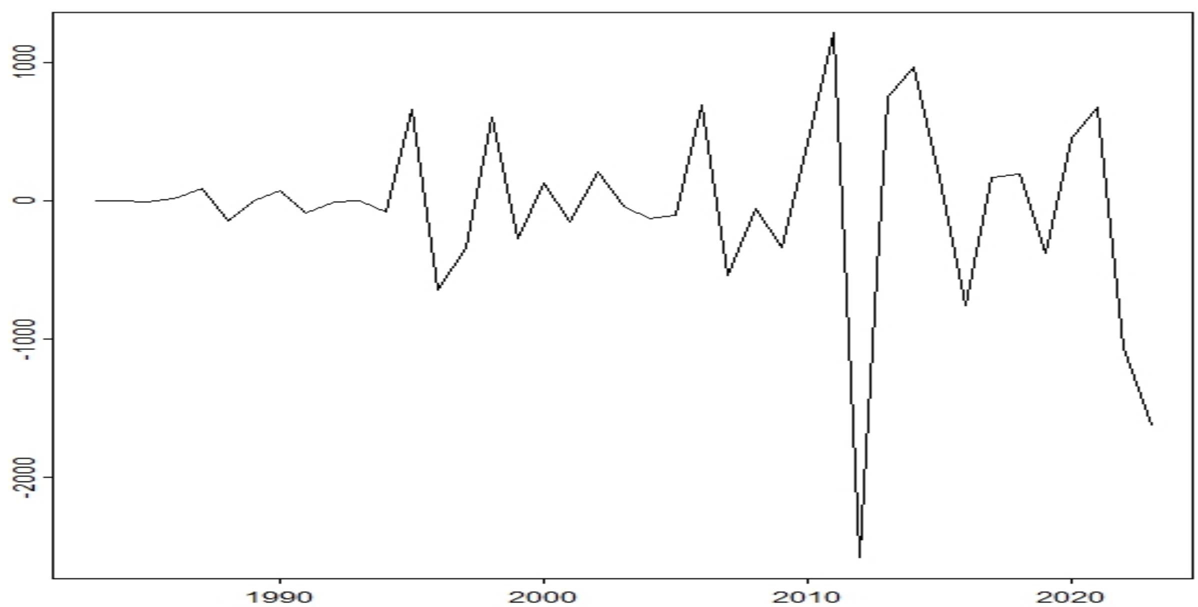
Source: Author's elaboration with data from SIACON (2024) using the statistical software R-Studio version 2023.06.0.

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

This was verified by means of the Dickey-Fuller test (Dickey & Fuller, 1979), which yields a value of -1.72 and a p-value of 0.68, which indicates that the series is not stationary. When a trend is observed, it can become stationary by means of differentiation.

A difference was applied to the time series and the Dickey-Fuller test is repeated (see **Figure 9**). The results indicate a stationary series with a 90% confidence level. The value of the Dickey-Fueller test is -3.25 with a p-value of 0.09.

Figure 9. Time series with a difference in the rural average price of grain corn (1980-2023)



