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CLIMATE CHANGE AND ITS EFFECTS ON PRICES OF VEGETABLES IN TAMIL NADU

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ABSTRACT

This study examines the impact of climate factors on vegetable prices, a key aspect influencing agricultural production decisions. As climate change increasingly disrupts weather patterns, understanding the relationship between climate variables and vegetable price fluctuations becomes essential for shaping agricultural policies, market predictions, and supply chain management. Using the ARIMAX model, this research analyzes the effects of temperature and rainfall on the prices of four major vegetables viz. tomato, onion, brinjal, and okra in Tamil Nadu from 2005 to 2019. The findings reveal that tomato and onion prices are significantly affected by climate conditions, while brinjal and okra prices show minimal sensitivity to weather variations. Additionally, the study employs the ARIMA model to forecast vegetable prices for 2020-2029, identifying optimal forecasting models for each vegetable based on the lowest AIC and BIC values. The forecast indicates substantial price fluctuations over the next decade, providing valuable insights for farmers to optimize crop planning and marketing strategies.

Keywords: ARIMAX, Forecasting, Market prediction, Vegetables price

India is the second-largest vegetable producer globally, contributing 10% to the world's total vegetable production (Kumar *et al.*, 2004). The country annually produces 1,91,769.11 metric tonnes (MT) of vegetables, with Tamil Nadu accounting for 4.1% of this total (National Horticulture Board, 2019). Price volatility in the vegetable market has significant consequences for various stakeholders, including consumers, producers, and markets. The production of vegetables is highly sensitive to climate change, particularly in agrarian regions (Bisbis *et al.*, 2018). Extreme weather events are key drivers of the fluctuations in vegetable prices (Li *et al.*, 2022). Changes in weather patterns directly impact planting, harvesting, transportation, and marketing activities, all of which contribute to price instability (Yang *et al.*, 2022). These price fluctuations, in turn, negatively affect consumer demand and producer income (Kumar and Mittal, 2022).

In Tamil Nadu, climate variability and change have had significant effects on both the production and pricing of major crops (Geethalakshmi *et al.*, 2023). This study focuses on Tamil Nadu, a tropical region characterized by an average minimum temperature of 29.0°C and an average annual rainfall of 1,647 mm. Key vegetables grown in the state, including tomato, onion, brinjal, okra (lady's finger), tapioca, and moringa, account for over 75% of the total vegetable cultivation area. The total area under vegetable crops in Tamil Nadu was 289.74 hectares, with a production of 8,678.82 MT (Horticulture Statistics at a Glance, 2018). Over recent years, the prices of major vegetables such as onion, tomato, brinjal, and okra have increased by 1.20%, 17.82%, 47.46%, and 50.88%, respectively (National Horticulture Board, 2019).

A major challenge in estimating vegetable prices is the seasonality inherent in the price data series. Tamil Nadu's diverse agro-climatic conditions render it particularly vulnerable to climate change, including altered rainfall patterns, more extreme temperatures, and an increased frequency of extreme weather events such as cyclones. These factors can drastically affect vegetable production, causing supply fluctuations that, in turn, influence market prices.

Keeping in view this context, understanding the vulnerabilities of Tamil Nadu's vegetable sector to climate change is critical for developing effective adaptation and mitigation strategies, as well as improving marketing practices. This study aims to explore the combined effects of weather parameters and vegetable prices, while also forecasting the price trends of major vegetables grown in Tamil Nadu.

MATERIALS AND METHODS

The ARIMAX (AutoRegressive Integrated Moving Average with Exogenous Variables) model is a powerful extension of the traditional ARIMA (AutoRegressive

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Integrated Moving Average) model, specifically designed to handle time series data by incorporating external variables that may influence the series under analysis. In essence, ARIMAX combines the predictive capabilities of ARIMA with the ability to include additional explanatory variables, known as exogenous variables. These exogenous variables are factors external to the primary time series but are considered to affect its behaviour. By integrating these external influences, ARIMAX can better capture the dynamics of the time series, leading to more accurate and robust forecasts (Lestari and Dini, 2024).

