

Sunflower Production Trends Forecast: ARIMA Time Series Analysis Across Major Global Producers

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Abstract

Forecasting the future production is a critical tool that enables strategic decision-making in agricultural planning and policy development processes. The sunflower is strategically important due to its use in oil production, the food industry, and animal husbandry. In this study, sunflower seed production data from 1961 to 2023 are analysed using autoregressive integrated moving average (ARIMA) to forecast production levels in major producing countries for the period 2024–2028. The results indicate a continued upward trend in global production, reaching approximately 63.7 Mt (million tonnes) by 2028. Among countries, Russia is projected to lead with 19.7 Mt, followed closely by Ukraine (11.8 Mt) and the combined "Other producers" category (approximately 11.7 Mt). According to the rankings, Argentina leads with 4.7 Mt, followed by China with 2.9 million tonnes, Türkiye and France with 2.4 Mt each, Romania with 2.3 Mt, and Bulgaria with 2.1 Mt. While production growth is projected, the widening of forecast confidence intervals reflects continued susceptibility to climatic variability, geopolitical uncertainties, and market volatility. To enhance food security, policymakers must prioritise adaptive agricultural strategies, robust risk management tools, and improved institutional cooperation. This study presents a country-level ARIMA-based forecast of sunflower production through 2028, offering insights into both global production dynamics and the resilience profiles of individual producing countries.

Keywords: Agricultural policy, ARIMA forecasting, Leading producer countries, Sunflower production.

INTRODUCTION

The sunflower (*Helianthus annuus L.*) is the world's third most widely produced oilseed, the fourth produced vegetable oil and a leading source of high-quality protein in oilseed meal (Pal et al., 2015; Pilorgé, 2020). The existing literature highlights the strategic significance of sunflowers, attributing it to their diverse applications and consumption patterns. Beyond their high oil content, sunflowers exhibit strong adaptability across various climatic conditions, are well-suited to mechanised agriculture, relatively easy to cultivate, and face minimal challenges

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in marketability (Kaya, 2020). Also, sunflowers are of strategic importance in the production of livestock feed and biodiesel (Ministry of Agriculture and Forestry of the Republic of Türkiye, 2024). The vast majority of sunflower seeds produced, that is, more than 90%, are used in the production of edible oil (FAO, 2009). Havrysh et al. (2023) emphasise the use and forms of sunflower waste as an energy source, while Iriarte and Villalobos (2013) state that sunflower biodiesel will have better environmental performance than fossil diesel. Debaeke et al. (2017) emphasise that sunflowers contribute to climate adaptation due to their low greenhouse gas emissions, as well as their competitiveness and appeal in terms of food and energy. Taher et al. (2018) state that, due to the continuous growth of the human population, the demand for edible sunflower seeds, oil, and by-products is increasing. They argue that efforts to increase sunflower production must be intensified to meet this demand.

The leading countries in terms of sunflower harvest area in 2023 are the Russian Federation (9,900,000 ha), Ukraine (5,201,600 ha), Argentina (2,453,245 ha), Romania (1,077,870 ha), China (1,000,000 ha), Türkiye (952,605 ha), Bulgaria (869,910 ha), and France (821,740 ha) (FAOSTAT, 2025). The Russia-Ukraine war, which began in 2022, has led to a reduction in cultivated land and disruptions in the production process for Ukrainian farmers, who account for around 30% of global sunflower production (Ministry of Agriculture and Forestry of the Republic of Türkiye, 2024). According to USDA data, countries' shares in global sunflower seed production are as follows: Russia ranks first with approximately 32%, followed by Ukraine with 25%, the European Union with 16%, Argentina with 10%, and Kazakhstan, China, and Türkiye with 3% each (USDA, 2025a). The industrial processing of sunflower seeds to extract oil, primarily by separating the meal, along with various and increasingly expanding applications, has boosted demand and consumption of this product. This situation has led to a significant increase in sunflower seed production, trade volume, and industrial processing activities worldwide (Premović, 2023).

This study aims to examine production trends in the leading sunflower-producing countries, apply the ARIMA-based analysis to forecast medium-term output, and utilise the findings to inform evidence-based food security policies. Although sunflower is a widely cultivated crop worldwide, comparative production projections for countries often focus on more popular crops such as soybeans, maize and wheat. The original value of the study lies in its focus on sunflowers, particularly in terms of production estimates for major producing countries. Accurate and timely forecasting of agricultural yields is regarded as an indispensable tool—not only for achieving food security and sustainability goals but also for effective production

management, resource allocation, and the development of foreign trade policies (Gökler, 2024). In addition, it can contribute to the existing literature by being examined from a multidisciplinary perspective, as it is related to various sub-themes, notably sunflowers, food security, the oilseed trade, and animal husbandry. The ARIMA approach is a classic yet powerful method for time series forecasting. A common way to find trends in economic and agricultural data and make predictions about the future is to use time series analysis. The main benefit is that it can make both short- and medium-term predictions by capturing the series' autocorrelation structure. Numerous studies have explored the application of this approach in agricultural production forecasting (Badmus and Ariyo, 2011; Prabakaran and Sivapragasam, 2014; Hossain and Abdulla, 2016; Sikalubya et al., 2019; Singh et al., 2021; Quartey-Papafio et al., 2021; Latifi and Fami, 2022; Thapa et al., 2022; Alshatib et al., 2025; Karakaya and Uzundumlu, 2025). This forecasting method is commonly employed in agricultural data analysis; however, research utilizing long-term datasets is still scarce, especially concerning particular product categories and cross-country comparisons. This study aims to address this gap in the literature. In this context, it seeks to contribute to both academic research and applied agricultural economics. Sunflower production projections play a crucial role in agricultural planning and food security, significantly contributing to the achievement of the Sustainable Development Goals (SDGs). Due to their high oil and protein content, sunflower seeds serve as a valuable nutritional source for humans and offer a sustainable alternative to dominant animal feed sources, namely soy and maize, which may contribute to achieving SDG 2 (Zero Hunger). Additionally, utilizing sunflower by-products such as shells, stems, and husks in animal feed, biofertilizers, and energy production promotes circular agriculture and improves waste management, aligning with SDG 12 (Responsible Consumption and Production). In this context, accurate sunflower production forecasts based on the study's findings can support the development of evidence-based policies that advance progress toward multiple SDGs.

Although global statistical data on sunflower seed production and processing are available in the current literature, studies that address these data using comparative estimation models at the country level are limited. This study aims to fill this gap by developing projections regarding countries' production potential and providing scientifically based assessments of the future of the global sunflower seed market. Sunflower seed is a strategic agricultural product, particularly in terms of oil production, and holds a critical position in terms of global food security, vegetable oil supply, and industrial raw material supply. Changes in production and trade dynamics resulting from increasing global demand and consumption have a direct impact on

countries' economic balances. Therefore, country-specific forecasts for sunflower seed production are of great importance for both agricultural planning and the food industry. This study aims to provide guidance for policymakers, investors, and industry actors in this field.

MATERIAL AND METHOD

In this study, sunflower seed production data from 1961 to 2023 were analyzed using the ARIMA model based on data from the Food and Agriculture Organization (FAOSTAT) database. FAO current data is shown up to 2023. Therefore, data from 1961 to 2023 was used in the analysis. This statistical framework, commonly applied to non-stationary time series (Box & Jenkins, 1976), follows the Box–Jenkins methodology, which includes four main stages: model identification, parameter estimation, diagnostic checking, and forecasting.

