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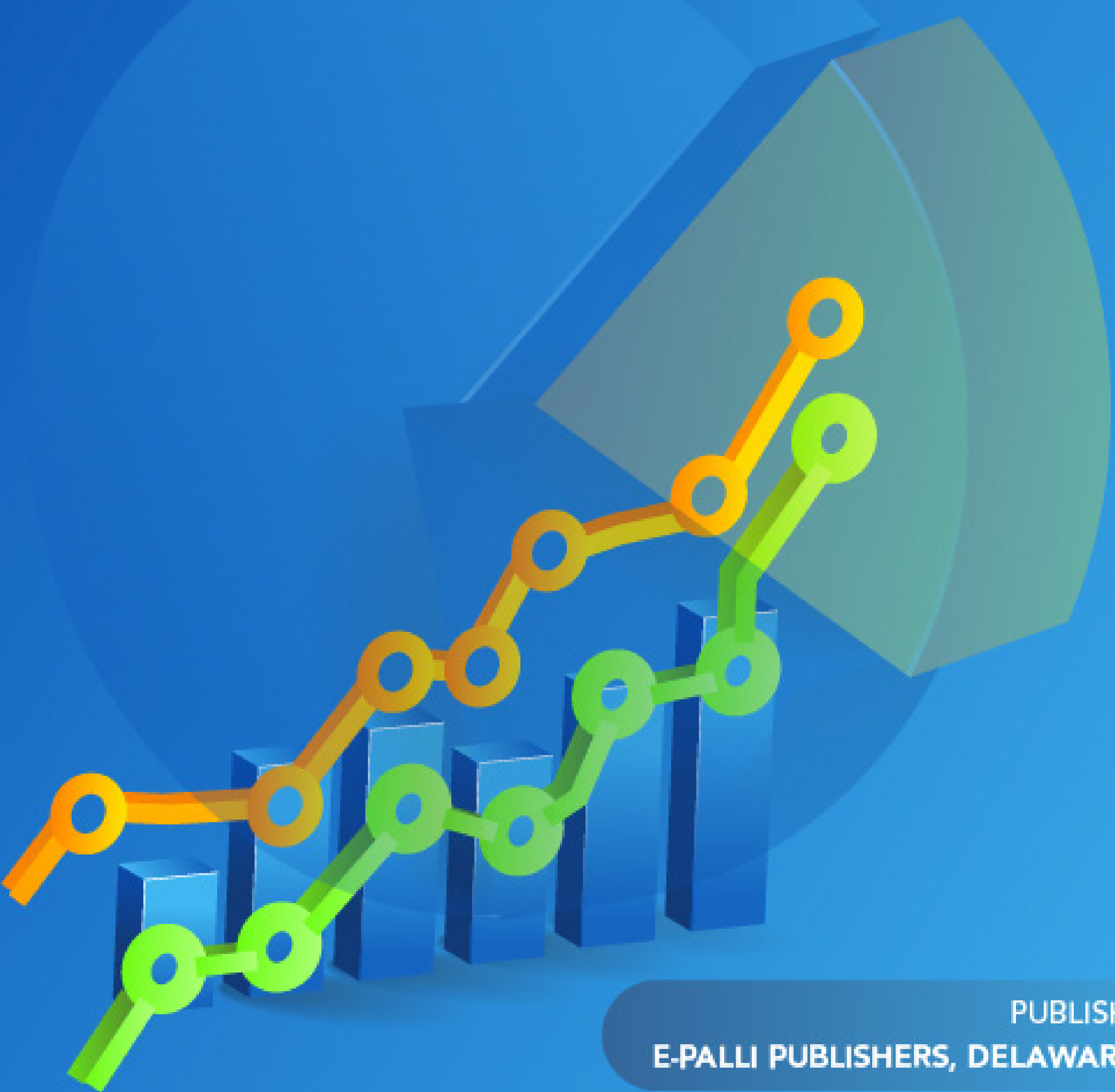

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U.S. Production and Trade Contribution to the Global Tomato Market: Analysis of U.S. Production Forecasts Using a Quadratic Trend Model

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ABSTRACT

Tomatoes are a globally popular horticultural crop, valued for their nutritional and economic significance. The United States is a major producer of fresh tomatoes, playing a crucial role in both domestic consumption and international trade. However, its production has shown variable trends over the past decade. This study analyzes U.S. tomato production trends from 2010 to 2023 using linear, quadratic, and exponential trend models and forecasts for 2024-2029 using the best-fit model. Data was collected from FAOSTAT and USDA databases. The models' performance was evaluated using Mean Absolute Deviation (MAD), Mean Squared Deviation (MSD), and Mean Absolute Percentage Error (MAPE), with the quadratic model achieving the highest predictive accuracy, recording the lowest forecasting errors (MAD = 876,821; MSD = 1.18×10^{12}; MAPE = 6.94%). Global production has continued to rise, led primarily by China and India, while U.S. production fluctuated moderately, reaching its highest level in 2014 and demonstrating an upward trend again in 2023. The predicted U.S. production is expected to decline gradually from 10.13 million metric tonnes in 2024 to 8.17 million metric tonnes in 2029. This suggests potential vulnerability in domestic supply and increasing reliance on imports, particularly from Mexico, which currently supplies nearly two-thirds of U.S. domestic demand. However, these forecasts should be viewed as general guidance rather than precise predictions of future prices. The findings highlight the need for adaptive production strategies, climate-resilient practices, and sustainable trade policies. By combining historical data with robust forecasting, this study addresses the gap in predictive analysis and provides practical insights for producers, policymakers, and supply chain stakeholders.