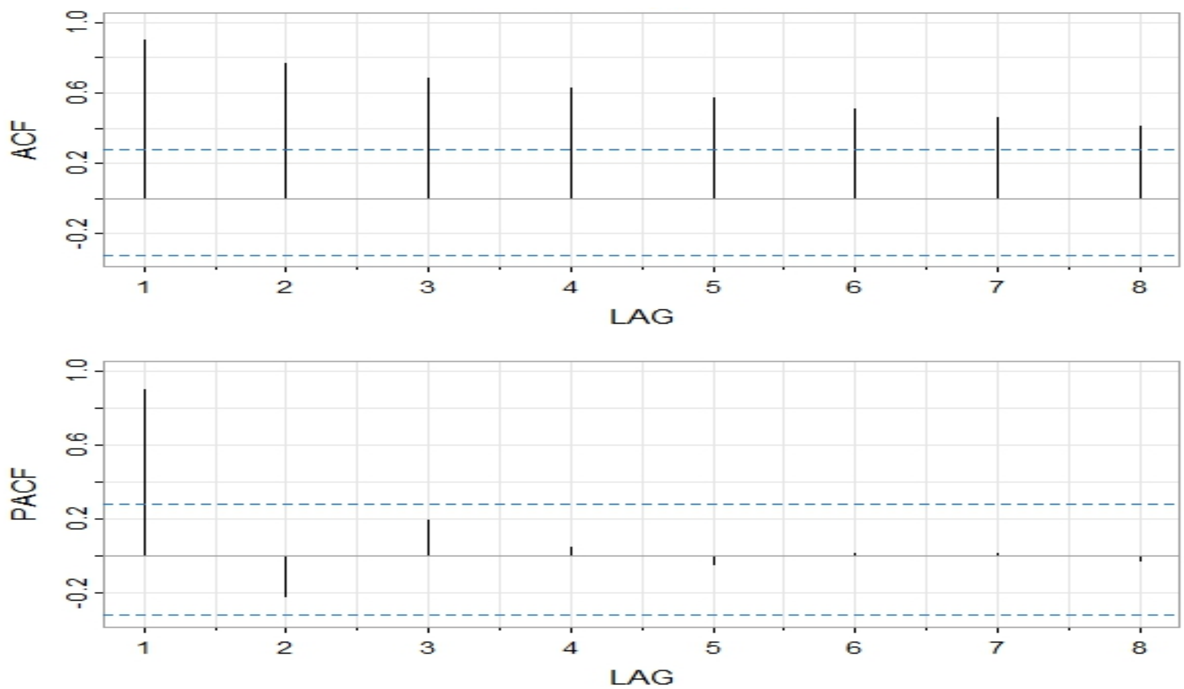
Source: Author's elaboration with data from SIACON (2024) using the statistical software R-Studio version 2023.06.0.

To know the values of the **ARIMA** process (**p, d, q**), the autocorrelation function (**ACF**) and partial autocorrelation (**PACF**) tests were reviewed. The results of the **ACF** suggest the order of the moving average process (**q**) and the **PACF** informs us of the order of the autoregressive process (**p**). If we observe a gradual decrease in **ACF** and **PACF**, it indicates an **ARIMA** process(**p,q**); in the case of a gradual decrease in **ACF** and sudden cut-off of **PACF**, it indicates that an **AR**(**p**) process is observed; finally, a gradual decrease in the **PACF** and a sudden cut in the **ACF** will indicate that we are in an **MA**(**q**) process.

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

The results of the **ACF** and **PACF** are shown in **Figure 10** and point to a gradual fall in the **ACF** and 1 peak outside the significance bands in the PACF process with a sudden drop. This suggests that we are in an autoregressive process of order one with a differentiation in the series. That is, an **ARIMA**(1,1,0).

Figure 10. ACF and PACD Tests of the Rural Average Price of Grain Maize Time Series (1980-2023)



Source: Author's elaboration with data from SIACON (2024) using the statistical software R-Studio version 2023.06.0.

Several models were run in addition to the **ARIMA** (1, 1, 0) to compare them with each other. R-studio and the "forecast" package has a function called "auto.arima" in which simulations are run to find the parameters (p, d, q) of a time series. The result of the auto.arima function was an **ARIMA** model(0, 1, 2). In addition, **ARIMA**(0, 1, 0) and **ARIMA**(1, 1, 2) models were run.

The comparison of the models was made using the Akaike criterion (**AIC**), the principle of parsimony and the post-estimation results of the residuals. The results of the **AIC** for the different models are presented in **Table 2**. The **AIC** shows us a goodness of fit where the lower value of the AIC represents a better fit of the model.

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

According to the **AIC** criterion, the model that best fits the data is the **ARIMA**(0, 1, 2). However, when reviewing the post-estimation tests of the errors, it was found that the **ARIMA** model(1, 1, 0) exhibits white noise in the errors. The above under the **ACF** tests on errors and according to the p-values of the Ljung-Box statistic. Finally, following the principle of parsimony, the **ARIMA** model is decided (1, 1, 0).

Table 2. ARIMA Model AIC of the Rural Average Price of Grain Corn Time Series (1980-2023)

ARIMA Model	AIC
(0, 1, 0)	14.71
(1, 1, 0)	14.74
(0, 1, 2)	14.56
(1, 1, 2)	14.58

Source: Author's elaboration with data from SIACON (2024) using the statistical software R-Studio version 2023.06.0.