One of the most common applications of the ARIMAX model involves examining the relationship between crop yields and weather parameters. This study, however, focuses on the connection between crop prices and weather parameters. Since the ARIMAX model is based on objective data-driven techniques, it does not require a survey to gather information. This enhances its efficiency and reliability, as it is grounded in measurable external factors that directly influence the time series being modelled.

In line with the objective of this study, the annual prices of major vegetables grown in Tamil Nadu were selected as the endogenous variables. Specifically, the annual prices of tomato, onion, brinjal, and okra were collected from the National Horticulture Board Database of India for the period from 2005 to 2019. Among these vegetables, tomato exhibits significant price variation, largely due to fluctuations in supply rather than market demand, often leading to periods of glut in the market (Arora *et al.*, 2018). In India, onions are cultivated in all three seasons i.e. '*Rabi*', '*Kharif*', and late '*Kharif*, whereas in Tamil Nadu, onions are primarily grown in the '*Rabi*' and '*Kharif*' seasons (Sharma *et al.*, 2022). The price of onions is more volatile compared to other vegetables, driven by factors such as low price-income elasticity, weak supply chains, and the hoarding of stocks (Gummagolmath *et al.*, 2020). For brinjal, a notable characteristic of its price fluctuations is the impact of high market costs, which increase the risks faced by growers (Sharma *et al.*, 2022). The price volatility of okra, on the other hand, cannot be fully explained by traditional demand and supply dynamics; speculative activities and stock hoarding have often been cited as significant contributors to the high volatility observed in okra prices (Sadiq *et al.*, 2018). The exogenous variables considered in this study include climatic parameters such as average temperature and annual rainfall. These data were sourced from the Prediction of Worldwide Energy Resources (POWER) NASA database, using the geographic coordinates of Tamil Nadu (Latitude: 11.1271, Longitude: 78.6569).

The aim of this study was to investigate the combined effects of weather parameters on vegetable prices in Tamil Nadu using the ARIMAX model. The ARIMAX model is an extension of the traditional ARIMA model, incorporating exogenous variables to enhance forecasting accuracy. The ARIMAX approach involves several steps, including identification, estimation, diagnostics, and forecasting, to analyze the given data effectively. The model itself is a linear combination of autoregressive and moving average components, with the inclusion of exogenous variables. In this study, climatic parameters such as average temperature and annual rainfall were used as exogenous variables to assess their impact on vegetable prices in Tamil Nadu (Box *et al.*, 2015). The ARIMAX for Y_t is expressed as

$$\Delta^d Y_t = \alpha + \sum_{i=1}^{p} \varphi_i \Delta^d Y_{t-i} + \sum_{j=1}^{q} \theta_j e_{t-j} + \sum_{m=1}^{k} \beta_m X_{m,t} + e_t$$

where denotes constant term, *p* denotes autoregressive order and *q* denotes moving average order. represents autoregressive coefficients and represents regression coefficients,represents an error term at time *t*, *k* denotes the number of explanatory variables, and *X* represents explanatory variables.

Stage 1: Identification focuses on 2 criteria – stationarity and determination of p, d, q. Stationarity check is performed by ADF and PP test. Determination of (p,d,q) are done by Auto Correlation Function for "q" and Partial Auto Correlation Function for "p". Identification of the model (p,d,q)

$$Y_t = C + \sum_{i=1}^{p} \alpha\, Y_{t-i} + \sum_{j=1}^{q} \theta\, E_{t-j} + E_t$$

Stage 2: Estimation focuses on to estimate all possible models. The model selection is done by comparing AIC and BIC, the smaller value is the better model.

Stage 3: Diagnostic and forecasting deals with checking of residuals of the model are white noise performed by Portmanteau test. In this test, the null hypothesis represents white noise in the residuals which states that there is no autocorrelation in the residuals of a time series model and can accept the null hypothesis if the p-value is more than 0.05 or reject the null hypothesis if the p-value is less than 0.05. This confirms that residuals are white noise and the process is stable and we can further proceed for forecasting.