INTRODUCTION

Tomato (*Solanum lycopersicum*), a member of the Solanaceae family, is one of the most widely cultivated horticultural crops worldwide, valued for both fresh consumption and industrial processing (Gerszberg *et al.,* 2015; Pavan, van Heusden, & Bai, 2009). Although originating in western South America, tomatoes were likely domesticated in Central America (Kimura & Sinha, 2008). The United States ranks among the top global producers of fresh tomatoes. Nutritionally, tomatoes provide essential nutrients, including minerals, vitamins, dietary fiber, antioxidants, proteins, and amino acids such as leucine, threonine, valine, histidine, lysine, and arginine (Ahn, 2016; Szabo, Cătoi, & Vodnar, 2018; Liu *et al.,* 2022). They also contain beneficial monounsaturated fatty acids (linoleic and linolenic acids), carotenoids (lycopene and β-carotene), and phytosterols (β-sitosterol, campesterol, and stigmasterol) (Ali *et al.,* 2020; Zio, 2024). Regular consumption of tomatoes is associated with multiple health benefits, including anticancer properties, reduced risks of cardiovascular and neurodegenerative diseases, improved intestinal health, enhanced skin condition, faster exercise recovery, and strengthened immunity. Lycopene, a naturally occurring carotenoid primarily present in tomatoes and tomato-derived products, is a bioactive phytochemical known for its significant health-promoting properties. As a potent antioxidant, lycopene has been reported to mitigate oxidative stress-induced metabolic dysfunctions and related disorders, including inflammation, obesity, and diabetes mellitus. Furthermore, it plays a protective role against various metabolic diseases that affect multiple organs, including the bones, eyes, kidneys, liver, lungs, heart, and nervous system (Shafe *et al.,* 2024). However, factors such as cultivation methods, processing techniques, intake levels, and nutrient bioavailability can affect these physiological benefits (Collins *et al.,* 2022).

As climacteric fruits, tomatoes undergo extensive metabolic transformations during their growth and ripening processes (Quinet *et al.,* 2019). Over the past 20 years, tomato production has increased steadily globally, making it the most produced vegetable crop worldwide (Gatahi, 2020). Three countries (China, India, and the United States) accounted for more than 55% of the world's tomato production in 2023, totaling more than 192 million metric tons (FAOSTAT, 2023). Tomatoes are grown in a variety of agro-ecological zones, as they serve as basic food and industrial raw material for the processing industry. Worldwide, in 2023, the annual export value of tomatoes exceeded USD 11 billion, illustrating their

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economic importance to both developed and developing countries (FAOSTAT, 2023). With the expansion of international trade, the demand for tomatoes has been further driven by increasing urbanization, growing health consciousness, and the increased adoption of greenhouse and hydroponic systems (Zheng *et al.,* 2023; Yuan *et al.,* 2025).

Despite its importance, few studies have used long-term data and predictive modeling frameworks to quantitatively analyze the dynamics of tomato production in the U.S. and globally. While previous studies focus on biological or nutritional aspects, fewer studies have linked production and trade data to forecasting models that could guide market planning and policy. Accurate tomato production forecasting is crucial for predicting future demand and supply, maintaining price stability, and informing input choices and trade negotiations (Abid *et al.,* 2014; Singh & Singh, 2021).

Therefore, the purposes of this research were to:

(i) analyze global and U.S. tomato production from 2010 to 2023,

(ii) develop and evaluate linear, quadratic, and exponential trend models to predict tomato production in the U.S. for 2024-2029 using the best-fit model and

(iii) examine the implications of these projections for production, market competitiveness, and trade policies.

LITERATURE REVIEW

Tomatoes had undergone several stages of domestication before their introduction to the Old World, where they were initially grown as ornamental plants (Blanca *et al.,* 2015). Today, they are among the most widely consumed vegetables, grown in diverse agro-climatic regions for both fresh markets and processing industries (Rezk *et al.,* 2021). Govindasamy *et al.* (2025) emphasized the crop's economic and nutritional importance across nations. Although production patterns vary regionally, tomatoes remain integral to both domestic consumption and international trade. The authors further highlighted the need for policy frameworks that address trade imbalances, promote technological innovation, and strengthen the sustainability of supply chains, aligning with broader goals of environmental stewardship and market resilience.

According to Pawlak *et al.* (2021), the U.S. agricultural sector demonstrates higher efficiency than many of its global counterparts, primarily due to more favorable factor ratios (land, labor, and capital), resulting in enhanced labor productivity and more effective resource utilization. Tomato processing is heavily concentrated in a few regions: mainly the United States, Italy, and China, which collectively account for nearly 65% of global output (FAOSTAT, 2023; Cammarano *et al.,* 2022). Climate change projections indicate a potential 6% reduction in global processing tomato production by 2050 relative to 1980-2009 averages, largely driven by increasing temperatures and water scarcity (Cammarano *et al.,* 2022). These climatic shifts may gradually transfer comparative advantages to cooler regions such as China and northern California (Cammarano *et al.,* 2022). Food systems are increasingly challenged to meet the growing demand for specialty crops amid the effects of climate change and increased competition for resources. According to Gustafson *et al.* (2021), U.S. supply chains for processed tomato products can achieve greater resilience through crop adaptation strategies.

The U.S. tomato industry also faces increasing competition from imports, especially from Mexico. Li *et al.* (2022) reported that the import of Mexican tomatoes has significantly depressed U.S. domestic prices, leading to an estimated $252 million (27%) reduction in revenue for domestic producers if imports increase by 50%. Such trends pose a threat to the long-term sustainability of the U.S. tomato sector. California's Mediterranean climate plays a key role in its status as a global leader in high-value crop production, particularly processing tomatoes, which account for approximately 95% of U.S. production and 30% of global production (Pathak & Stoddard, 2018). There is uncertainty in production, infrastructure, and financial aspects of the tomato supply chain (Pardaev, 2022).

