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Statistical Analysis of the Effects of Temperature and Rainfall on Tomato Production in Benue State

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Abstract

Tomato, a highly nutritious crop, is widely consumed worldwide. Although Benue State's fertile soil and favorable climate support year-round cultivation, fresh tomato supply remains limited at certain times each year due to seasonal farming practices and farmers' limited awareness. A Seasonal Autoregressive Integrated Moving Average Model with exogenous variables (SARIMAX) was used as a quantitative tool to provide realistic and reliable advisory support for tomato production. This study employed monthly secondary data on tomato production in Benue State (1980–2013; 408 observations) obtained from BNARDA, alongside monthly temperature and rainfall data (1980–2017; 456 observations) from the Nigerian Meteorological Agency. Temperature and rainfall (1980–2013) were incorporated as exogenous variables in a SARIMAX model to analyze tomato production, while the additional years were used as exogenous variables for forecasting. SARIMA (1,1,2)(0,1,2)[12] (Xreg) outperformed the SARIMA counterpart, reducing AIC from 8464.2 to 8126.02 and improving forecast accuracy with lower RMSE (6528.52 vs. 7575.78) and MAPE (74.09% vs. 87.13%), confirming temperature and rainfall as significant drivers of tomato production in Benue State. Results from this work suggest that the system of tomato farming be controlled and improved upon, instead of allowing climatic factors decide what happens. This would enable steady supply and improved quality of tomato in Benue State.

KEY WORDS: SARIMAX, Exogenous Variable, Parsimonious Model, Forecast

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1. INTRODUCTION

Tomato (*Lycopersicon esculentum*.) is a fruit vegetable that is widely grown around the world. It is one vegetable crop that has enormously achieved popularity over the last one hundred years and is practically grown in every country of the world in outdoor fields, greenhouses and net houses (Ayandiji and Adeniyi, 2011; Akinola et al., 2023). This crop is not just widely cultivated in Nigeria and the world but also consumed massively everywhere around the world and can also be a very good source of income to people who cultivate it in commercial quantities (Tambo and Gbemu, 2010; Abu et al., 2011; Oluchukwu, Ozoemene, Chidimma, and Happiness, 2025). It is easily destroyed by freezing temperatures and injured by light frosts (Brandenberger et al., 2017). The fruit vegetable blossoms will not set fruit for economic yields if day temperatures rise above 38°C (100.4°F), or if night temperatures remain above 21°C or drop below 10°C. Tomato fruit is best produced if the average temperature ranges between 18 – 25°C with a constant watering of 3 – 5cm deep, and relative humidity of 70% to 80% (Hartz et al., 2017; Kürklü, Pearson, and Felek, 2025).

In Nigeria, tomato is grown all over the country during the rainy season while a few regions practice dry season farming of tomato, this practice has been standing for ages (Umeh et al., 2002). Major tomato producing areas in Nigeria lie between latitudes 7.5°N and 13°N, and within a temperature range of 25 – 34 °C (Villareal, 1980). The Benue State Agricultural and Rural Development Authority (BNARDA) data estimates show that tomato yield by January of 1980 was 4,265.4 tons while the official data of the same organization in the state indicated about 24, 360 tons of tomato yield by December 2013. Also, the Food and Agricultural Organization (FAO) in their official data said the annual production of tomatoes in Nigeria stood at about 1.93 million tons. With all these, it was acclaimed in 2013 that Nigeria is simultaneously the world's 13th largest tomato producer but rather the world's largest importer of tomato paste (Mira, Nike, Jared, and Shane, 2013). Later on, reports indicated a downward revision, noting that Nigeria ranked as the 16th largest tomato-producing nation globally, but still possesses a comparative advantage and strong potential to lead in tomato production and exports (Ugonna, Jolaoso, and Onwualu, 2015; Umar, Rahman, and Zanello, 2025). This is to say that in spite of the high popularity tomato has assumed, its total production in Nigeria in general and Benue state in particular is grossly inadequate.