The stationarity of the series is first assessed by the Augmented Dickey–Fuller (ADF) test. If the p-value is below 5%, the series is deemed stationary; otherwise, differencing is implemented. Subsequently, several parameter combinations are assessed to identify the optimum ARIMA (p,d,q) specification, chosen according to the minimal AIC (Akaike Information Criterion) and BIC (Bayesian Information Criterion) values (Burnham & Anderson, 2004). The adequacy of the chosen specification is then validated by residual analysis, confirming that residuals exhibit a mean close to zero, constant variance, and absence of autocorrelation. Upon establishing the right setup, predictions are produced within confidence intervals.

The ARIMA framework consists of three main components: autoregressive (AR), integrated (I), and moving average (MA). The autoregressive component expresses the dependence of a time series on its past observations, where the AR(p) form includes a linear combination of the p lagged values. The integrated part indicates the number of differences required to achieve stationarity, typically one for trend-dominated series. The moving average component incorporates the effects of past shocks on the error terms.

The AR equation is presented in formula 1, and the variable formation equation in formula 2 (Shumway et al., 2000).

$$y_t = \left(\alpha + \sum_{i=1}^p \varphi_i * y_{t-i} + \varepsilon_t \right) \quad \text{and} \quad (1)$$

$$\alpha = \mu(1 - \varphi_1 - \varphi_2 \dots - \varphi_p) \quad (2)$$

y_t = t time series observation values,

α = constant,

φ_i = The parameters of the y_{t-i} during the delay period,

ε_t = t-time white noise (represented as WN (0, σ^2))

The MA equation is as shown in formula 3.

$$y_t = \left(\alpha + \sum_{i=1}^q \theta_i * \varepsilon_{t-i} \right) \quad (3)$$

θ_i = The parameters of ε_{t-i} at lag i and,

The structure of the ARMA component is outlined in equation 4.

$$y_t = \left(\alpha + \sum_{i=1}^p \varphi_i * y_{t-i} + \varepsilon_t \right) + \left(\sum_{i=1}^q \theta_i * \varepsilon_{t-i} \right) \quad (4)$$

When the ARMA is opened, formula 5 is obtained (Mishra et al., 2021).

$$y_t = \alpha + \varphi_1 y_{t-1} + \varphi_2 y_{t-2} + \dots + \varphi_p y_{t-p} + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \dots + \theta_q \varepsilon_{t-q} \quad (5)$$

p= Maximum lag length for AR,

q= Maximum lag length for MA,

By applying a differencing operation to the 5th equation, the ARIMA structure presented in the 6th equation was obtained.

$$y_t = \left(\alpha + \sum_{i=1}^p \varphi_i * y_{t-i} + \varepsilon_t \right) * (1 - B)^d + \left(\sum_{i=1}^q \theta_i * \varepsilon_{t-i} \right) \quad (6)$$

The ARIMA structure is expressed in an alternative form in equation 7th (SAS, 2025).

$$\varphi(B)(1 - B)^d * y_t = \theta(B) * \varepsilon_t \quad (7)$$

$(1 - B)^d$ = denotes the differencing operator of order d.

Adapting equation 6 into 7 resulted in the ARIMA structure shown in 8th (Kadilar, 2009).

$$(1 - a_1 B^1 - a_2 B^2 \dots - a_p B^p) * (1 - B)^d y_t = (1 - \theta_1 B^1 - \theta_2 B^2 - \dots - \theta_q B^q) \varepsilon_t \quad (8)$$

$(1 - B)^d y_t$ expression d=1 for $y_t = y_{t-1}$ can be written as. In addition d=2 for $B^2 y_t = y_{t-2}$ or $B^1 y_{t-1} = y_{t-2}$ can be written. a_1 , a_2 , and a_3 denote the coefficients of the autoregressive (AR) terms with order (p = 3), and θ_1 and θ_2 denote the coefficients of the moving average (MA) terms with order (q = 2) (Uzundumlu et al., 2023).

When p=3, d=1, and q=2, the structure is ARIMA(3,1,2), i.e.

$$(1 - a_1 B^1 - a_2 B^2 - a_3 B^3) * (1 - B)^1 y_t = (1 - \theta_1 B - \theta_2 B^2) \varepsilon_t$$

RESULTS AND DISCUSSION

Table 1 presents the competitive conditions of global sunflower production by year, using the HHI (Herfindahl-Hirschman Index), HHI^{-1} (the inverse of the HHI), and CR (Concentration Ratios – CR₁ to CR₅) criteria. These indicators reveal the degree of production concentration and the level of competition. As shown in Table 1, the high HHI value of 0.47 and the low HHI^{-1} value of 2.13 during the 1961–1970 period indicate that production was concentrated in a few countries and competition was low. During the 1991–2000 period, the decline in HHI to

0.09 and the increase in HHI^{-1} to 10 indicate that production spread across more countries and competition increased. However, the rise in HHI to 0.16–0.17 and the fall in HHI^{-1} to 6.03 during the 2021–2028 period suggest that competition has somewhat decreased, with production beginning to concentrate again in certain countries.

Table 1. Competitive condition of global sunflower production during the years.

Years	HHI	HHI^{-1}	CR ₁	CR ₂	CR ₃	CR ₄	CR ₅	Major Producing Countries	Number
1961-1970	0.47	2.13	66.42	76.13	83.27	87.91	90.84	USSR, Argentina, Romania, Bulgaria, YSFC	39-42
1971-1980	0.27	3.70	47.70	57.17	65.91	72.60	77.10	USSR, Argentina, USA, Romania, Türkiye	45-47
1981-1990	0.15	6.79	29.68	44.34	52.75	60.24	67.55	USSR, Argentina, France, USA, China	47-55
1991-2000	0.09	10.00	20.72	32.76	41.64	49.97	57.05	Argentina, Russia, Ukraine, France, USA	55-71
2001-2010	0.11	9.05	18.75	34.93	46.77	52.90	58.20	Russia, Ukraine, Argentina, China, France	69-71
2011-2020	0.14	6.90	25.78	49.21	56.23	61.87	66.90	Ukraine, Russia, Argentina, China, Romania	71-74
2021-2023	0.17	6.03	29.66	53.62	60.91	65.15	69.27	Russia, Ukraine, Argentina, Türkiye, Romania	74
2024-2028	0.15	6.76	30.52	48.62	56.12	60.84	64.59	Russia, Ukraine, Argentina, China, Türkiye	74-76

Between 1961 and 2023, worldwide sunflower seed production transitioned from a highly concentrated market to a moderately concentrated one. In the 1960s, the Herfindahl-Hirschman Index (HHI) was 0.47, with the USSR, Argentina, Romania, Bulgaria, and YSFC predominating, and the top five nations accounting for about 90% of global production. Between 1971 and 2000, market concentration decreased consistently (HHI decreasing to 0.09) as Argentina, Russia, Ukraine, France, and the USA became prominent producers, with the top five accounting for 57–77% of world output. From 2001 to 2023, concentration had a modest rise (HHI around 0.11–0.17), mostly driven by Ukraine, Russia, Argentina, China, Romania, and Türkiye. From 2024 to 2028, the market is anticipated to maintain a moderate level of concentration, reflected by an HHI of 0.15. Russia (30.5%), Ukraine (18.1%), Argentina (7.5%), China (4.7%), and Türkiye (3.8%) together represent around 64.6% of worldwide production, indicating that a small number of nations persist in dominating output. This concentration shows that there is limited competition and highlights how powerful companies can influence global prices and production methods, which is typical of an oligopolistic market structure. Despite minor swings over the decades, the worldwide sunflower seed market is mostly influenced by a limited number of major producers, notably Russia and Ukraine, whose combined share nears fifty percent of total world production.