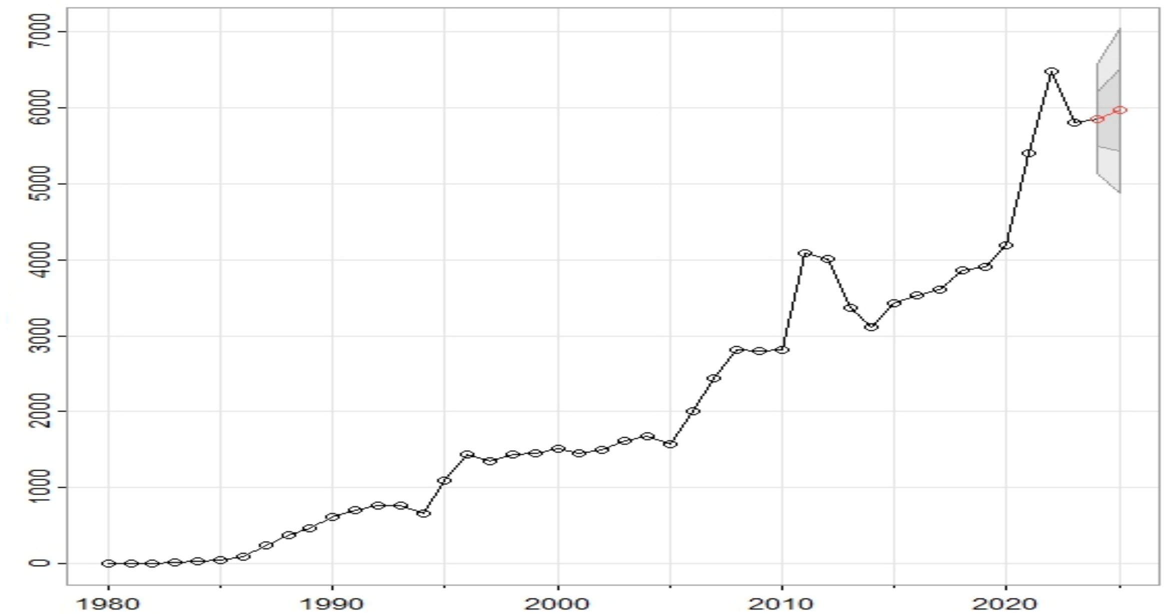
Taking into account the above results, a forecast model is run for two periods using the **ARIMA**(1, 1, 0). The results are shown in **Figure 11** and **Table 3.** The results of the model predict an increase in prices per ton of grain corn during the years 2024 and 2025.

Specifically, for 2024 the forecast price is $5,843.1 pesos per ton and for 2025 the price is forecast at $5,962.9 pesos per ton.

Taking the estimated standard errors for each year (2024 and 2025) of the model, confidence intervals were constructed at 90% and 95% of the predicted values of the price of grain corn, the results are presented in **Table 3.**

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

Figure 11. Rural Average Grain Corn Price Time Series Forecast (1980-2023)



Source: Author's elaboration with data from SIACON (2024) using the statistical software R-Studio version 2023.06.0.

Table 3. ARIMA Model AIC of the Rural Average Price of Grain Corn Time Series (1980-2023)

	Spot forecast	90% confidence interval		95% confidence interval	
2024	MX$5,843.10	MX$5,484.70	MX$6,201.50	MX$5,126.30	MX$6,559.90
2025	MX$5,962.90	MX$5,423.90	MX$6,501.90	MX$4,884.90	MX$7,040.90

Source: Author's elaboration with data from SIACON (2024) using the statistical software R-Studio version 2023.06.0.

6. DISCUSSION

The importance of corn for Mexico transcends its economic value. It is a staple in Mexican gastronomy and a symbol of the culture of this country. However, during the last decades, dependence on foreigners to supply the growing domestic demand for the grain has increased. This has also had repercussions for domestic producers, who do not have the technological or productive capacities to compete in international markets.

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

When analyzing the productivity in the planting, harvesting and marketing of grain corn, it was found that the price of this responds to national and international supply and demand forces.

The domestic price shows variations in different regions; however, in real terms there is a general stagnation in the price with an average real annual growth of 2.2% over the last 20 years.