RESULTS AND DISCUSSION

The descriptive statistics of the selected variables are presented in Table 1. Among the vegetables analyzed, Okra has the highest mean price, with an average of Rs. 1710.73 per quintal, followed by Onion at Rs. 1654.86 per quintal. The standard deviation, which indicates the extent of price fluctuations, is highest for

Table 1 Descriptive statistics for weather and agricultural price variables

Variable	Average temperature	Annual rainfall	Onion Price	Tomato Price	Brinjal Price	Okra Price
Mean	28.30	952.98	1654.86	1258.27	1612.17	1710.73
Std Dev	0.44	217.74	787.62	543.42	759.27	618.60
Range	1.58	830.30	2440.55	1630.92	2152.27	2032.17
Minimum	27.45	535.00	539.36	562.25	646.82	736.67
Maximum	29.03	1365.30	2979.92	2193.17	2799.08	2768.83

Onion, suggesting greater price variability, followed by Brinjal. This indicates that Onion prices experience more frequent or larger price changes compared to other vegetables in the dataset.

The trend pattern of vegetable prices is illustrated in Figure 1. The variability in vegetable prices is captured by the R-squared value, which shows that Okra exhibits the highest price variability, followed by Brinjal, Tomato, and Onion, all displaying an increasing trend over time. The graph clearly highlights an abnormal price hike for Onion during certain years, indicating periods of significant price fluctuations or spikes. This suggests that the price of Onion is subject to unusual or exceptional market conditions in specific years.

The trend pattern of climate parameters in Tamil Nadu is shown in Figure 2. Over the study period, the average temperature exhibits greater variability compared to annual rainfall. The temperature shows an increasing trend, while rainfall follows a declining trend. These trends suggest a shift in climatic conditions that may have implications for agricultural production and the pricing of vegetables in the region.

The next section outlines the application of the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests to confirm the stationarity of the data. The Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) are then used to determine the appropriate order of the moving average (q) and autoregressive (p) components, respectively. The most suitable model for the study is selected based on the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). Using the selected model, the study employs the ARIMAX approach to investigate the effects of climate change on vegetable prices in Tamil Nadu.

Model Fitting

A key assumption for time series modelling is that the selected data series must be stationary in order to proceed with further analysis. To test for stationarity, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests were conducted. The results, presented in Table 2, indicate that both the vegetable price and weather parameter data series are stationary at the level, with a 1% level of significance. This confirms that the data is suitable for further time series analysis.

Model selection criteria

The determination of the orders p and q is achieved using the Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF). In this study, STATA software was used to fit the ARIMA models. The Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values of the ARIMA models were calculated to assess model fit and identify the most suitable model for further analysis.

From Table 3, it is evident that the ARIMA models with the smallest values of the Akaike's Information