Modeling Agricultural Production Trends

Forecasting agricultural production often uses the use of deterministic trend models such as the linear trend model, quadratic trend model, and exponential trend model. These models capture historical growth patterns and project future trends in agricultural outputs. Their application across various crops has demonstrated consistent effectiveness, as summarized below:

Table 1: Applications of Trend Models in Forecasting Agricultural Commodity Production across Different Countries

Commodity	Country	References
Maize production	Pakistan	Tahir & Habib, 2013
Potato production and trade analysis	United States	Ojha *et al.,* 2025
Wheat production	Bangladesh	Karim *et al.,* 2010
Plantation Crops	Indonesia	Nurfadila *et al.,* 2022

These studies collectively show that trend-based models provide a robust analytical framework for understanding long-term agricultural production dynamics and forecasting future changes under varying climatic and economic conditions.

MATERIALS AND METHODS

Data Collection and Analysis

This study used secondary time-series data on global and U.S. tomato production spanning the period from 2010 to 2023. Data were obtained from the Food and Agriculture Organization of the United Nations (FAOSTAT, 2025) and the United States Department of Agriculture (USDA). The FAOSTAT database provided comprehensive global production statistics, which were used to identify the top five tomato-producing countries worldwide (2017-2023) and to analyze long-term global production trends. U.S.-specific data from USDA reports were employed to assess national production patterns and trade performance, including import and export dynamics. Data on tomato production for the top two producing states in the United States from 2017 to 2024 were obtained from the USDA, National Agricultural Statistics Service (USDA-NASS).

The self-sufficiency ratio (SSR) is calculated to determine what percentage of a country's total consumption or domestic demand is met through domestic production rather than imports (Abdelradi, 2018; FAO, 2001; FAO, 2021; Govindasamy, Ceylan, & Özkan, 2025; Bikernieks, 2021).

Self-Sufficiency Ratio (SSR)=P/(P+I-E)*100 (1)

Where:

P = Domestic production

I = Import

E = Export

All data were organized and processed using Microsoft Excel and R Studio for statistical analysis. Descriptive statistics were computed to summarize production trends, and time series visualizations were generated to identify temporal variations. Data validation and cross-referencing between FAOSTAT and USDA were performed to ensure accuracy and consistency across all years and variables. These datasets formed the empirical foundation for developing and testing forecasting models to predict U.S. tomato production.

Selection and Performance Evaluation of Forecasting Models for U.S. Tomato Production

Time-series data on U.S. tomato production from 2010 to 2023 were utilized to develop and evaluate forecasting models. To identify the best-fitting model, three trend-based time series models: linear trend, quadratic trend, and exponential growth, were tested. The selected model was then employed to forecast U.S. tomato production for the period 2024-2029. The functional forms of these models, which have been applied in previous agricultural forecasting studies (Abid *et al.,* 2014, 2018; Karim *et al.,* 2010; Singh & Singh, 2021; Tahir & Habib, 2013), are presented below:

1. Linear Trend Model: $Yt = a + bt$ (2)
2. Quadratic Trend Model: $Yt = a + bt + ct^2$ (3)
3. Exponential Growth Model: $Yt = ae^{bt}$ (4)

Where:

Yt = Tomato production in the United States at time t (2010-2023)

t= Time trend variable, representing the observation period and indicating the direction and magnitude of change over time

a,b,c = Model parameters estimated from the data

Model Evaluation Metrics

To assess the performance and predictive accuracy of each model, three standard error metrics were employed: Mean Absolute Error (MAE), Mean Squared Deviation (MSD), and Mean Absolute Percentage Error (MAPE). These measures evaluate the deviation between actual and predicted values, providing a quantitative basis for comparing models. These evaluation metrics have been widely applied in previous studies on agricultural price forecasting to assess model performance and predictive accuracy (Li & Lian, 2025; Sanwa & Chi, 2025).

The equations for the respective evaluation metrics are as follows:

Mean Absolute Error (MAE)

$$MAE= \frac{1}{n}\sum_{t=i}^{n} | y_i - \hat{y}_i \quad (5)$$

Mean Squared Deviation (MSD)

$$MSD= \frac{1}{n}\sum_{t=i}^{n}(y_i - \hat{y}_i)^2 \quad (6)$$

Mean Absolute Percentage Error (MAPE)

$$MAPE = \frac{100}{n}\sum_{t=i}^{n} \left| \frac{\{y_i - \hat{y}_i\}}{y_i} \right| \quad (7)$$

Where:

n is the number of observations

yi represents the actual values

yiˆ are the predicted values.

Lower values of these error measures indicate a higher degree of model accuracy and better fit to the observed data (Montgomery *et al.,* 2012). The model achieving the smallest MAD, MSD, and MAPE values was selected as the optimal forecasting model for U.S. tomato production.

RESULTS AND DISCUSSION

Global Tomato Production

Tomatoes are among the most extensively cultivated and economically important horticultural crops worldwide. They are valued for their high nutritional content, diverse uses, and vital role in global food security (Sattar *et al.,* 2024). According to the Food and Agriculture Organization (FAO, 2024), global tomato production exceeded 190 million metric tonnes in 2023, making it the world's leading vegetable crop by volume. A few major producers: China, India, Turkey, and the United States, account for over 60% of the total global output (FAOSTAT, 2024).

Figure 1 illustrates the annual global tomato production from 2010 to 2023, measured in million metric tonnes. Over the past 14 years, tomato output has shown a consistent upward trend, rising from approximately 150 million tonnes in 2010 to nearly 200 million tonnes by 2023. Each bar represents a calendar year, with shading progressing from light gray (earlier years) to dark gray (recent years), visually reinforcing the temporal growth. The steady increase suggests expanding cultivation, improved agricultural practices, and rising global demand for tomatoes in both for fresh consumption and processed products.

