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Forecasting of prices of top vegetables in APMC of Meerut district, Uttar Pradesh

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Abstract

The most economically significant vegetable crops (TOP) are in India, serving as critical indicators of food price inflation despite constituting only a small share of the Consumer Price Index (CPI) basket. Price forecasting of these crops is essential for farmers, traders and policy makers to make informed marketing and procurement decisions. The present study forecasts monthly prices of tomato, onion and potato at three Agricultural Produce Market Committees (APMCs) Meerut, Mawana and Sardhana in Meerut district, Uttar Pradesh, using monthly secondary data from January 2014 to December 2024. Missing values in the price series were imputed using the Kalman smoothing technique. The Box-Jenkins ARIMA Research methodology was applied, involving Augmented Dickey Fuller (ADF) stationarity testing, ACF-PACF based model identification and Akaike Information Criterion (AIC) based model selection. ARIMA (1,1,3) was identified as the best fitting model for six of the nine crop-market combinations, while ARIMA (2,1,3) and ARIMA (1,1,1) were best suited for the remaining series. Model validation using a train-test split (2014-2022 training; 2023-2024 testing) yielded Mean Absolute Percentage Error (MAPE) values ranging from 26.02 per cent to 45.75 per cent for seven of the nine series, indicating reasonable forecast accuracy. Onion price series at Mawana and Sardhana APMCs recorded markedly higher overall MAPE (163.12% and 76.02% respectively) due to extreme price crash episodes; a segmented MAPE analysis confirmed that excluding these shock months improved accuracy to 30.76 per cent and 26.36 per cent respectively. Twelve month ahead forecasts (January-December 2025) indicate a general mean reverting trend in vegetable prices across all three markets. The findings underscore both the utility and the limitations of univariate ARIMA models for forecasting highly volatile perishable commodity prices.

Keywords: Price forecasting, ARIMA, Kalman smoothing, APMC, vegetable prices, Meerut

1. Introduction

India is the world's second largest producer of vegetables, with tomato, onion and potato (TOP vegetables) occupying a position of extraordinary economic significance among the country's diverse vegetable portfolio (Agricultural Statistics at a Glance, 2023). Despite constituting only 2.2 per cent of the Consumer Price Index basket, price movements of TOP vegetables have historically contributed disproportionately to headline inflation, at times accounting for as much as 17.2 per cent of total inflation during periods of acute price volatility (The Hindu Business Line, 2023). Recent data indicates that vegetables contributed 43.7 per cent to food inflation during FY 2025, with potatoes recording 53.3 per cent inflation, onions 37.4 per cent and tomatoes 18.8 per cent (Economic Times, 2025).

Due to the seasonal and perishable nature of vegetable production and year round consumption demand, large fluctuations are observed in market arrivals, which in turn contribute to significant price instability. This instability is further compounded by the presence of numerous marketing intermediaries, high price seasonality, short shelf life, and weather dependent supply variability (Shrestha and Pandey,

2010) ^[13]. Accurate price forecasting can help farmers determine the optimal time and market for selling their produce, assist traders in inventory planning, and support policy makers in designing timely market interventions such as the Government of India's Operation Greens scheme. Meerut district in western Uttar Pradesh, located approximately 70 kilometres from Delhi, is a strategically important agricultural hub supplying major consumption centres including the National Capital Region. Given the escalating frequency of price volatility episodes affecting TOP vegetables, understanding and forecasting price behaviour in a representative market like Meerut can provide valuable insights for evidence-based market interventions. Keeping this in view, the present study forecasts the monthly prices of tomato, onion and potato across three APMC markets in Meerut district Meerut, Mawana and Sardhana using the Autoregressive Integrated Moving Average (ARIMA) methodology.

2. Materials and Methods

2.1 Study Area and Data

The study was conducted using monthly secondary data on

prices and arrivals of tomato, onion and potato collected from three purposively selected APMCs in Meerut district Meerut, Mawana and Sardhana representing one large primary market and two secondary markets of contrasting trading volumes. The study period spanned January 2014 to December 2024, providing 132 monthly observations for each of the nine crop market combinations.

2.2 Missing Value Treatment

The collected data contained missing observations ranging from 0.8 per cent (potato, Meerut) to 18.2 per cent (tomato, Mawana) due to reporting gaps in APMC records. Missing values were imputed using the Kalman smoothing technique, a state-space based interpolation method that leverages the temporal structure of the series to estimate missing observations. The quality of imputation was validated using a hold-out approach in which 10 per cent of observed data points were randomly masked and recovered, with accuracy assessed using RMSE, MAE, MAPE and ACF correlation between the original and imputed series.

2.3 ARIMA Modelling

The Box-Jenkins ARIMA(p,d,q) methodology (Box and Jenkins, 1976) [4] was applied to each price series. The Augmented Dickey Fuller (ADF) test was first used to test for stationarity; non-stationary series were differenced once (d = 1) and retested. The Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) of the (differenced)

series were examined to identify candidate autoregressive (p) and moving average (q) orders. Multiple candidate models AR(1), AR(2), MA(1), ARMA(1,1), ARIMA(0,1,1), ARIMA(1,1,0), ARIMA(1,1,1), ARIMA(1,1,3) and ARIMA(2,1,3) were fitted for each series, and the model with the lowest Akaike Information Criterion (AIC) was selected as the best fit.

2.4 Model Validation and Forecasting

The selected model was validated using a train-test split: data from January 2014 to December 2022 (108 months) were used to fit the model, and fitted model was used to forecast 24 months ahead (January 2023 to December 2024), which were compared against actual observed prices using RMSE, MAE and MAPE. For series in which extreme price shock months (Absolute Percentage Error, APE > 100%) inflated the overall MAPE, a segmented MAPE analysis was additionally performed, distinguishing forecast accuracy under normal market conditions from accuracy during exceptional shock episodes. After validation, each best-fit model was refitted on the complete 2014-2024 dataset and used to generate 12-month-ahead forecasts (January-December 2025) along with 95 per cent confidence intervals. All analyses were performed using R-Studio software.