The results of the econometric analysis present forecasts for 2024 and 2025 in the price of corn using an **ARIMA** model. Forecasts indicate that the price of corn could be between $5,126 to $6,560 pesos in 2024 and between $4,885 and $7,041 in 2025 with a 95% confidence interval.

The **ARIMA** model is a univariate technique, so the future use of multivariate techniques such as **VAR** models could be recommended. In addition, given the richness of the database presented by SIACON (2024), spatial panel data could be worked on to incorporate the data with the cross-section at the state level and also look for possible spatial dependencies in the data.

The analysis is performed from a multidisciplinary approach, by using econometric tools in the forecast of prices in an agricultural commodity. The results may be used for sustainable development in the area of agricultural policy, specifically in poverty reduction by giving more certainty in the price range to small farmers in Mexico. The results are inserted in previous literature that employs **ARIMA** model in agricultural forecasts (Jadhav, et al., 2017; Yasmin & Moniruzzaman, 2024).

The study innovatively applies the **ARIMA** model—traditionally used in economic and financial contexts—to agricultural price forecasting. This cross-disciplinary application enhances the analytical framework available to researchers and practitioners in the agricultural sector, enabling more accurate and data-driven decisions (Jadhav, et al., 2017).

The study innovatively applies the **ARIMA** model, a statistical technique traditionally used in economic and financial contexts, to agricultural price forecasting. This cross-disciplinary application enhances the analytical framework available to researchers and practitioners in the agricultural sector, allowing for more accurate and data-driven decisions related to corn prices in Mexico. Furthermore, integrating the **ARIMA** model with sustainable agricultural practices represents a unique blend of statistical modeling and sustainability, providing a comprehensive approach to tackling price volatility in agriculture. The use of such advanced predictive tools in the agricultural sector can foster innovative solutions to longstanding problems of price volatility and market uncertainty (Yasmin & Moniruzzaman, 2024).

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

By utilizing time-series analysis through the **ARIMA** model, the study demonstrates improved forecasting capabilities compared to traditional forecasting methods. This innovation in predictive analytics allows stakeholders to make more informed decisions based on projected price trends, thereby optimizing their production and marketing strategies.

The research adopts a multidisciplinary approach, integrating perspectives from agricultural economics, sustainability, and statistical modeling. This integration fosters innovative solutions by leveraging diverse expertise to address complex problems within agricultural practices and policies (Pardey et al., 2013).

Hence, the contributions to Sustainable Development Goals (**SDGs**) (UN, 2015) are the following:

Goal 1: No Poverty. By forecasting corn prices and reducing uncertainty, the study aids smallholder farmers in planning their harvests and sales. This can help improve their income stability, thereby contributing to poverty alleviation in agricultural communities.

Goal 2: Zero Hunger. Corn is a staple food in Mexico. The ability to predict price trends can help ensure that food supply chains remain stable, enhancing food security. Policymakers can use the findings to implement strategies that guarantee affordable access to essential food items, contributing to improved nutritional outcomes.

Goal 12: Responsible Consumption and Production. The research supports sustainable agricultural practices by providing insights into production planning and market dynamics. Encouraging efficient resource use and reducing waste in the agricultural sector aligns with responsible consumption and production targets outlined in the **SDGs.**

Goal 13: Climate Action. By focusing on price volatility, the study indirectly addresses climate resilience in agriculture. As the **ARIMA** model includes historical data that reflect climate impacts on yield and prices, it helps stakeholders understand how climate variability may influence future agricultural outcomes, driving proactive adaptation and mitigation strategies.

Goal 17: Partnerships for the Goals. Through its application of multidisciplinary research, the study promotes collaboration between various stakeholders, including academia, policymakers, and agricultural practitioners. This cooperation is essential for achieving comprehensive solutions for sustainable development in agriculture.

Overall, the study makes significant contributions to innovation by applying advanced predictive tools in agriculture, fostering a multidisciplinary approach, and enhancing data-driven decision-making. In terms of sustainable development goals, it addresses critical issues such as poverty alleviation, food security, responsible production, and climate resilience, thus contributing to a more sustainable and equitable agricultural future in Mexico and beyond.The results support and advance the previous findings in this field (Jadhav, et al., 2017; Yasmin & Moniruzzaman, 2024).