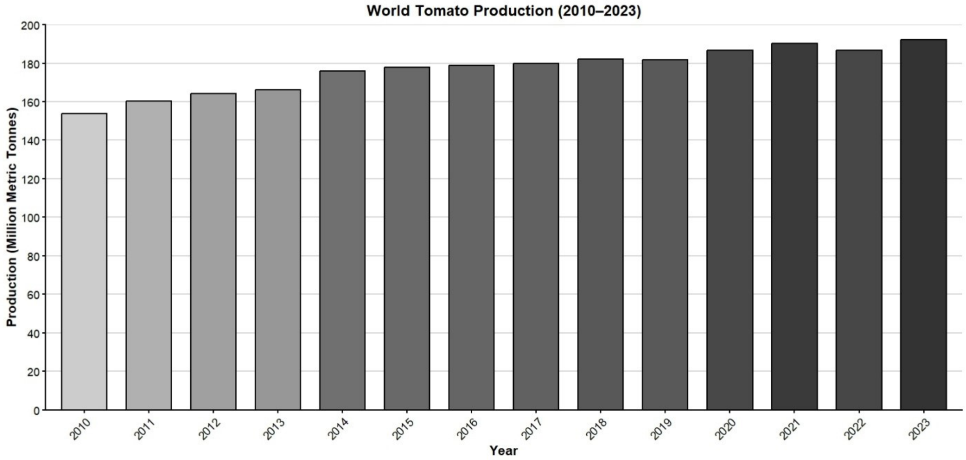

Figure 1: Global Tomato Production, 2010 - 2023 (Million Metric Tonnes).
Source: Authors' compilation based on the FAOSTAT database

Table 2: Top Five Tomato Producing Countries in the World (2017-2023)

Year	Country	Production (MMT)
2017	China	59.1
	India	20.7
	Turkey	12.75
	United States	11.13
	Egypt	6.72
2018	China	60.92
	India	19.75
	United States	12.61
	Turkey	12.15
	Egypt	6.77
2019	China	62.86
	India	19
	Turkey	12.84
	United States	10.85
	Egypt	6.81
2020	China	64.64
	India	20.55
	Turkey	13.2
	United States	10.93
	Egypt	6.24
2021	China	66.53
	India	21.18
	Turkey	13.09
	United States	10.44
	Italy	6.64
2022	China	68.29
	India	20.69
	Turkey	13
	United States	10.23
	Egypt	6.36

2023	China	70.11
	India	20.42
	Turkey	13.3
	United States	12.37
	Egypt	6.21

Source: Authors' compilation based on the FAOSTAT database

Table 2 summarizes global tomato production trends from 2017 to 2023 for the leading producing countries. China consistently remains the largest producer, with production steadily increasing from 59.1 MMT in 2017 to 70.11 MMT in 2023. India ranks second, with production generally stable between 19.0 and 21.18 MMT. Turkey maintains a moderate increase over the years, producing around 12-13 MMT annually.

A notable observation is the fluctuating production in the United States, which ranges from 10.44 MMT to 12.61 MMT over the study period. The U.S. ranked third globally only in 2018, while in all other years it remained fourth among the top producers. Unlike China and India, the U.S. does not exhibit a clear upward trend; instead, its production varies year to year, likely reflecting shifts in market demand, climate variability, changes in processing tomato acreage, and technological adjustments within the sector.

These trends indicate that China and India dominate global tomato production, supplying a substantial share of the world's output. The relatively stable production in Turkey, Egypt, and Italy suggests consistent cultivation practices and adaptation to local conditions. Variations in U.S. production may be influenced by market demand, climatic factors, or technological advancements. Understanding these patterns is important for global supply assessments, trade policy decisions, and price forecasting, as production trends in major countries significantly impact market availability and tomato prices worldwide.

Overview of Global Tomato Trade: Imports and Exports

Top three Tomato (fresh or chilled) importers in the world (2017-2023)

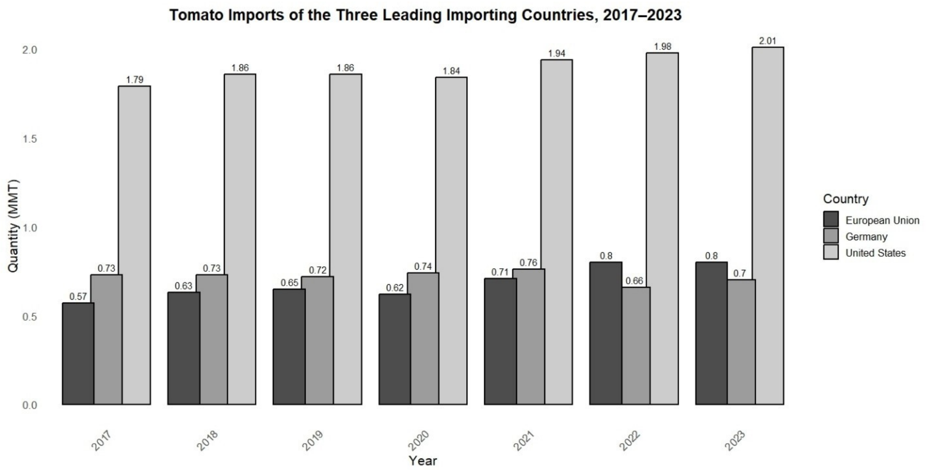

Figure 2: Annual Tomato Imports by the Top Three Importing Countries (2017-2023).
Source: Authors' compilation based on the FAOSTAT database

Figure 2 summarizes the import trends of tomatoes (fresh or chilled) for the top three global importers- the United States, Germany, and the European Union, during the period from 2017 to 2023. The United States consistently imported the largest quantities, rising from 1.79 MMT in 2017 to 2.01 MMT in 2023. Germany's imports remained increasing, between 0.66 and 0.76 MMT, whereas the European Union showed a gradual increase from 0.57 MMT to 0.80 MMT over the same period. These patterns highlight sustained growth in tomato imports for the United States and the European Union, while Germany's import volumes remained comparatively consistent.