Projection of sunflower production in the leading producing countries

The ADF test findings and the Excel graphs indicate that the p-values for all nations are inconsequential at the 5% significance level. Consequently, the data were rendered stationary by calculating the initial difference. Table 2 presents the projected figures for all nations for the years 2024–2028.

Table 2. ARIMA Forecast Results.

Variables	ARIMA (p, d, q)	Forecast values (Mt)				
		2024	2025	2026	2027	2028
World	5,1,1	60.83	59.07	62.12	61.25	63.66
Rusia	0,1,1	17.80	18.27	18.74	19.21	19.68
Ukraine	1,1,3	12.31	9.65	11.37	10.42	11.80
Argentina	2,1,1	4.59	4.37	4.58	4.73	4.75
China	1,1,1	2.93	2.90	2.88	2.88	2.90
France	0,1,3	2.25	2.22	2.33	2.36	2.39
Türkiye	0,1,0	2.23	2.27	2.30	2.33	2.37
Romania	1,1,3	2.06	2.16	2.31	2.29	2.34
Bulgaria	0,1,1	1.95	1.98	2.01	2.04	2.06

The forecasted values obtained from ARIMA are reported in Table 2. Predictions are provided for a maximum period of five years, as extending the forecast horizon beyond this may compromise accuracy and reliability (Padhan, 2012). More complex structures (high p and q values) are generally selected for more variable or intricate series. The specifications for the world, Russia, Romania, and Türkiye, for example, are quite complex, suggesting that their data exhibit more detailed dynamics. Conversely, simpler approaches have been favoured for countries such as China (1,1,1) and France (0,1,3).

Table 3. Ranking Criterion Tests Based on p and q Values (AIC, BIC, DW, and MFE) for the World

p,d,q	BIC	DW	AIC	2015-2023 MFE	p	WNP	RN	ACR
0,1,3	1950.82	2.21	1948.72	-1.94	+	-+	+	-
0,1,4	1955.15	2.24	1953.05	-2.83	-	-+	+	-
3,1,3	1950.92	2.21	1948.83	-1.91	-	-+	+	-
5,1,0	1951.10	2.33	1949.00	-1.24	+	-+	+	-
5,1,4	1950.74	2.30	1948.64	-1.85	+	-+	+	-
5,1,1	1946.01	1.97	1943.91	-2.63	+	+	+	+

The results in Table 3 show that the ARIMA (5,1,1) structure outperforms other specifications for global data. It achieves the lowest AIC (1943.91) and BIC (1946.01) values, indicating optimal fit, while the Durbin-Watson (DW) statistic (1.97) suggests no autocorrelation. The Mean Forecast Error (MFE) (-2.63) reflects minimal bias. Diagnostic tests confirm statistical significance (p value), absence of white noise issues (WNP), normally distributed residuals (RN), and no autocorrelation (ACR). Overall, based on information criteria

and diagnostics, ARIMA (5,1,1) is considered the most reliable and suitable model for forecasting the World series from 2015 to 2023.

Figure 1 illustrates that worldwide sunflower output has consistently escalated over the last sixty years, increasing about tenfold since the 1960s. This rise is mostly attributable to the proliferation of sunflower farming throughout additional nations and areas, along with technical advancements such as hybrid seeds and mechanization. Production increased in the 2000s, surpassing 50 Mt post-2010. Soare and Chiurciu (2018) indicated that the most extensive sunflower cultivation area was recorded in 2016, reflecting a 4.52% increase relative to 2012, the year with the minimal cultivation area. By the early 2020s, worldwide output stabilized at 45 and 55 million tons, indicating the increasing importance of sunflowers in agricultural and food systems. The primary factors contributing to this favorable trend include increasing worldwide demand for oilseeds, the development of additional cultivation areas, and enhancements in production technology. Notwithstanding variations from 2000 to 2022, the general trend of sunflower output is higher. According to the OECD/FAO (2018), the production of oil-producing crops excluding soybeans is expected to increase over the next decade, but at a slower rate (3.1% versus 1.6%).

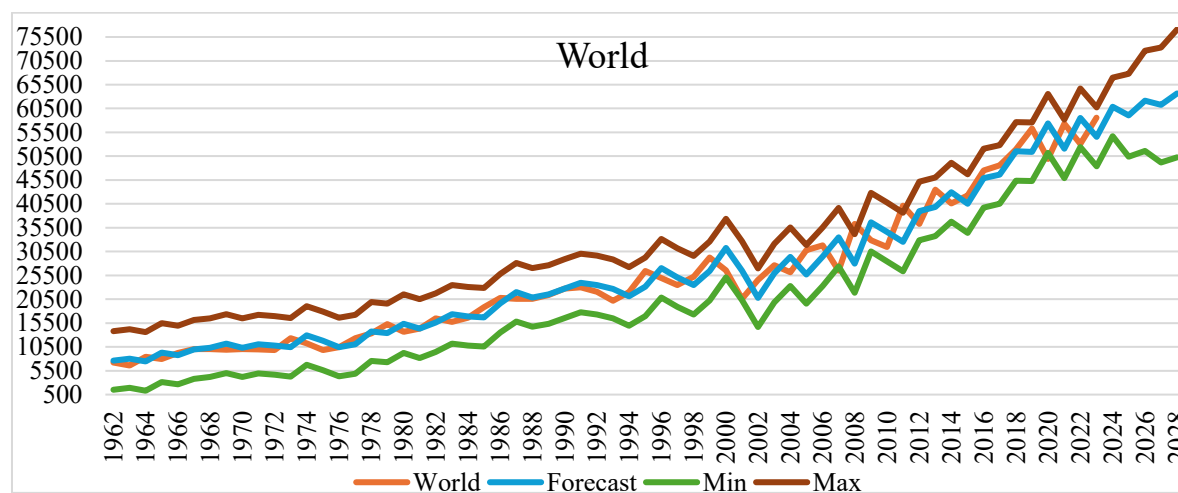


Figure 1. World sunflower production (1961-2023 actual and 2024-2028 estimates) (1000 tonnes).

The Box–Jenkins methodology forecasts that worldwide sunflower production will approximate 63.7 million tons by 2028, with an average predicted output of 61.4 million tons during the period from 2024 to 2028. The model forecasts around 60.8 Mt for 2024, with the lowest and maximum estimates of 55 Mt and 67 Mt, respectively. The USDA (2024a) projects output at 52.4 million tons by 2025. The USDA's prediction for the June 2025/26 marketing

year is 56.3 Mt, representing a rebound of 3.9 Mt from the prior year and approaching record levels (USDA, 2025a). Gökler (2024) indicates a reduction to 50.7 Mt in 2022–2023, signifying an 11.6% decrease relative to the previous year. Our analysis projects 2025 output at 59.1 million tons. The expanding uncertainty range around ARIMA forecasts highlights the impact of climate variability, economic changes, and possible supply disruptions on output. The estimates suggest a consistent increase in sunflower output, notwithstanding temporary variations and uncertainty.