The general farm practice in Benue state is observed to be seasonal and tomato is one of such crops cultivated seasonally around the state. One intriguing fact about this system of farming is that climate has become very unstable and poses a very big challenge to the world food production (Nurry and Alam, 2012). Tomato like any other green plant needs water (rainfall) and sunlight (that comes together with temperature) for its germination, growth, plant development and maturity, photosynthesis and fruit production (yield). However, excessive and uncontrolled water supply coupled with fluctuating temperature leads to tomato disease, rot and unfavorable conditions to the plant and hence its fruits (at harvest). This we believe has effect on the yield that comes out of the farms and is measured at various locations to represent the quantity of tomatoes produced in Benue State (Naika et al., 2009). In the light of the above, many global studies have been carried out in an attempt to identify and quantify the impact of climate on food production (Yoosoon et al., 2016; Ibrahim and Musa, 2023; Umar, Rahman, and Zanello, 2025). However, these have failed to address the local and regional specificity and consequences of climatic factors such as temperature and rainfall on tomato production in Benue State. This work employs time series modelling of tomato production in Benue state that takes temperature and rainfall into account as an attempt to fill these knowledge gaps.

2. MATERIALS AND METHODS

2.1. *Data Sources*

All data used in this research work were obtained from secondary sources. Monthly data on air temperature and rainfall for 38 years (1980 − 2017) were collected from the Nigerian Meteorological Agency Office in Makurdi while monthly data on tomato production in Benue state for 34 years (1980 − 2013) were collected from Benue State Agricultural and Rural Development Authority (BNARDA).

2.2. *Seasonal Autoregressive Integrated Moving Average with Exogenous Variables (SARIMAX) Model for tomato production in Benue State*

An ARIMA model of order (p,d,q) (Aburto and Weber, 2003; Cools et al., 2009;)

$$\phi_p(B)(1-B)^d Z_t = c + \theta_q(B)\varepsilon_t \quad (1)$$

where, B is the delay or lag operator, $\phi_p(B)$ is the autoregressive operator of p-order, $\theta_q(B)$ is the moving average operator of q-order, $(1-B)^d$ is the differencing operator of order d to remove non-seasonal stationarity, Z_t is the observation of the series at time t, ε_t is the residual error in ARIMA model, and c is a constant.

From here, modeling ARIMA with a seasonal component identified SARIMA (Seasonal

Autoregressive Integrated Moving Average) model. The SARIMA model can be represented as (Aburto and Weber, 2007; Cools et al., 2009; Cammarano et al., 2022; Ibrahim and Musa, 2023)):

$$\mathrm{\phi_p(B)\Phi_P(B^S)(1-B)^d(1-B^S)^D Z_t = c + \theta_q(B)\Theta_Q(B^S)\varepsilon_t} \qquad (2)$$

where, $\Phi_P(B)$ is the Seasonal autoregressive operator with P-order, $\Theta_Q(B)$ is the Seasonal moving average operator with Q-order, and S is the Seasonal length.

Now, the SARIMA model in (2) has the capability to handle stationary and non-stationary time series with seasonal elements. The generation of time series forecasts using SARIMA is better if no outlying data occurs (Cools et al., 2009; Ibrahim and Musa, 2023)). The outlying data in a time series may often point out significant events or exceptions and provide useful information on the model. Therefore, it is important to consider external variables, which deliver meaningful answers to the outlying data. As an alternative of modeling a time series $\square_t$ with only a combination of past values, $\square_t$ can be explained by both SARIMA and external variables (regressors). Hence, the SARIMAX model was built for tomato production in Benue State with temperature and rainfall as regressors using Box-Jenkins SARIMA approach and multiple linear regression (MLR).