Top three Tomato (Fresh or chilled) exporters worldwide (2017-2023)

Figure 3 shows the top three global exporters of fresh or chilled tomatoes, Mexico, the Netherlands, and Spain, between 2017 and 2023, measured in million metric tonnes (MMT). Mexico consistently led global exports, increasing from 1.51 MMT in 2017 to 2.01 MMT in 2023. The Netherlands maintained relatively stable exports, ranging from 0.86 to 1.09 MMT over the period, while Spain showed a gradual decline from 0.81 MMT in 2017 to 0.52 MMT in 2023. Overall, these trends highlight Mexico's dominant role in global tomato exports and the steady yet lower export volumes from European suppliers.

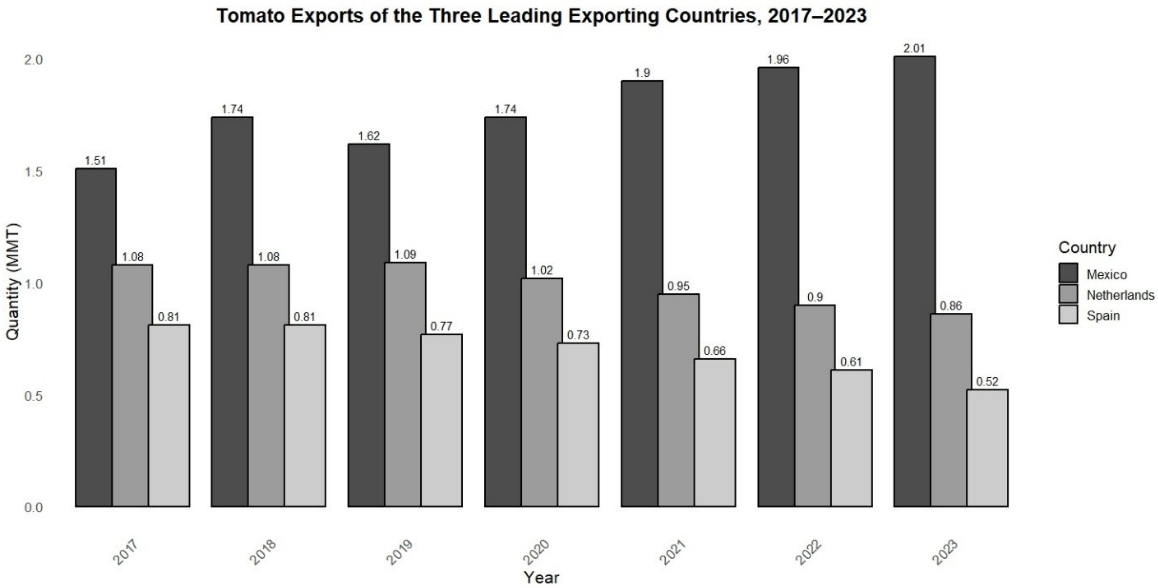

Figure 3: Annual Tomato Exports from the Top Three Exporting Countries (2017-2023).
Source: Authors' compilation based on the FAOSTAT database

U.S. Tomato Production (2010-2023) (MMT)

The figure shows that, from 2010 to 2023, annual tomato production in the U.S., measured in MMT, experienced notable variability. Production peaked in 2014 at approximately 15.9 MMT, then decreased to a low of 10.2 MMT in 2022 before increasing to 12.37 MMT in 2023. These fluctuations reflect the combined influence of climatic variability, changes in cultivation and management practices, market demand, and economic factors affecting tomato farming. Short-term increases, such as those in 2014 and 2023, likely resulted from favorable growing conditions and improved production techniques, whereas declines may have been caused by environmental stressors, pest or disease pressures, and market constraints.

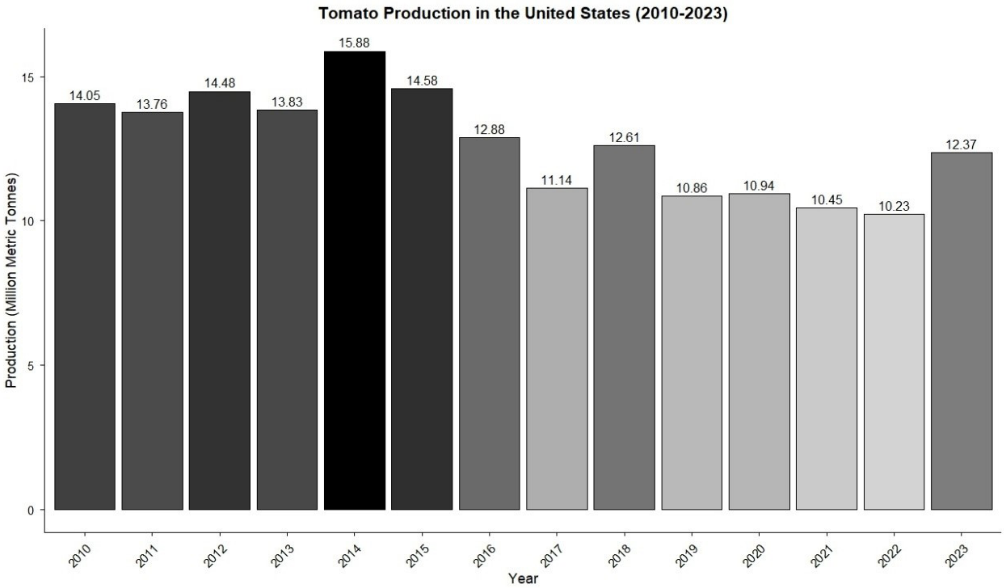

Figure 4: Annual Trends in Tomato Production in the United States, 2010-2023 (MMT).
Source: Authors' compilation based on the FAOSTAT database

The observed trends provide valuable insights into the temporal dynamics of U.S. tomato production, supporting strategic policy planning, supply chain optimization, and economic assessment in the industry. The fresh tomato supply chain is highly seasonal and vulnerable to labor shortages, transportation bottlenecks, and weather disruptions. The limited adoption of greenhouse production, combined with the higher costs and complexity of supply chains for mature-green tomatoes, compared with vine-ripe varieties, further reduces overall production efficiency. Understanding these dynamics is essential for enhancing resilience, stabilizing supply chains, supporting farmer livelihoods, and maintaining a balance between domestic consumption and export demands (Guan *et al.,* 2022).