6.1 Theoretical implications

The result reached in this study have important theoretical implications. As with many agricultural products, corn prices are determined by laws of supply and demand. However, the price determination is more complex when these forces are influenced by government policies and programs as well as trade agreements. Added to this, market forces may be altered by consumer preferences, the changing needs of end users and factors affecting the production process (for example, weather, soil erosion, input costs, etc.).

The findings presented in the study effectively illustrate the integration of the ARIMA model with sustainable practices to forecast corn prices in Mexico, echoing the insights from various authors referenced throughout the research. For instance, the study builds on the work of Box et al. (2015), demonstrating the utility of the ARIMA model for time series analysis, which is crucial for understanding price fluctuations in agricultural commodities. It aligns with Jadhav et al. (2017) and Yasmin & Moniruzzaman (2024), who highlight the advantages of employing ARIMA models to accurately predict agricultural prices and yield, ultimately underscoring the model's relevance in policy-making and sustainability efforts. The research reveals significant findings, including an anticipated increase in corn prices for 2024 and 2025, with forecasts indicating a range of $5,126 to $6,560 per ton in 2024 and $4,885 to $7,041 in 2025. This price prediction not only sheds light on the current volatility faced by farmers but also suggests that accurate forecasting can reduce uncertainty, thereby aiding smallholder farmers in planning and decision-making. Ultimately, the study contributes to achieving Sustainable Development Goals (SDGs 1 and 2) by supporting food security and poverty reduction through informed agricultural practices and policies (United Nations, 2015).

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

Determining prices with forecast models has been applied to many agricultural commodities including corn. This study provides further evidence of how to apply time-series models to forecast corn prices in the Mexican market and how to model the behavior of prices using **ARIMA** estimation techniques.

For example, price volatility in maize affects farmers' income stability and decision-making. Therefore, applied **ARIMA** models to forecast agricultural yield may illustrate how price forecasting tools can guide policy initiatives regarding production. (Yasmin & Moniruzzaman, 2024; Agbo, 2023).

ARIMA models provide a powerful method for forecasting agricultural prices compared to regression models (López-García et al., 2021; Maiga, 2024). This technique also allows us to addresses the complexity of agricultural markets by using advanced statistical models. Previous studies highlight that understanding dynamics through advanced inferential statistical methods increases understanding of agricultural production and pricing mechanisms (Bezabih et al., 2023).

The literature review supports the idea that the **ARIMA** model is a valuable forecasting tool in agriculture, particularly maize, with multifaceted implications for sustainability, economic stability, and informed policymaking, as demonstrated through the evidence and studies cited by various authors.

The multidisciplinary approach, provides an innovative way of employing econometric tools for time-series analysis in the price forecasts of agricultural products. The results may be used for sustainable development policy in the area of agricultural poverty reduction by reducing price uncertainty for small farmers.

6.2 Practical implications

The estimation of forecast models may be applied to decision making especially in the agricultural sector. Understanding price dynamics of corn results in powerful information valuable to policymakers, agricultural stakeholders and researchers. The results are useful to guide policy, programs and projects aimed to enhancing agricultural productivity and food security particularly in developing nations. For example, related to problems regarding expenditure of households on food (Guimond-Ramos et al., 2023) or the degradation and sustainability of agricultural practices (Valdez-Galvez et al., 2023).

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

The foundational theory presented previously by Box et al. (2015) explains the Box-Jenkins methodology, emphasizing the model's relevance in both academic and real-world scenarios, reflecting its utility in addressing price fluctuations and informing sustainable agricultural practices with practical implications.

The multidisciplinary approach employed in this study has a social impact by providing valuable information for sustainable development policy. This may, in turn, impact agricultural poverty reduction by reducing price uncertainty for small farmers.

7. CONCLUSION

This section of the study is structured to provide a comprehensive overview of the key findings and their implications for agricultural policy and practice in Mexico. It begins by summarizing the main conclusions regarding the projected trends in corn prices for 2024 and 2025, emphasizing both the anticipated upward trajectory and the inherent price volatility that farmers face. Following this, the section discusses the methodological significance of employing the **ARIMA** model, underscoring its effectiveness in addressing price uncertainty within the agricultural sector.