The SARIMAX model is a SARIMA model with external variables denoted as SARIMAX (p,d,q) $(P,D,Q)_S$ (X), where X is the vector of external variables. The external variables can be modeled by multi linear regression equation given by (3).

$$Y_t = \beta_0 + \beta_1 X_{1,t} + \beta_2 X_{2,t} + \cdots + \beta_k X_{k,t} + \omega_t \qquad (3)$$

where, $X_{1,t}, X_{2,t}, \ldots, X_{k,t}$ are observations of k number of external variables; Y_t is the dependent variable, $\beta_0, \beta_1, \ldots, \beta_k$ are regression coefficients of external variables, and ω_t is a stochastic residual, i.e. the residual series that is independent of input series. The residual series ω_t can be represented in the form of SARIMA model as follows (Peter and Silvia, 2012)

$$\mathrm{\omega_t = \frac{\theta_q(B)\Theta_Q(B^S)}{\phi_p(B)\Phi_P(B^S)(1-B)^d(1-B^S)^D}\varepsilon_t} \qquad (4)$$

From Eqn (4) a general SARIMAX model equation was obtained by substituting (4) in (3) given as (Aburto and Weber, 2007; Cools et al., 2009; Cammarano et al., 2022; Ibrahim and Musa, 2023))

$$Y_t = \beta_0 + \beta_1 X_{1,t} + \beta_2 X_{2,t} + \cdots + \beta_k X_{k,t} + \frac{\theta_q(B)\Theta_Q(B^S)}{\phi_p(B)\Phi_P(B^S)(1-B)^d(1-B^S)^D}\varepsilon_t \qquad (5)$$

Hence, the general SARIMAX model given in (5) above permits the regression coefficient to be interpreted in the usual and easier way, (Hyndman, 2010).

The Dickey-Fuller generalized least squares test was used to test for the presence of a unit root in the time series data used in this work. The presence of a nonzero trend was assumed in the underlying data. This means it was assumed that the original series y_t was the result of a linear trend and an integrated AR(1) process. The autocorrelation function (ACF) and partial autocorrelation function (PACF) plots were used to determine the order of the SARIMA model (Makridakis et al., 1998). The Akaike information criterion was used to measure the relative quality of statistical models at the identification stage for this research data and also at the final stage for the built model. The Ljung-Box test was adopted and used to test for autocorrelation in the residuals, (Baum and Schaffer, 2013). The Jarque–Bera test, a goodness-of-fit test of whether sample data have the skewness and kurtosis matching a normal distribution was adopted to check if the residuals of the SARIMAX model were normally distributed as part of confirming the adequacy of our model.

2.3. *Performance Measures*

A forecast value added (FVA) analysis was used to evaluate the performance of forecasting process, (Gilliland, 2011). In this case, the performance measures of the SARIMA model were compared to that of the SARIMAX model to determine if the addition of factors in SARIMAX truly had effects on the forecasting performance or not. That is, the FVA analysis insisted the trade-off between the amounts of resources utilized on forecasting and the amounts of paybacks from them and hence, the mean absolute percentage error (MAPE) and root mean squared error (RMSE) were used as the performance measures of forecast accuracy

3. RESULTS

3.1. *Identification of model for tomato production in Benue State*

A time series plot of monthly tomato production in Benue state was done from January 1980 to December 2013 (Figure 1). The figure displays a seasonal fluctuation that repeats every twelve months. This point to the fact that tomato is seasonally produced in Benue and hence the seasonal period, s = 12. There is a slight trend that is not completely determined and so we investigate data stationarity, Figures 2a and 2b present the ACF and PACF for the original series of tomato production in Benue state. The ACF presents a sharp decreasing trend in the first seasonal lag from out of bound to within bound. Also, the ACF and PACF both displayed a slow rising trend to the peak followed by a slow decreasing trend in the remaining lags but plotted within bounds. This indicated the presence of a slight trend and seasonality in the data, hence, nonstationary behavior and suggests a first order difference to detrend and a seasonal differencing to deseasonalize. Figures 3a and 3b show the ACF and PACF for first order differencing (detrend) and deseasonalized series of tomato production in Benue State. The ACF is peaked in the first seasonal lag and tails off, cutting in the second seasonal lag while the PACF is peaked in the first seasonal lag and tails off gradually cutting off in the fourth seasonal lag. This suggested a stationary process and so we proceeded to conduct a dickey-fuller generalized least square (DFGLS) test (Table 1). The test returned a Dickey-Fuller test statistic of -13.9941 with critical values of -2.58, -1.95 and -1.62 for 1%, 5% and 10% levels of significance respectively hence, the null hypothesis was rejected at all levels. This meant that after detrending and deseasonalizing the original series using a generalized least squares regression, the residuals were found to be stationary.