Table 4. Diagnostic Evaluation of Russia Model Specifications (2015–2023) Using AIC, BIC, DW, and MFE Metrics in Relation to p and q Values

p,d,q	BIC	DW	AIC	2015-2023 MFE	p	WNP	RN	ACR
1,1,0	899.72	2.02	898.35	-4.49	+	+	-+	+
0,1,1	899.59	1.97	898.22	-5.45	+	+	+	+
1,1,1	899.36	2.16	897.99	6.57	-	+	-+	+
2,1,1	899.48	1.99	898.11	-5.02	-	+	+	+
4,1,0	899.06	1.97	897.69	5.31	-	-+	+	+

Table 4 reveals that the ARIMA (0,1,1) approach has enhanced performance for Russia from 2015 to 2023, relative to other setups. It attains outstanding outcomes across several metrics, including DW, MFE, and diagnostic evaluations, such as p-value, WNP, RN, and ACR. Although AIC and BIC offer hints at model fit and parsimony, their comparable values diminish their use in discerning the optimal choice. Consequently, more focus was directed towards the prediction accuracy, residual independence, and general consistency, resulting in the selection of ARIMA (0,1,1) as the optimal method for Russia's time-series production data.

Russia is one of the world's largest sunflower producers due to its vast arable land and favourable climatic conditions. Figure 2 shows that Russia's sunflower production has been on a steady upward trend since 1992.

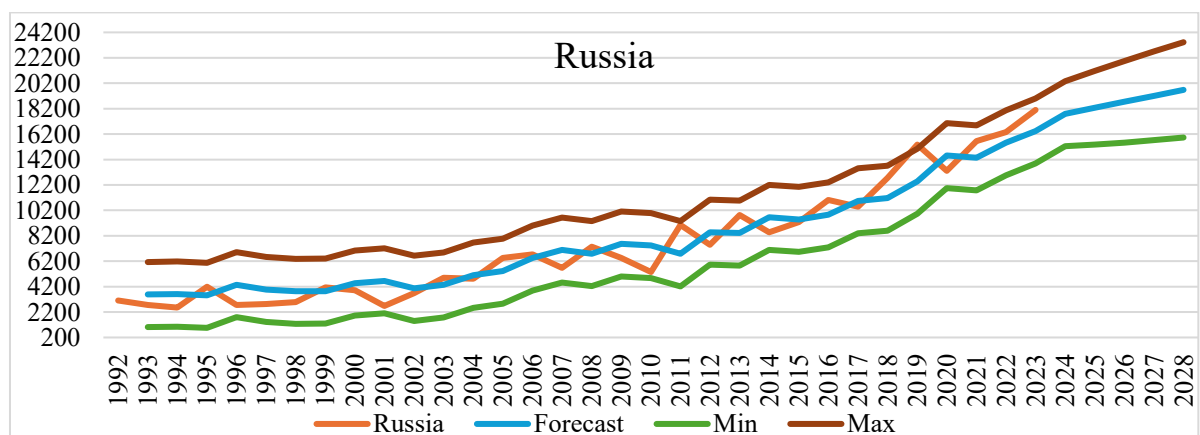


Figure 2. Russia sunflower production (1961-2023 actual and 2024- 2028 estimates) (1000 tonnes).

Russia's sunflower output has shown a substantial increase, especially after 2010, indicating enhancements in production capacity. From 1992 to 2003, production was very low and variable, averaging around 5–6 Mt. Output increased steadily between 2004 and 2022, reaching an estimated 18.2–19.2 Mt by that year. The ARIMA framework projects sustained increase, estimating 17.8 Mt for 2024, with lower and upper bounds of 15.2 Mt and 20.4 Mt, respectively, and around 19.7 Mt by 2028. The USDA estimates 2024 output at 16.9 million tons, while it projects a record 17.5 million tons for the 2025 year, representing a 4% increase from the prior year and an 11% rise over the five-year average. The increasing peak production values, particularly post-2020, signify substantial development potential for Russia's sunflower industry. Historical patterns and forecasts indicate that Russia will sustain elevated production levels in the following years, reinforcing its status as a prominent global sunflower producer.

Table 5. Comparative Ranking of Time Series Approach for Ukrania (2015–2023) Based on p and q Values Using AIC, BIC, DW, and MFE Criteria

p,d,q	BIC	DW	AIC	2015-2023 MFE	p	WNP	RN	ACR
2,1,2	899.88	2.25	898.51	-4.82	-	-+	+	-+
1,1,3	829.80	1.99	828.39	4.04	+	+	+	+
2,1,0	897.64	2.43	896.27	2.77	-	-	+	-
3,1,0	894.17	2.02	892.80	1.84	-	-	+	-
4,1,0	899.60	1.65	898.23	-2.18	+	+	+	+
0,1,2	900.06	2.29	898.70	2.17	+	-	+	-
5,1,0	896.72	1.95	895.35	4.38	-	+	+	+

Table 5 compares ARIMA (p,d,q) for Ukraine from 2015 to 2023, using AIC, BIC, DW, and MFE metrics. The ARIMA (1,1,3) exhibits the optimal fit, shown by the lowest AIC and BIC values, a DW statistic approaching 2, and a consistently positive MFE, indicating robust performance prior to 2021. The coefficients are statistically sound and unaffected by the structural disruptions resulting from the 2021 Russia–Ukraine war. Consequently, the model yields dependable outcomes for the pre-war era, enabling the research to concentrate mostly on descriptive evaluation and predictive accuracy grounded on consistent historical data.

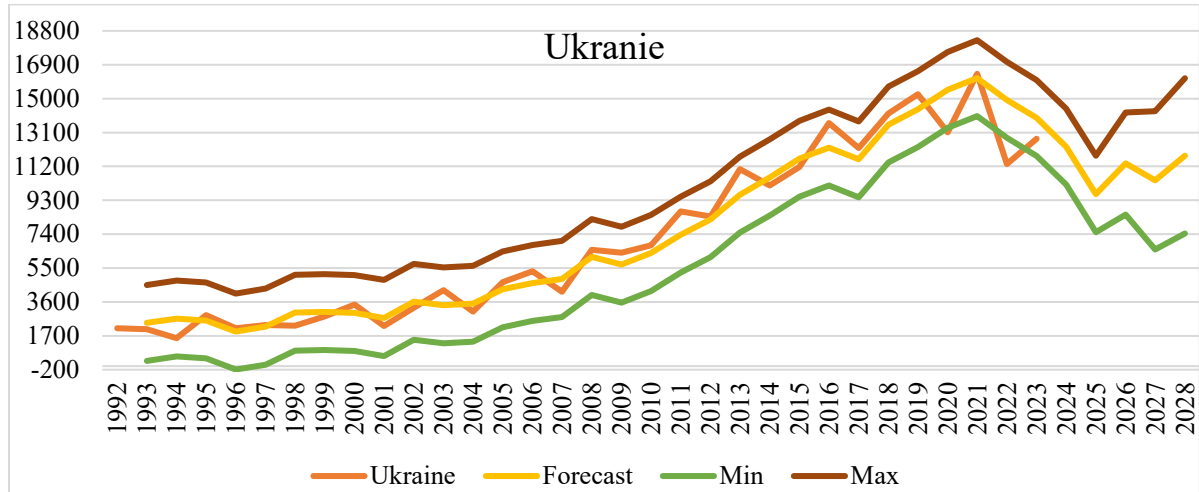


Figure 3. Ukraine sunflower production (1961-2023 actual and 2024- 2028 estimates) (1000 tonnes).