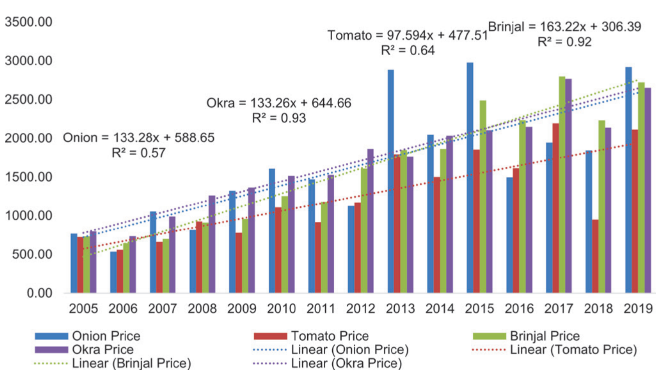

Fig. 1. Price trend of major vegetables in Tamil Nadu

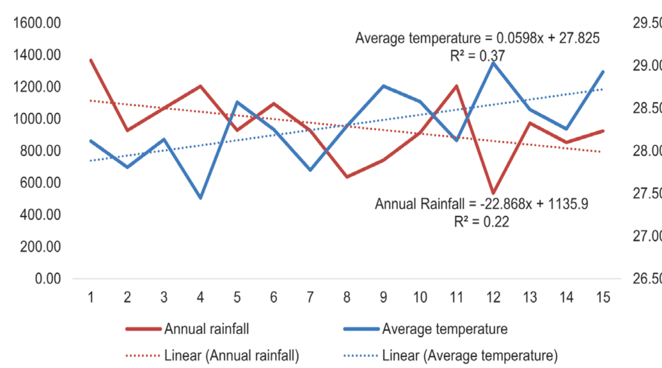

Fig. 2. Trend of climate parameters in Tamil Nadu

Table 2. Results of Stationarity tests

Test	ADF† (at level)		PP† (at level)	
Variable	With Trend	Without Trend	With Trend	Without Trend
Tomato Price	-5.155***	-1.933	-5.081***	-1.764
Onion Price	-3.999**	-2.026	-3.992**	-1.915
Brinjal Price	-4.670***	-0.531	-4.625***	-0.083
Okra Price	-5.974***	-0.882	-6.469***	-0.412
Annual Rainfall	-4.622***	-4.294***	-4.745***	-4.308
Average Temperature	-5.146***	-2.980*	-6.929***	-2.962

†ADF: Augmented Dickey-Fuller test, PP: Phillips-Perron test
***, ** and *: Significant at *p≤0.01, 0.05* and *0.1*, respectively.

Criterion (AIC) and Bayesian Information Criterion (BIC) are the most suitable for price forecasting. Specifically, the models ARIMA (2,0,0), ARIMA (0,0,2), ARIMA (1,0,2), and ARIMA (2,0,0) are found to be appropriate for forecasting the prices of Tomato, Onion, Brinjal, and Okra, respectively. The estimated parameters for these chosen models are provided in the following Table 3.

The *p*-values and parameter estimates for the AutoRegressive Integrated Moving Average with Exogenous Variables (ARIMAX) models-ARIMAX(2,0,0) for Tomato price, ARIMAX(0,0,2) for Onion price, ARIMAX(1,0,2) for Brinjal price, and ARIMAX(2,0,0) for Okra price, are provided in Table 3. These models include average temperature and annual rainfall as exogenous variables. For the ARIMAX(2,0,0) model for Tomato price, the *p*-values for the AR(2) term and average temperature are significant at the 5% level, indicating that an increase in average temperature leads to higher tomato prices. In the case of the ARIMAX(0,0,2) model for Onion price, the *p*-values for the MA(2) term and annual rainfall are significant at the 5% level, while average temperature is significant at the 10% level. This suggests that onion prices are significantly influenced by increases in both annual rainfall and average temperature. For the ARIMAX(1,0,2) model for Brinjal price, the *p*-values for the AR(1) term and MA(2) are significant at the 5% level, indicating that the price of Brinjal is influenced by its own past values and the moving average component, but not by climate factors. Similarly, for the ARIMAX(2,0,0) model for Okra price, the *p*-values for the AR(2) term are significant at the 5% level, indicating that Okra prices are also primarily influenced by past price values rather than climate variables. The results suggest that the prices of Tomato and Onion are significantly influenced by climate factors, particularly average temperature and annual rainfall. However, the prices of Brinjal and Okra do not appear to be affected by these climatic parameters, indicating a degree of resilience in these crops or the presence of other dominant factors driving their prices.

Additionally, the residuals of the fitted models were examined for white noise using the Portmanteau test. The results indicate that the residuals are white noise, suggesting that the models adequately capture the underlying patterns in the data without leaving any significant autocorrelation. After performing this diagnostic check, the ARIMAX models were used to forecast the prices of the selected vegetables.

The ARIMA models (2,0,0), (0,0,2), (1,0,2), and (2,0,0) were selected as the most effective models

Table 3. Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values for various ARIMA model combinations for price variables

ARIMA Model	Model 1 Tomato Price		Model 2 Onion Price		Model 3 Brinjal Price		Model 4 Okra Price	
	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC
(1,0,1)	232.84	235.67	245.65	248.48	226.49	229.32	223.40	226.23
(2,0,1)	229.11	232.65	244.42	247.96	223.97	227.51	222.98	226.52
(1,0,2)	228.47	232.01	247.31	250.32	**215.48**	**218.31**	223.13	225.96
(2,0,2)	229.71	233.96	248.07	252.32	217.40	220.94	224.98	229.23
(2,0,0)	**227.26**	**230.10**	243.99	246.82	224.32	227.15	**221.72**	**224.55**
(0,0,2)	230.30	233.13	**243.95**	**246.78**	229.49	232.32	223.23	225.35
(1,0,0)	233.76	235.89	245.24	247.36	225.77	227.90	222.79	224.92
(0,0,1)	235.34	237.46	246.48	248.61	239.28	241.40	233.26	235.39