Additionally, the conclusions highlight the broader implications for sustainable development, particularly in relation to food security and poverty reduction among smallholder farmers. The section also acknowledges the limitations of the study, suggesting areas for future research, such as the exploration of regional price variations, thereby emphasizing the ongoing need for innovative approaches to enhance resilience in agriculture. Overall, the conclusions serve as a bridge connecting the study's theoretical contributions with practical applications aimed at fostering sustainable agricultural practices in Mexico.

7.1 How answer the question and explain the research hypothesis.

Mexico has increased its dependence on corn imports due to insufficient domestic production of the grain. By 2024, a deficit of 900 million tons needed to meet domestic demand could be reached. By employing the **ARIMA** model to forecast prices of corn, the study has shown that price uncertainty may be dealt with using time-series analysis forecast tools. This is part of a growing literature that employs time-series econometric tools to the agricultural sector. The study has shown that given the current volatility and uncertainty in the price of corn in Mexico, the

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

ARIMA model may be used to forecast corn prices in Mexico from a multidisciplinary approach with sustainable development policy implications.

The hypothesis related to the research question posed in this study is the following, **H:** "*Given the current volatility and uncertainty in corn prices in Mexico, the integration of the ARIMA (Autoregressive Integrated Moving Average) model with sustainable agricultural practices will effectively forecast corn prices, thereby providing valuable insights for reducing price volatility and uncertainty faced by farmers. This will ultimately contribute to more informed decision-making in agricultural policy and practice, promoting sustainable development within the agricultural sector"* is proved in the study by demonstrating the effectiveness of the **ARIMA** model in forecasting corn prices and its integration with sustainable agricultural practices. The integration of the **ARIMA** model with sustainable agricultural practices has effectively forecasted corn prices in Mexico, providing valuable insights that reduce price volatility and uncertainty faced by farmers. Consequently, this integration has contributed to more informed decision-making in agricultural policy and practice, promoting sustainable development within the agricultural sector.

The study uses the ARIMA (1,1,0) model, determined to best fit the data based on the Akaike Information Criterion (**AIC**), residual analysis, and the principle of parsimony. The model predicts an increase in corn prices for 2024 and 2025, providing farmers and policymakers with valuable insights into future price trends. By showing that the **ARIMA** model can handle price volatility and uncertainties, the study supports informed decision-making for agricultural policies that aim to promote sustainability. The research highlights how this method can inform resource optimization and contribute to the Sustainable Development Goals, emphasizing its multidisciplinary approach while enhancing economic stability for smallholder farmers.

7.2 Research findings

From the data analyzed, we can observe that there is a stagnation in the real marketing prices of grain corn in Mexico. The real annual growth is 2.2% for the last 20 years. Price heterogeneity is also observed in different regions, and local and international supply and demand forces appear to influence market price determination. In recent years, geo-political conflicts have put upward pressure on prices.

Vol. 04. No.08. Jul-Dec (2024): 63-95
https://doi.org/10.55965/setp.4.08.a3
eISSN: 2954-4041

The results contribute to a theoretical discussion on employing statistical tools to reduce market uncertainty on agricultural commodities. The study has included a multidisciplinary approach by provide empirical practical results on corn prices for decision making. The results are innovative in using the **ARIMA** statistical tool to analyze a specific commodity (corn) in a specific market (Mexico) a multidisciplinary approach with sustainable development policy implications.

The results of the corn price forecasts point to an upward trend for the years 2024 and 2025 where the price could reach between \$5,126 to \$6,560 pesos in 2024 and between \$4,885 and \$7,041 by 2025.

7.3 Research final scope

The conclusions of the study suggest an upward trend in corn prices for 2024 and 2025, however, price stagnation and uncertainty is observed. Although government policies have introduced price guarantees for corn in Mexico, they only cover less than 3% of total production. A limitation of the study lies in observing overall corn prices in Mexico, future studies should analyze price divergence by regions or states in Mexico. Also, a spatial analysis may result in observing underlying forces that determine the price of corn in Mexico.

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Vol. 04. No.08. Jul-Dec (2024): 63-95
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Vol. 04. No.08. Jul-Dec (2024): 63-95
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