3. Results and Discussion

3.1 Best-Fit ARIMA Models

Table 1: Best-Fit ARIMA Models and Validation Accuracy for Price Series of Major Vegetables in Meerut District APMCs

Market	Crop	Best Model	AIC	Overall MAPE (%)	Normal-Period MAPE (%)
Mawana	Onion	ARIMA(1,1,3)	2034.43	163.12	30.76
	Potato	ARIMA(1,1,3)	1785.83	30.46	—
	Tomato	ARIMA(1,1,3)	2051.54	45.75	—
Meerut	Onion	ARIMA(2,1,3)	1959.37	28.16	—
	Potato	ARIMA(1,1,3)	1778.84	35.36	—
	Tomato	ARIMA(1,1,1)	2088.16	35.33	—
Sardhana	Onion	ARIMA(2,1,3)	1905.67	76.02	26.36
	Potato	ARIMA(2,1,3)	1714.84	26.02	—
	Tomato	ARIMA(1,1,3)	2022.16	33.97	—

ARIMA (1,1,3) emerged as the best fitting model for six of the nine price series, indicating a broadly consistent autoregressive-moving average price formation process across vegetable markets in the district. ARIMA (2,1,3), requiring an additional autoregressive term, was best suited for onion at Meerut and Sardhana and potato at Sardhana, suggesting a more complex price memory structure for onion at the larger and more interconnected markets. This is consistent with the finding of Ramesh *et al.* (2022) [12], who reported that optimal ARIMA model orders varied across locations for the same commodity, reflecting location-specific price formation mechanisms. Consistent with Mallikarjuna *et al.* (2019) [10] and Jalikatti *et al.* (2015) [8], the ARIMA framework proved suitable for capturing the autocorrelation structure of Indian vegetable price series.

3.2 Forecast Accuracy

Seven of the nine crop-market combinations recorded validation MAPE values between 26.02 per cent and 45.75 per cent, falling within the "reasonable forecast" range for agricultural commodity price series (Lewis, 1982). Potato

consistently recorded the lowest MAPE across all three markets, consistent with Meena *et al.* (2024) [11] and Dhakre and Bhattacharya (2014) [5], who attributed the greater forecast ability of potato prices to the moderating influence of cold storage infrastructure.

Onion price series at Mawana (overall MAPE = 163.12%) and Sardhana (overall MAPE = 76.02%) APMCs recorded substantially elevated validation errors, driven entirely by a small number of extreme price crash months during late 2023 and mid 2024, when actual prices fell to as low as ₹150-₹288 per quintal while the model continued to forecast prices near the historical mean. When these shock months (6 at Mawana, 4 at Sardhana) were excluded, normal-period MAPE improved to 30.76 per cent and 26.36 per cent respectively comparable to the other seven series. This finding is consistent with Timilsina and Bhandari (2020) [15] and Agarwal *et al.* (2018) [1], who documented that onion markets are characterized by extreme price volatility driven by sudden supply gluts and demand collapses that are structurally difficult for univariate time series models to anticipate. Hyndman and Koehler (2006) [7] similarly caution that

MAPE-based accuracy measures can be severely distorted when actual values approach zero, supporting the use of the segmented MAPE approach adopted here.

3.3 Twelve-Month Price Forecasts (January-December 2025)

Refitting the best models on the complete 2014-2024 dataset generated 12 month ahead forecasts showing a general mean reverting pattern across markets. Onion prices were forecast to recover from the 2024 price crash at Mawana APMC (from ₹855 in January 2025 to ₹1,615 by December 2025), while at Meerut and Sardhana APMCs onion prices were forecast to decline from elevated late-2024 levels at Sardhana following a distinctive U-shaped path, bottoming at ₹931 in August 2025 before recovering to ₹1,141 by December 2025. Potato prices were forecast to decline gradually across all three markets, while tomato prices were forecast to decline initially before stabilizing around each market's historical mean. This mean-reverting behaviour is consistent with Amir *et al.* (2021)^[2] for onion and with Kumar *et al.* (2011)^[9] for potato, both of whom reported ARIMA forecasts converging towards long-run price levels following periods of disruption. Confidence intervals widened progressively over the forecast horizon in all cases particularly for onion and tomato consistent with Ramesh *et al.* (2022)^[12], who noted that forecast uncertainty compounds rapidly beyond 6-8 months for volatile agricultural commodities.

4. Conclusion

The present study demonstrates that ARIMA models, combined with Kalman smoothing for missing value treatment, provide a reasonably accurate framework for forecasting vegetable prices at APMC markets in Meerut district under normal market conditions, with MAPE values in the 26-46 per cent range for the majority of crop market combinations studied. ARIMA (1,1,3) was the most broadly applicable model specification, while onion price series required more complex specifications at larger, more interconnected markets. A key contribution of this study is the identification of a fundamental limitation of univariate ARIMA models their inability to anticipate extreme, shock-driven price collapses, as evidenced for onion at Mawana and Sardhana APMCs and the development of a segmented MAPE approach to meaningfully separate genuine model performance from the impact of such exceptional events. The 12 month forecasts generated indicate an overall mean reverting trend in vegetable prices across the district for 2025. These findings can assist farmers in timing their marketing decisions, help traders in inventory planning, and inform policy makers in designing targeted price stabilization interventions, particularly for onion, which remains the most volatile and least predictable of the three TOP vegetables studied.

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