Ukraine is one of the leading producers and exporters of sunflowers globally, significantly influencing international food markets. Sunflower production occupies around 62% of Ukraine's technical cropland (Petrenko et al., 2023). Production has increased significantly since the mid-2000s, positioning Ukraine as a worldwide leader alongside Russia. From 2000 to 2022, sunflower production rose 4.7-fold, exceeding 17 million tons in 2021 (Sydiakina & Podriezov, 2024). High-yield methodologies, favorable soil and climatic conditions, and sophisticated agricultural technology propel this expansion. Ukraine has made substantial contributions to sunflower production, representing 26–39% of European output and 13–29% of worldwide output. Production reached its zenith in 2019 and 2021 but is anticipated to settle at about 11.8 Mt by 2028, with projections varying between 7.4 and 16.1 Mt. USDA data estimates 13 Mt for 2024 and 12.7 Mt for the 2025/26 marketing year; however, this analysis forecasts 12.3 Mt for 2024 and 9.7 Mt for 2025, suggesting possible short-term reductions prior to long-term stability.

Table 6. Model Ranking for Türkiye (2015–2023) Based on p and q Parameters Using AIC, BIC, DW, and MFE

p,d,q	BIC	DW	AIC	2015-2023 MFE	p	WNP	RN	ACR
0,1,0	1582.82	1.99	1580.73	-1.15	+	+	+	+
3,1,2	1583.00	1.95	1580.91	-1.49	-	+	+	+
4,1,2	1581.41	1.95	1579.31	-1.23	-	+	+	+

Table 6 combines the ARIMA(p,d,q) framework for Türkiye from 2015 to 2023 using AIC, BIC, DW, and MFE metrics. The ARIMA (0,1,0) exhibited optimal performance, as shown by AIC and BIC values of 1580.73 and 1582.82, a DW statistic of 1.99, and a minimum mean forecast error of -1.15, signifying little autocorrelation and robust prediction accuracy. Higher-

order models, such as ARIMA(3,1,2) and ARIMA(4,1,2), provide only marginal enhancements, while somewhat elevating the residual autocorrelation. In summary, ARIMA(0,1,0) offers a straightforward, steady, and dependable depiction of Türkiye's sunflower production patterns.

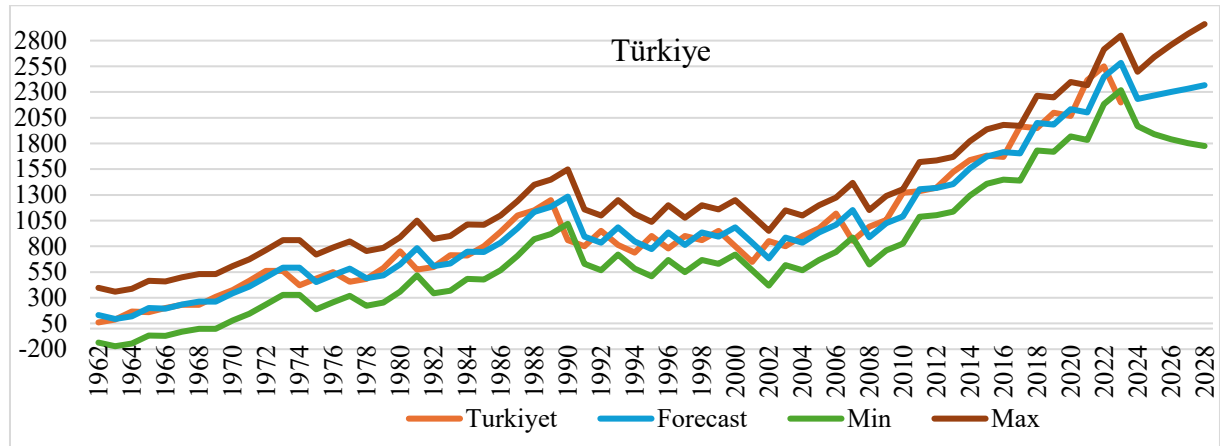


Figure 4. Türkiye sunflower production (1961-2023 actual and 2024- 2028 estimates) (1000 tonnes).

Figure 4 demonstrates that Türkiye's sunflower output remained relatively stable at low levels throughout the 1960s and 1970s, thereafter seeing a significant growth trend beginning in the mid-1980s. The yearly output figures, measured in thousands tons, rose from around 750 thousand tons in 1980 to above 2.5 million tons by 2022, indicating substantial and consistent growth with few variations during the period. Türkiye's sunflower output is anticipated to progressively rise, reaching roughly 2.43 million tons in 2024 and continuously increasing to over 2.23 million tons by 2028.

Table 7. Comparative Ranking of Time Series Models for Argentina (2015–2023) Based on p and q Values Using AIC, BIC, DW, and MFE Criteria.

p,d,q	BIC	DW	AIC	2015-2023 MFE	p	WNP	RN	ACR
1,1,1	1800.07	1.97	1797.97	-4.82	-	+	+	+
2,1,0	1797.01	2.02	1794.91	-4.94	+	+	+	+
2,1,1	1796.75	1.99	1794.65	-4.79	+	+	+	+
3,1,1	1801.78	1.94	1799.68	-5.50	-	-+	+	+
0,1,2	1797.90	2.03	1795.81	-5.09	+	+	+	+
1,1,2	1797.57	1.99	1795.48	-4.94	+	+	+	+
5,1,2	1797.91	2.03	1795.81	-5.10	-	+	+	+

Table 7 presents the ARIMA(p,d,q) models for Argentina from 2015 to 2023 evaluated according to the AIC, BIC, DW, and MFE criteria. The ARIMA(2,1,1) model had superior performance, as shown by the lowest AIC (1794.91) and BIC (1796.75) values, a DW statistic of approximately 2 (1.99), and a small prediction bias (MFE = -4.79). Diagnostic tests validated

its statistical soundness, lack of white noise, and appropriately distributed residuals, confirming it as the most dependable and effective model for predicting sunflower output in Argentina.

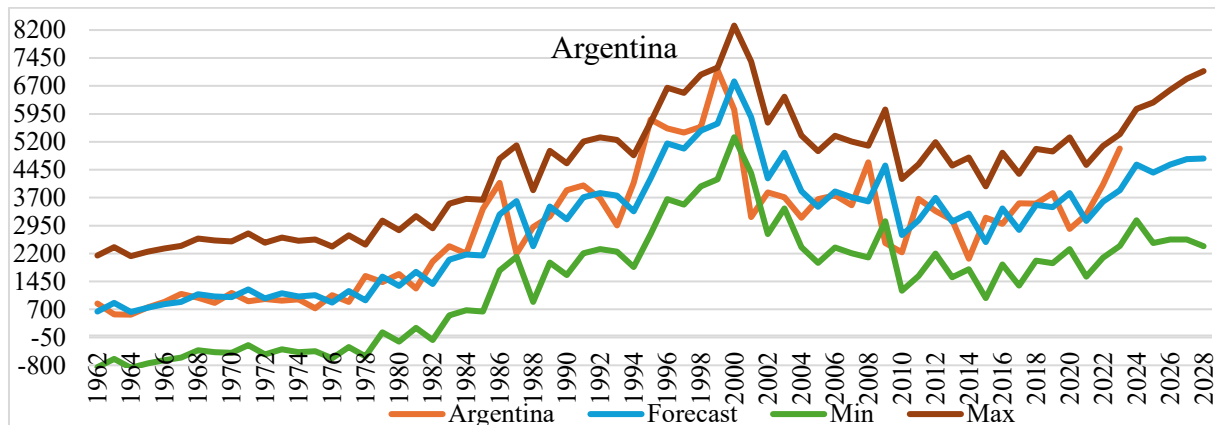


Figure 5. Argentina sunflower production (1961-2023 actual and 2024- 2028 estimates) (1000 tonnes).