3.2. *Estimation of Model Parameters*

In Figures 3a and 3b, the ACF peaks at lag 1 and cuts off at lag 2 while the PACF peaks at lag 1 and cuts off at lag 4 and so this indicate that SARIMA model of order p=1; P=0,1; q=1,2 and Q=1,2,3,4 was appropriate. An auto-ARIMA was run which returned SARIMA $(1,1,2)(0,1,2)_{[12]}$ as the best model based on AIC, AICc and BIC criteria. The autoregressive and seasonal parameters were also estimated and the summary statistics for SARIMA $(1,1,2)(0,1,2)_{[12]}$ is displayed in Table 2.

The exogenous variables (temperature and rainfall) were added, the resulting summary statistics of SARIMA $(1,1,2)(0,1,2)_{[12]}$ (Xreg) is displayed in Table 3 and indicated SARIMAX is an improvement of the SARIMA model. This was evident in the decrease in AIC from 8464.2 of SARIMA $(1,1,2)(0,1,2)_{[12]}$ to 8126.02 of SARIMA $(1,1,2)(0,1,2)_{[12]}$ (Xreg).

3.3. *Diagnostics of Model Fitness*

We further checked for model fitness of SARIMA $(1,1,2)(0,1,2)_{[12]}$ (Xreg). A time series plot of the residuals was made and is displayed in Figure 4. The auto-correlation function (ACF) and partial auto-correlation function (PACF) up to 37 lags were computed. The ACF and PACF all plotted within the upper and lower bounds, the plots are both peaked at the first lag and tails off gradually as the lags increased. The ACF and

PACF of the first seven lags is displayed in Figures 5a and 5b, respectively. The significance of residuals was tested using Ljung-Box and the Jarque-Bera tests. It is evident from Table 4 that the residuals were not autocorrelated and were having skewness and kurtosis resembling that of the normal distribution. The table displays the results of the Ljung-Box and Jarque-Bera statistics computed at 95% confidence level. Given the high p-values associated with the statistics, the null hypotheses of independence in this residual series were not rejected.

3.4. *Model forecasting*

The selected SARIMA (1,1,2)(0,1,2)$_{[12]}$ (Xreg) model was used to forecast the monthly tomato production in Benue State from January 2014 to December 2021 (Figure 6). The predicted values were compared with the observed values and it was observed that the predicted values of tomato production were close to the observed values. In both cases, there are some years the production is high and some that the production is low. This result indicates important changes will not occur in tomato yields up to the end of 2021 if temperature and rainfall conditions would also not change drastically. The figure also indicates the 95% and 80% confidence interval of what could happen if the conditions change drastically.

3.5. *Model Performance Measures*

The performance measures of SARIMA and SARIMAX models were computed using the RMSE and MAPE (Table 5). The results indicate that there is an improvement in the model performance from SARIMA to SARIMAX. There is a decrease in the root mean square from 7575.78 to 6528 and also a corresponding decrease in mean absolute percentage error from 87.13 to 74.09. By implication, this is clearly indicating that temperature and rainfall has significant effect on tomato yield in Benue State.