Table 4. Parameter estimates for ARIMAX models of crop prices (Tomato, Onion, Brinjal, Okra)

Dependent Variable: Tomato Price (2,0,0)				
Parameter	**Coefficient**	**Standard Error**	***t* value**	***p* value**
AR1	0.042	0.188	0.22	0.823
AR2	0.779	0.209	3.73	0.000
Average temperature	462.137	181.804	2.54	0.011
Annual Rainfall	0.202	0.462	0.44	0.662
Dependent Variable: Onion Price (0,0,2)				
Parameter	**Coefficient**	**Standard Error**	***t* value**	***p* value**
MA1	0.648	0.653	0.99	0.321
MA2	1.000	0.415	2.41	0.016
Average temperature	899.311	386.301	1.73	0.084
Annual Rainfall	1.478	0.856	2.33	0.020
Dependent Variable: Brinjal Price (1,0,2)				
Parameter	**Coefficient**	**Standard Error**	***t* value**	***p* value**
AR1	0.941	0.143	6.56	0.000
MA1	-0.548	390.866	0.00	0.999
MA2	1.000	1424.293	1.98	0.013
Average temperature	93.633	154.017	0.61	0.543
Annual Rainfall	0.063	0.410	0.15	0.877
Dependent Variable: Okra Price (2,0,0)				
Parameter	**Coefficient**	**Standard Error**	***t* value**	***p* value**
AR1	0.551	0.454	1.21	0.225
AR2	0.403	0.510	1.79	0.043
Average temperature	158.602	434.450	0.37	0.715
Annual Rainfall	0.218	0.642	0.34	0.734

for predicting the price forecasts of tomato, onion, brinjal, and okra in Tamil Nadu, based on 15 years of time series data. The ARIMA model is suitable for forecasting time series data with various structural patterns and autocorrelations between successive values. The forecasts generated by the ARIMA models indicate a decline in prices for the year 2020, followed by an increase in 2021. This upward trend continues through to 2029, reflecting overall fluctuations in the prices of these vegetables over the forecast period. The predicted price dynamics highlight both short-term declines and longer-term upward trends in vegetable prices. These fluctuations suggest the influence of multiple factors, including both market and climatic conditions.

Table 5. Results of Portmanteau Test for Residuals' White Noise

Null hypothesis: The residuals are white noise

Diagnostic test	**Prob > *chi*²**
Tomato Price	0.9159
Onion Price	0.9817
Brinjal Price	0.9312
Okra Price	0.9862

($p>0.05$, accept null hypothesis)

The present study conducted in Tamil Nadu reveals an alarming trend of rising temperatures and decreasing rainfall over the years, presenting significant challenges to agricultural production. Among the selected vegetables, onion prices have exhibited abnormal spikes during certain years, highlighting their vulnerability to external factors. Time series analysis highlights the influence of climate factors on tomato and onion prices, while brinjal and okra prices appear more resilient to climate impacts, or are probably influenced by other dominant factors. These findings align with previous research, which emphasizes the complex relationship between climate and agricultural outcomes (Velusamy *et al.*, 2022). In India, weather phenomena such as cyclones, floods, and droughts frequently damage crops, leading to supply disruptions and price escalations. For instance, onion and tomato prices fluctuate seasonally, often peaking during lean seasons and declining when supply is abundant, driven by market arrivals (Kishore and Shekhar, 2022). This study clearly indicates that temperature has a significant impact on tomato prices, while both temperature and rainfall play crucial roles in

Table 6. Actual and forecasted vegetable prices (2005–2029)