Argentina's sunflower production has shown notable historical variation, as presented in the Figure 5 covering 1961–2023 and forecasts for 2024–2028. Production peaked around 1.65 Mt in 1980 but has since fluctuated, particularly declining after 2010. Since the 2000s, output levels have remained below previous decades, reflecting irregular production patterns. According to the **Box–Jenkins methodology** production is expected to reach about 5.0 Mt in 2024, within a range of 3.3–6.4 Mt. **The USDA similarly projects 5.1 Mt for 2024 and 4.3 Mt for the 2025 years, while this study estimates 4.6 Mt for 2025, indicating moderate short-term stability with limited growth prospects.**

Table 8. Diagnostic Evaluation of Romania ARIMA Framework Specifications (2015–2023) Using AIC, BIC, DW, and MFE Metrics in Relation to p and q Values

p,d,q	BIC	DW	AIC	2015-2023 MFE	p	WNP	RN	ACR
1,1,0	1696.52	1.97	1694.42	6.61	+	+	-+	+
0,1,1	1697.12	1.91	1695.02	5.13	+	+	-+	+
1,1,1	1696.56	1.96	1694.46	6.57	-	+	-+	+
4,1,3	1693.07	2.03	1690.98	0.13	-	-+	+	-+
1,1,3	1691.97	1.98	1689.87	5.20	+	+	+	+

Table 8 presents a diagnostic assessment of several ARIMA specifications for Romania from 2015 to 2023, using AIC, BIC, DW, and MFE measures. Among the models, ARIMA(1,1,3) was deemed the most appropriate, exhibiting the lowest AIC (1689.87) and a competitive BIC (1691.97), signifying an effective equilibrium between fit and simplicity. The DW value (1.98) indicates little residual autocorrelation, but the MFE (5.20) signifies an acceptable prediction bias. Diagnostic tests validate the model as statistically accurate for projecting Romania's

sunflower output, confirming the presence of well-behaved residuals without white noise concerns.

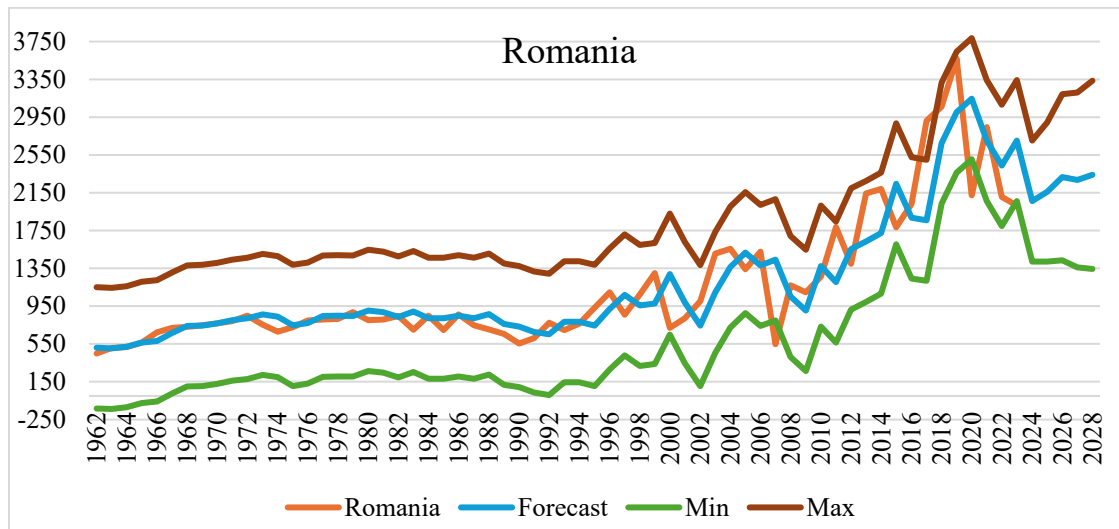


Figure 6. Romania sunflower production (1961-2023 actual and 2024- 2028 estimates) (1000 tonnes).

Romania ranks first in the sunflower cultivation area inside the EU-28 (Popescu, 2020) and has been a significant contributor to worldwide sunflower output since 2000. Figure 6 illustrates Romania's sunflower production from 1961 to 2023, including predictions for 2024–2028 in thousand tons. Production was comparatively low and consistent during the 1960s and 1970s, but has typically increased since 1990, reaching a high of around 3.9 Mt in 2018, attributed to EU CAP subsidies, technical advancements, and market integration (Harvey, 2015). Dincă et al. (2024) observed a significant reduction in sunflower farming in Brăila in 2021, decreasing from 81,454 to 58,946 hectares, with stability thereafter. Since 2013, EU initiatives have prompted significant producers such as Romania to augment oil and protein content, optimize value chains, adopt integrated weed control, and address pests and illnesses (Surca, 2018). ARIMA projections indicate that output will approximate 2.7 Mt by 2028. Eurostat projects 1.49 Mt for 2024, but ARIMA anticipates 2.1 Mt, with a range of 1.9 to 2.8 Mt.

Table 9. Diagnostic Comparison of Model Specifications for China (2015–2023) According to p and q Values Using AIC, BIC, DW, and MFE Criteria.

p,d,q	BIC	DW	AIC	2015-2023 MFE	p	WNP	RN	ACR
5,1,0	1666.03	2.00	1663.93	1.34	+	+	-+	-+
2,1,0	1668.12	1.88	1666.03	2.57	-	-+	-+	-+
1,1,1	1663.32	1.92	1661.23	1.20	+	+	+	+
0,1,5	1664.72	1.99	1662.63	1.48	+	-+	+	-+

Table 9 compares the ARIMA specifications for China (2015–2023) using the AIC, BIC, DW, and MFE. ARIMA(1,1,1) showed the lowest AIC (1661.23), competitive BIC (1663.32), DW

1.92, and MFE 1.20, indicating minimal autocorrelation and forecast bias. Diagnostics showed that the residuals were well-behaved and statistically significant, with only minor WNP problems. Other models, such as ARIMA (5,1,0), (2,1,0), and (0,1,5), have higher AIC/BIC values or minor residual irregularities. Overall, ARIMA(1,1,1) was the most reliable specification for China's sunflower production during this period.

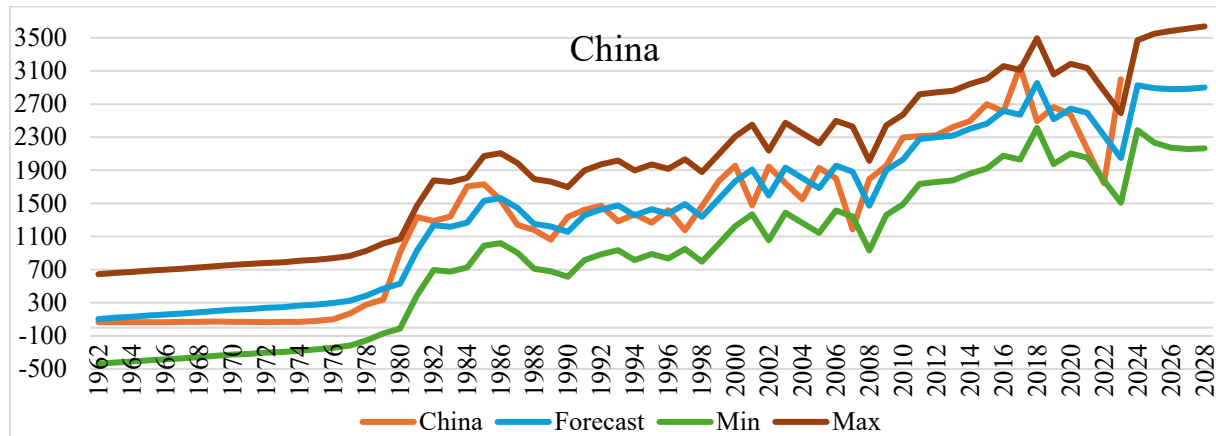


Figure 7. China sunflower (1961-2023 actual and 2024- 2028 estimates) (1000 tonnes).