Trends in U.S. Tomato Production, Trade, and Self-Sufficiency (2010-2023)

Figure 5 illustrates trends in U.S. tomato production, trade, and self-sufficiency from 2010 to 2023. Domestic

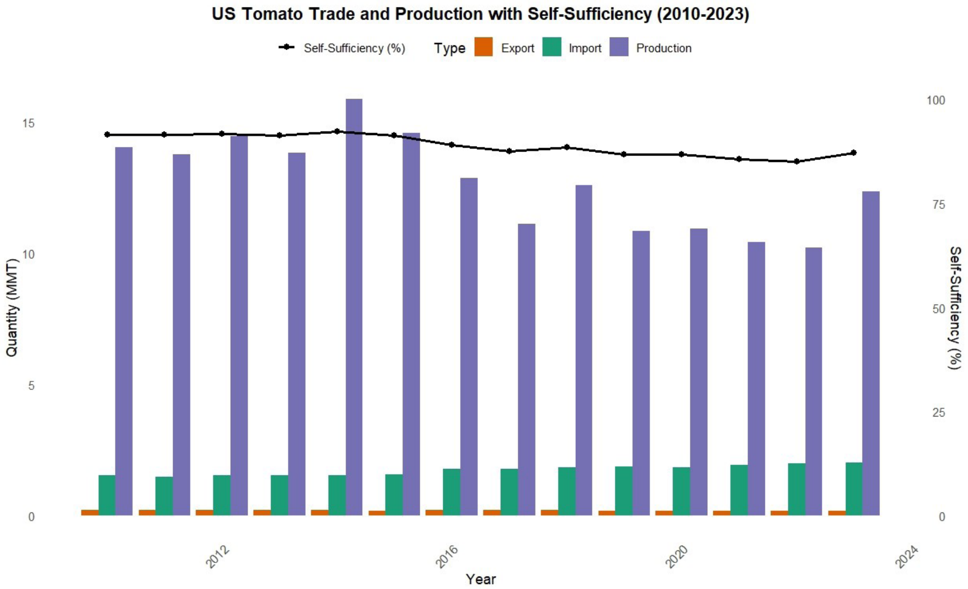

Figure 5: U.S. Tomato Production, Trade, and Self-Sufficiency from 2010 to 2023.
Source: Authors' compilation based on the FAOSTAT database

production remained dominant throughout the period, peaking around the mid-2010s before gradually declining in later years. Imports showed a steady increase, while exports remained minimal, indicating that the U.S. is primarily a domestic producer and consumer of tomatoes. Despite a slight decline in production in 2022, the overall self-sufficiency ratio remained high, consistently above 75%, showing that domestic output largely met domestic demand.

The slight decrease in self-sufficiency toward the late 2010s likely reflects increasing reliance on imports due to factors such as climate variability, production costs, or changes in farming practices. The small rebound in recent years may indicate a partial recovery in domestic production. Overall, the figure shows that while the U.S. tomato sector remains largely self-reliant, maintaining long-term production stability is crucial to sustain its high level of self-sufficiency and reduce vulnerability to external supply disruptions.

Top Tomato-Producing States in the United States (2017-2024)

Table 3 presents annual tomato production for the two leading tomato-producing states in the U.S, California

Table 3: Top Tomato Producing States in the U.S. (2017-2024)

States/ Year	Production (MMT)							
	2017	2018	2019	2020	2021	2022	2023	2024
California	10.46	12.28	11.19	11.31	10.78	10.50	12.81	11.09
Florida	0.42	0.38	0.39	0.36	0.35	0.42	0.45	0.32

Source: Authors' compilation based on the USDA database

and Florida, from 2017 to 2024. California consistently had the highest production, ranging from 10.46 MMT in 2017 to a peak of 12.81 MMT in 2023. In contrast, Florida's production was substantially lower, fluctuating between 0.32 MMT in 2024 and 0.45 MMT in 2023. Over the eight years, California's production exhibited moderate year-to-year variation, while Florida's production experienced more noticeable fluctuations, including a decline in 2024. These data highlight California's dominant role in U.S. tomato production and Florida's smaller, yet variable, contribution.

Shifts in the U.S. Domestic and Imported Fresh Tomato Markets (2024-2025)

In 2024, the USDA Economic Research Service (ERS) estimated that U.S. fresh tomato production declined by approximately 9% compared to the previous year, with greenhouse production partly offsetting a sharper 15% decrease in field-grown tomatoes reported by USDA NASS. Greenhouse tomatoes continue to make up an increasing share of the domestic supply. Despite the overall production decline, the value of the crop decreased by only 4%, supported by a 12% year-over-year increase in grower prices. Both harvested acreage and yields decreased in California and Florida, with higher temperatures in California's San Joaquin Valley during July 2024 accelerating fruit development and contributing to supply gaps later in the season.