Year	Tomato Price	Onion Price	Brinjal Price	Okra Price
	Actual	Actual	Actual	Actual
2005	725.83	769.18	734.55	798.50
2006	562.25	539.36	646.82	736.67
2007	663.17	1055.58	700.83	988.42
2008	926.33	816.00	911.25	1259.83
2009	779.50	1322.42	958.42	1363.75
2010	1108.00	1608.17	1253.50	1515.92
2011	918.17	1470.75	1178.67	1527.75
2012	1170.83	1125.50	1610.00	1863.08
2013	1793.50	2885.50	1847.33	1765.42
2014	1501.75	2043.33	1862.75	2032.75
2015	1854.00	2979.92	2488.33	2105.17
2016	1614.17	1498.08	2234.17	2147.50
2017	2193.17	1944.75	2799.08	2768.83
2018	950.25	1844.25	2232.92	2137.83
2019	2113.08	2920.08	2724.00	2649.50
	Forecasted (2,0,0)	**Forecasted (0,0,2)**	**Forecasted (1,0,2)**	**Forecasted (2,0,0)**
2020	1081.40	2226.43	2341.35	2362.23
2021	1875.62	2292.23	2418.57	2467.34
2022	1161.07	1662.78	2366.99	2381.31
2023	1702.71	1722.41	2318.65	2389.91
2024	1207.11	1815.15	2273.37	2353.16
2025	1575.82	1612.47	2230.95	2339.57
2026	1231.51	1653.12	2191.20	2315.57
2027	1481.94	1666.78	2153.96	2297.57
2028	1242.27	1689.88	2119.07	2277.50
2029	1411.88	1669.43	2086.39	2259.30

determining onion prices. Onion production is especially sensitive to rainfall and humidity, which directly affect market prices (Birthal *et al.*, 2019). Heavy rainstorms between September and November often result in substantial crop losses, disrupting market dynamics (Ghosh *et al.*, 2022). Seasonal price variations and fluctuations in market arrivals are common, influenced by changes in production, rainfall patterns, storage limitations, and export demands (Gummagolmath *et al.*, 2020). These complexities emphasize the importance of understanding and mitigating the impacts of climate change on agricultural markets to ensure food security and market stability.

CONCLUSION

In conclusion, climate change exacerbates the volatility of perishable vegetable prices, with environmental extremes such as temperature fluctuations and rainfall variations being key drivers of reduced yields and price instability. This study utilized the ARIMAX model to analyze vegetable price data, incorporating weather parameters as exogenous variables to assess their impact on the prices of major vegetables viz. Tomato, Onion, Brinjal, and Okra grown in Tamil Nadu. The Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were employed to select the optimal models for each vegetable, resulting in ARIMAX(2,0,0) for Tomato, ARIMAX(0,0,2) for Onion, ARIMAX(1,0,2) for Brinjal, and ARIMAX(2,0,0) for Okra. The findings reveal that both average temperature and annual rainfall significantly influence the prices of Tomato and Onion, respectively, making these vegetables particularly sensitive to climatic conditions in Tamil Nadu. These insights are valuable for policymakers, extension workers, and farmers, providing a foundation for better crop planning and marketing decisions. Accurate price forecasting can help optimize returns and mitigate risks, ensuring that Minimum Support Prices (MSP) for vegetables are more effective.

The study emphasizes the importance of integrating climate factors into agricultural policy and decision-making. Policymakers and researchers are encouraged to use this model to predict the prices of horticultural products while accounting for the effects of temperature and rainfall. Future research could explore alternative econometric models and expand the analysis to similar climate zones. Additionally, more comprehensive studies could incorporate other factors influencing vegetable prices for a deeper understanding of price variation. The current study is limited to the macro-level effects of climate change in Tamil Nadu; therefore, future research should consider regional variations at the district level to capture the full spectrum of climate impacts on local agricultural markets.

Authors' Contribution

Conceptualization of research (J.V.A); methodology (J.V.A) and (D.K); Designing, (D.K) and (A.P); data collection, (A.P); analysis of data and interpretation (J.V.A) and (D.K); preparation of the manuscript (J.V.A) and (A.P).

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Conflicts of interest

The authors declare that they have no conflicts of interest.

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