Figure 7 illustrates China's sunflower output from 1961 to 2023, together with forecasts for 2024–2028 (thousands of tons). China, with approximately 590,000 hectares dedicated to sunflower cultivation (95% for consumable purposes), is the sixth largest producer worldwide (Guo et al., 2021; Feng, 2022). Production has consistently risen since the early 1980s, peaking at around 2.5 Mt in 2018, and normally oscillating between 1.5 and 2.8 Mt. This expansion signifies domestic consumption methods, enhanced yields, and the use of genetic and agricultural innovations (Feng et al., 2022). ARIMA estimates project output to reach around 2.9 Mt by 2028, with minimum and maximum projections of 2.4 Mt and 3.5 Mt, respectively. The USDA reports 1.75 million tons by 2024; however, this study's forecasts 2.9 million tons, indicating significant growth potential. China's sunflower industry exhibits steady growth and enhanced productivity bolstered by technical innovations and local demand strategies.

Table 10. Comparative Assessment of Time Series Model Performance for Bulgaria (2015–2023) According to p and q Specifications Using AIC, BIC, DW, and MFE Metrics.

p,d,q	BIC	DW	AIC	2015-2023 MFE	p	WNP	RN	ACR
5,1,0	1620.75	2.12	1618.66	3.58	-	-	+	-
0,1,1	1620.33	1.98	1618.24	2.71	+	+	+	+
1,1,1	1620.20	1.98	1618.10	2.86	-	+	+	+
2,1,1	1620.31	1.98	1618.22	2.65	-	-+	+	+
5,1,2	1620.96	2.13	1618.87	-5.09	-	-	+	-+

Table 10 presents a comparative assessment of time series model performance for Bulgaria from 2015 to 2023, evaluating different p and q specifications using AIC, BIC, DW, and MFE

metrics. Among the models, ARIMA(0,1,1) exhibits the best balanced performance, characterized by low AIC (1618.24) and BIC (1620.33) values, a DW statistic around 2 (1.98) indicating minimum autocorrelation, and a modest MFE (2.71), implying acceptable prediction bias. The diagnostics suggest that ARIMA(0,1,1) is the most dependable model for predicting Bulgaria's sunflower output throughout this timeframe.

Bulgaria is a major sunflower producer thanks to its geographical location in the Black Sea region and favourable climatic conditions. Since joining the EU, the country has undergone significant transformations in the agricultural sector, which has also been reflected in sunflower production.

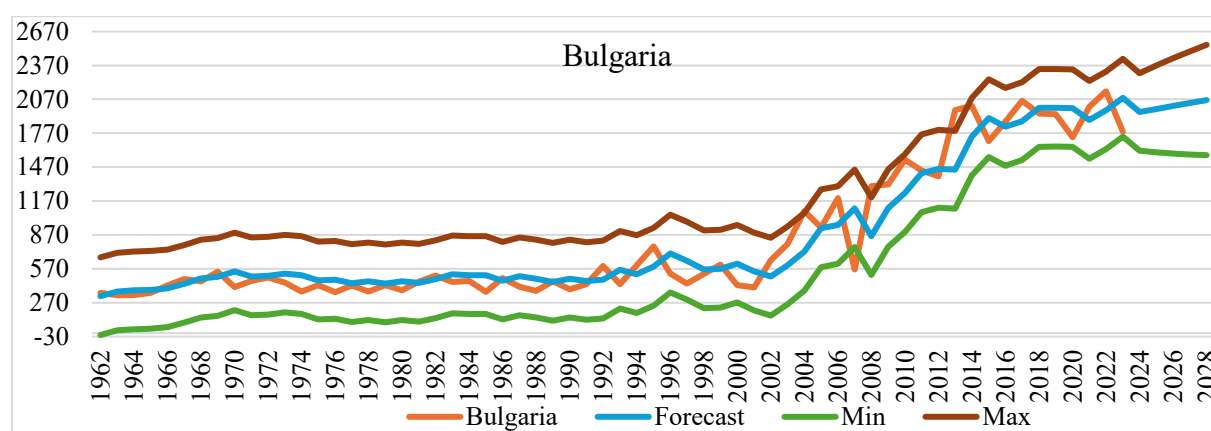


Figure 8. Bulgaria sunflower production (1961-2023 actual and 2024- 2028 estimates) (1000 tonnes).

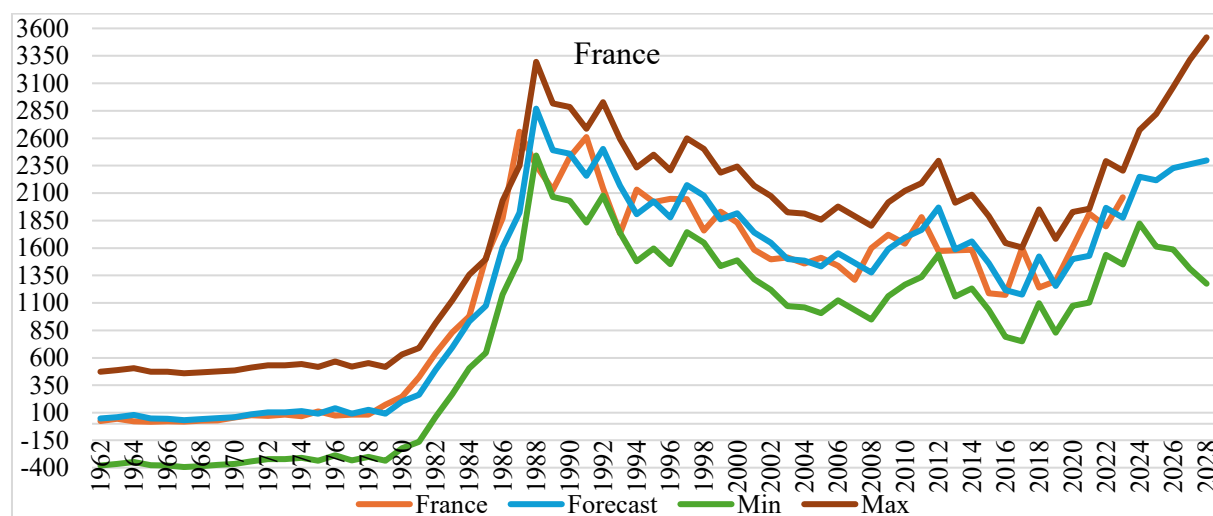
Bulgaria and Romania are the leading producers of sunflower seeds within the EU (Hristov et al., 2019). Until the end of the 1990s, production typically ranged from 500,000 to 800,000 t. Following a period of rapid growth after 2010, production reached 1.5–2.5 Mt, establishing Bulgaria as one of Europe's leading sunflower producers. According to the study results, production is expected to reach approximately 2.06 Mt by 2028. The minimum and maximum production quantities are estimated to be 1.6 and 2.6 Mt, respectively. Eurostat data predicts that Bulgaria's sunflower production will reach approximately 1.64 Mt in 2024. Our study estimates Bulgaria's sunflower production volume at 1.9 Mt. The minimum and maximum estimates are 1.6 and 2.3 Mt, respectively. However, a report by the USDA (2024b) states that production is expected to decline by 4% compared to last year and by 21% compared to the 2022 year, reaching 1.7 Mt in the 2024 year.