Fresh tomato imports made up 72% of the U.S. domestic supply in 2024, mostly from Mexico (90%) and Canada (9%), indicating that imports from Mexico alone accounted for 65% of the total domestic supply. Total import volume reached a record 4.7 billion pounds, a 15% increase from 2023, with approximately 60% classified as greenhouse-grown production. Among greenhouse tomato imports, round tomatoes had the largest share of value (25%), followed by grape (23%), Roma (17%), cherry (4%), and other unspecified varieties. In the first two months of 2025, import values increased by 14%, while volumes remained relatively stable, rising by 0.03% compared to the same period in 2024. Organic tomatoes accounted for 3-8% of the total monthly import value during 2024 (Davis *et al.,* 2025). In July 2025, U.S. agricultural trade recorded exports of $13.2 billion and imports of $18.2 billion, resulting in a trade deficit of approximately $5.0 billion (USDA FAS, 2025).

Diagnostic Measures for Choosing the Best Forecasting Model

The reliability of forecasting methods was evaluated using three accuracy measures, also known as forecasting errors: Mean Absolute Percentage Error (MAPE), Mean Absolute Deviation (MAD), and Mean Squared Deviation (MSD).

- Mean Absolute Percentage Error (MAPE): Measures how accurately the fitted time series values match the actual data, expressed as a percentage.
- Mean Absolute Deviation (MAD): Measures the accuracy of fitted time series values in the same units as the data, helping to visualize the magnitude of error.
- Mean Squared Deviation (MSD): Calculated using a consistent denominator regardless of the model

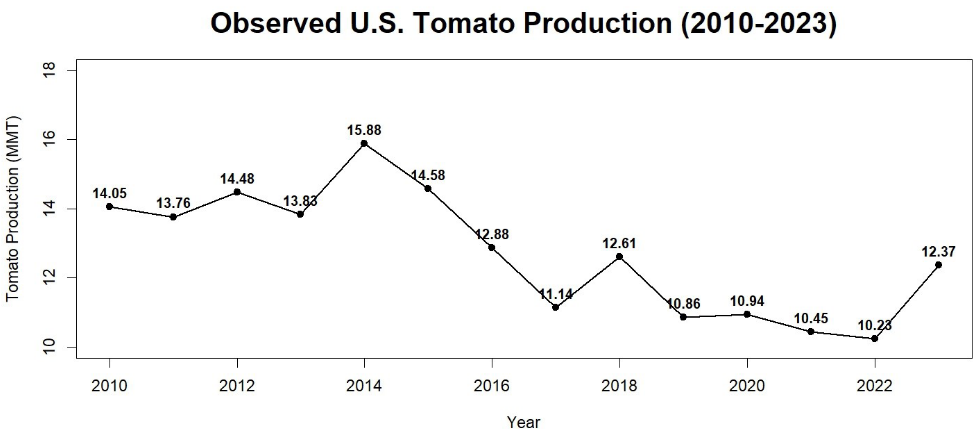

Figure 6: Yearly U.S. tomato production trend from 2010 to 2023 (MMT).
Source: Authors' compilation based on the FAOSTAT database

Table 4: Summary Statistics of U.S. Tomato Production (2010-2023).

Statistics	**Value**
Mean production	12,718,172
Standard Error	476045.228
Standard deviation	1,781,198
Sample variance	3.17 × 1012
Kurtosis	-1.169
Skewness	0.08197
Range	5640683
Minimum production	10,234,317
25th percentile (Q1)	10,988,990
Median (50th percentile	12,745,070
75th percentile (Q3)	13,996,900
Maximum production	15,875,000

Source: Authors' compilation based on the FAOSTAT database and is more sensitive than MAD, especially in cases of abnormally large forecast errors.

Smaller values of these measures indicate a better-fitting model with fewer forecasting errors (Karim & Akhter, 2010). In this study, the quadratic model was identified as the best-fitting model, and the data series was stationary for model identification.

The summary statistics (Table 4) provide an overview of tomato production in the U.S. from 2010 to 2023. On average, production was about 12.72 million metric tons, with a standard deviation of 1.78 million metric tons, indicating moderate year-to-year variability. Production ranged from 10.23 million to 15.88 million metric tons, with some fluctuations. The data distribution is nearly symmetric (skewness = 0.08) and slightly flatter than a normal distribution (kurtosis = -1.17), suggesting relatively few extreme values. The median production (12.75 million metric tons) is close to the mean, further reflecting the stability of production. Overall, tomato production during this period was consistent, with moderate year-to-year variations.

Table 5: Comparison of Forecasting Models' Performance Using MAD, MSD, and MAPE Metrics

Evaluation metrics	**Forecasting models**		
	Linear	**Quadratic**	**Exponential**
Mean Absolute Deviation (MAD)	880246.53	876820.66	890093.37
Mean Squared Deviation (MSD)	1.182×10^{12}	1.18×10^{12}	1.196×10^{12}
Mean Absolute Percentage Error (MAPE)	0.0695	0.0694	0.0698

Table 5 indicates that all three forecasting models: linear, quadratic, and exponential, performed relatively similarly, with only minor differences in various error measures. Among them, the quadratic model achieved the lowest Mean Absolute Deviation (MAD = 876,820.66) and Mean Squared Deviation (MSD = 1.17988×10^{12}), suggesting it provided the most accurate forecasts overall. The Mean Absolute Percentage Error (MAPE) values were also very close across models, all around 7%, indicating a generally good level of forecasting accuracy. Overall, these results suggest that the quadratic model slightly outperformed the others and might offer a better fit for the data, although all three models demonstrated comparable and reliable predictive performance.

Table 6: Forecasted U.S. Tomato Production Using the Best-Fit Model (Quadratic) (2025-2027).