Table 11. Model Specifications for France (2015–2023) for Diagnostic Evaluation Connecting DW, AIC, BIC, and MFE Measures to p and q Values

p,d,q	BIC	DW	AIC	2015-2023 MFE	p	WNP	RN	ACR
3,1,0	1650.64	1.98	1648.54	-0.34	+	+	+	+
1,1,1	1653.17	2.00	1651.08	0.86	-	+	-+	+
0,1,3	1648.58	1.99	1646.49	-0.66	+	+	+	+
5,1,4	1652.21	2.01	1650.11	0.28	-	-+	+	-

Table 11 illustrates the parameters for France from 2015 to 2023, evaluated according to AIC, BIC, DW, and MFE criteria. Among the evaluated models, ARIMA(0,1,3) has superior performance, shown by the lowest AIC (1646.49) and BIC (1648.58) values, a DW statistic around 2 (1.99) indicating little autocorrelation, and a slight negative MFE (-0.66) implying insignificant prediction bias. The findings validate ARIMA(0,1,3) as the most appropriate and statistically sound model for predicting sunflower output in France during this timeframe.

Figure 9 reveals that France's sunflower production has grown rapidly since the 1980s. Production increased significantly between 1980 and 1990, exceeding 3.0 Mt. This increase is related to significant changes in the EU's support policies for the oilseed sector, such as incentives for biodiesel production, and a shift among farmers towards this product (Vear, 2016).

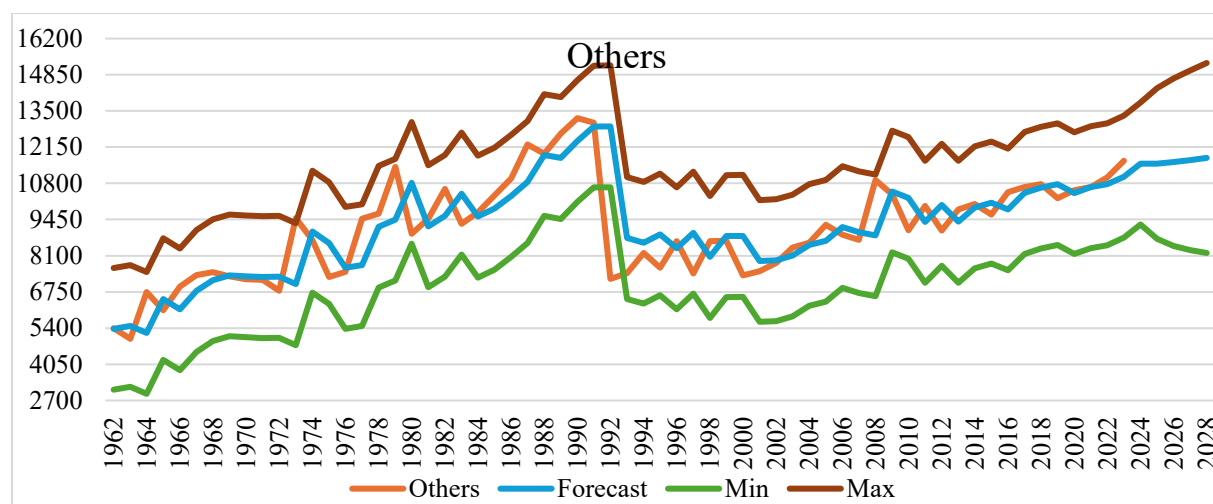
**Figure 9.** France sunflower production (1961-2023 actual and 2024- 2028 estimates) (1000 tonnes).

However, production has shown fluctuations since 1990, with periods of decline and stagnation evident since the early 2000s. Our forecasts indicate that output is anticipated to reach around 2.4 Mt by 2028. In 2024, output is projected to be about 2.2 Mt, with a potential range of 1.8 to 2.7 Mt. Eurostat projects sunflower output for 2024 to be 1.5 Mt.

Table 12. Diagnostic Comparison of Model Specifications (2015–2023) Based on p and q Values Using AIC, BIC, DW, and MFE Criteria

p,d,q	BIC	DW	AIC	2015-2023 MFE	p	WNP	RN	ACR
3,1,2	1848.77	2.01	1846.67	-0.78	-	+	-+	-+
0,1,0	1851.70	2.08	1849.61	-0.60	-	+	-+	-+
1,1,1	1848.67	2.00	1846.58	-0.92	+	+	+	+

Table 12 presents the diagnostic review of different model specifications for Others from 2015 to 2023. It connects AIC, BIC, DW, and MFE measures to different sets of p and q parameters. ARIMA(1,1,1) is the best option because it has the lowest AIC (1846.58) and BIC (1848.67) values, a DW statistic close to 2 (2.00), which means there is no residual autocorrelation, and an MFE of -0.92, which means there is little prediction bias. These results show that model is the best and most reliable statistical model for this series.

**Figure 10.** Others sunflower production (1961-2023 actual and 2024- 2028 estimates) (1000 tonnes).

The figure 10 illustrates that sunflower output in the "Other countries" category increased consistently from over 5.3 million tonnes in 1961 to over 11.6 million tonnes in 2023. Overall output has almost doubled since the 1980s, despite minor fluctuations in the 1990s and early 2000s. The increasing trend is attributable to consistent expansion outside the major producing nations. Based on the means from 2021 to 2023, Hungary produced the most sunflowers, with 1,671,353 tons, or 2.97% of the total output of the countries that were looked at. With 1,190,847 tonnes (2.11%), Kazakhstan came in second, and Tanzania came in third, with 1,146,667 tonnes (2.04%). The US came in fourth place with 1,054,070 tonnes, which is 1.87 percent of all sunflowers grown. Spain, Moldova, South Africa, and Serbia all created between 0.65 and 0.82 million tonnes, which is 1.15 to 1.45 percent of all sunflowers grown (FAOSTAT, 2025).

Overall, these numbers show that Hungary was the biggest producer and that other big makers didn't produce as much during the years 2021–2023. Forecasts indicate that production will rise to around 12 Mt by 2028, implying sustained growth in this heterogeneous group's share of the global sunflower supply.

ARIMA forecasts indicate that sunflower production will grow steadily in the coming period. Sunflower may play a key role in sustainable agricultural policies thanks to its low greenhouse gas emissions; models need to be revised to take climate and environmental factors into account in order to reduce future production uncertainties (Debaeke et al., 2017).

CONCLUSIONS

This study examined production trends in the world's major sunflower-producing countries and provided projections for future years. Sunflower is a strategically significant crop, contributing to vegetable oil, animal feed, and biofuel production, thereby playing a vital role in both food security and energy independence. The estimates demonstrate a close match with actual production figures, supporting the credibility of the projections. Global sunflower production is projected to increase steadily from 60.8 million tons in 2024 to 63.7 million tons in 2028, reflecting rising demand and technological improvements. Russia remains a key producer, rising from 17.8 Mt to 19.7 Mt, while Ukraine shows fluctuations, declining to 9.65 Mt in 2025 before reaching 11.8 Mt by 2028. Argentina and China maintain stable production around 4.6–4.8 Mt and 2.9 Mt, respectively, while European producers (France, Romania, and Bulgaria) and Türkiye exhibit gradual growth. These trends support economic development and environmental sustainability, aligning with several SDGs. However, the findings underscore the need to reduce structural vulnerabilities, enhance agricultural productivity, and strengthen risk management to ensure the long-term sustainability of sunflower production worldwide.

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