Year	**Forecasted Production (Tonnes)**	**Lower 95% CI**	**Upper 95% CI**
2024	10,126,997	6,440,547.2	13,813,447
2025	9,749,533	5,514,123.8	13,984,941
2026	9,366,072	4,430,495.4	14,301,650
2027	8,976,617	3,197,930.7	14,755,304
2028	8,581,167	1,825,566.7	15,336,766
2029	8,179,721	321,338.6	16,038,103

Note: CI- confidence interval

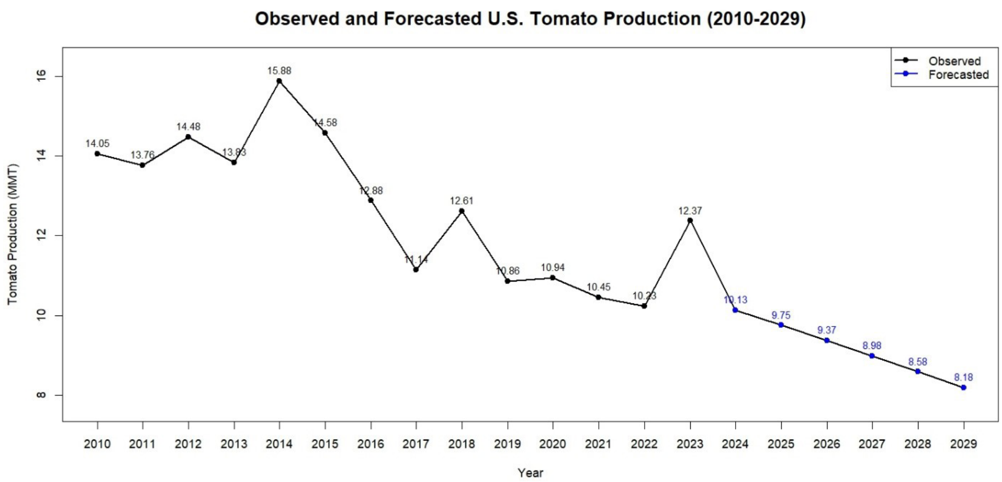

Figure 7: Forecast of U.S. tomato production from 2010 to 2027 using a quadratic trend model.

Figure 7 illustrates the forecasted tomato production in the United States for 2024-2029, based on 2010 to 2023 production data using the best-fit quadratic model. Observed values are shown as black points connected by a solid line, while forecasted values are shown as blue points connected by a dashed line. Tomato production is expressed in million metric tons (MMT).

The trend indicates that production fluctuated between 13-16 MMT during 2010-2023, with a peak in 2014 (≈15.88 MMT) and subsequent declines in the later years. The quadratic model predicts a gradual decline in production from 10.13 MMT in 2024 to 8.18 MMT by 2029. This projection provides insights into potential future production trends and can inform agricultural planning and policy.

Several studies have consistently shown that the quadratic trend model outperforms other approaches in forecasting agricultural production. Abid *et al.* (2014), for instance, reported that the quadratic model provided the best fit for predicting maize area and production in Pakistan from 1980-81 to 2011-12. Similarly, Tahir and Habib (2013) identified the quadratic trend model as the optimal method for analyzing maize production trends in Pakistan from 1990 to 2011, with forecasts aligning closely with observed values. In India, Singh and Singh (2021) further confirmed the effectiveness of the quadratic trend model, reporting the lowest forecasting error values for rice area and production. Correspondingly, Ojha *et al.* (2025) applied similar modeling approaches to U.S. potato production and concluded that the quadratic trend model provided the best fit, forecasting an accelerated decline between 2023 and 2025. Collectively, these findings underscore the quadratic trend model's robustness in capturing nonlinear patterns and long-term dynamics in agricultural production forecasting.

Future Directions

Future studies on tomato production should incorporate trade analysis, advanced forecasting techniques, and multidimensional datasets to improve predictive accuracy. Expanding beyond deterministic trend equations by integrating models, such as Autoregressive Integrated Moving Average (ARIMA), Seasonal ARIMA (SARIMA), and machine-learning frameworks, including Random Forest and Long Short-Term Memory (LSTM), would enable the modeling of non-linear and seasonal crop yield patterns (Singh *et al.,* 2021). Correlations between climatic indicators: temperature, rainfall, and evapotranspiration, and economic factors: input costs, labor wages, and trade volumes, would help provide accurate estimates under newly emerging farming practices (Abid *et al.,* 2014; Karim *et al.,* 2010; Tahir *et al.,* 2013). Additionally, regional analyses of water availability, soil quality, greenhouse use patterns, and local adaptation strategies could further advance farming resilience and profitability (Pathak *et al.,* 2018; Cammarano *et al.,* 2022; Davis *et al.,* 2025).

Furthermore, future studies should also investigate sustainability, market, and policy aspects. Under the USMCA and the U.S.-Mexico Suspension Agreement, integrating production projections with trade simulations can assess the impacts of import dependency and policy changes (Li *et al.,* 2022; Guan *et al.,* 2022; USDA FAS, 2025). Analyzing consumer preferences and willingness to pay for tomatoes grown in greenhouses, organically, or locally would shed light on changing demand patterns impacting both domestic and international markets (Food Policy, 2023; Yuan *et al.,* 2025). Additionally, combining life-cycle assessment (LCA) with economic forecasting can quantify carbon, energy, and water footprints across production systems, promoting sustainable supply-chain development and climate-smart agricultural planning (Zheng *et al.,* 2023; Gustafson *et al.,* 2021; Pawlak *et al.,* 2021).

CONCLUSION

The study found that global tomato production growth from 2010 to 2023 was mainly driven by China and India, while U.S. production experienced moderate fluctuations due to climatic and economic factors. The quadratic trend model proved most effective for forecasting U.S. tomato production because it captures nonlinear variation in time series. Results highlight the U.S. market's increasing reliance on tomato imports, especially from Mexico, alongside a gradual expansion of greenhouse production as a mitigation strategy. To improve production stability and trade competitiveness, policies should prioritize climate adaptation, yield efficiency, and sustainable market diversification. Overall, this study offers a strong quantitative basis for informed decision-making in tomato production management and strategic trade planning.

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