4. TABLES AND FIGURES

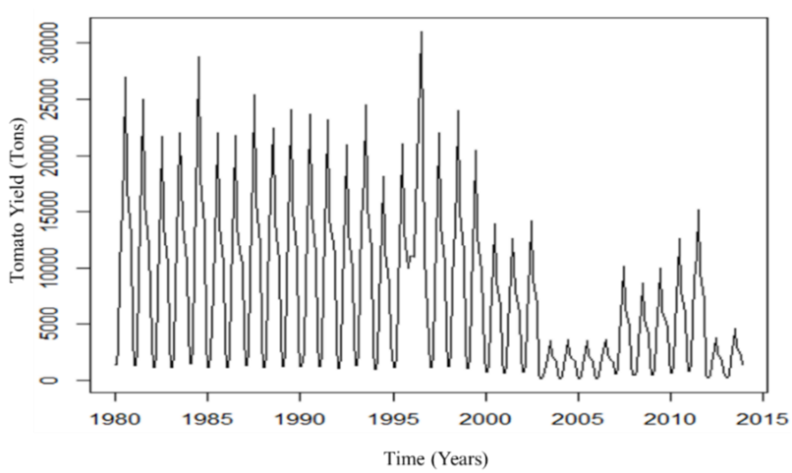

Figure 1: Time series of monthly tomato production in Benue State 1980 - 2013

Table 1: Results of Dickey-Fuller generalized least squares (DFGLS) test

Null Hypothesis: Tomato production data has unit root.			
		t-Statistic	Prob.***
Augmented Dickey-Fuller test statistic		-13.9941	0.001
Test critical values:	1% level	-2.58	
	5% level	-1.95	
	10% level	-1.62	

Table 2: Summary statistics of SARIMA $(1,1,2)(0,1,2)_{[12]}$ model

Model	AIC	AIC_c	BIC		
SARIMA $(1,1,2)(0,1,2)_{[12]}$	8464.2	8464.48	8492.28		
Estimates of model parameters					
	Mean	ϕ_1	θ_1	θ_2	Θ_1	Θ_2
SARIMA $(1,1,2)(0,1,2)_{[12]}$	10080.732	0.8854	0.1205	0.0963	-0.2593	0.1896
SE	3621.714	0.0269	0.0542	0.0542	0.0543	0.0453

Table 3: Summary statistics for SARIMA $(1,1,2)(0,1,2)_{[12]}$ (Xreg) model

	Estimate	SE
AIC	8126.02	
Parameter estimates		
ϕ_1	0.0177	0.9837
θ_1	0.0160	0.9829
θ_2	0.0170	0.0718
Θ_1	-1.4912	0.0510
Θ_2	0.5559	0.0519
Temperature	-2.4146	320.53
Rainfall	-0.5147	3.3170

Table 4: Test of significance for SARIMA $(1,1,2)(0,1,2)_{[12]}$ (Xreg) residuals

Test	Null hypothesis	X-squared	P-value
Ljung-Box	Residuals are independently distributed	4.9045	0.67
Jarque-Bera	Residuals skewness = 0 and excess kurtosis = 0	659630	0.82

Table 5: Forecast performance measures of SARIMA and SARIMAX models

Forecasting method	RMSE	MAPE
SARIMA	7575.78	87.13
SARIMAX	6528.52	74.09

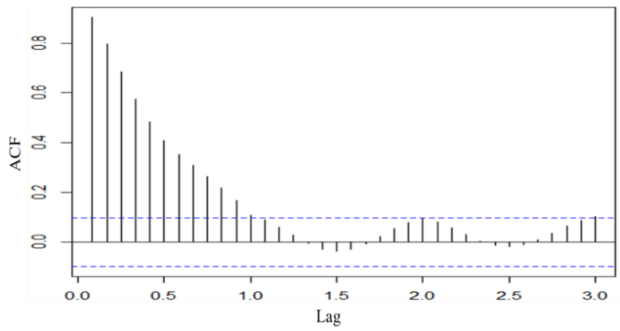

Figure 2A: ACF for original time series of tomato production in Benue State

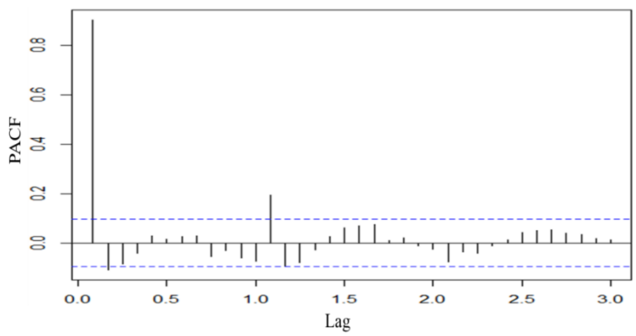

Figure 2B: PACF for original time series of tomato production in Benue State

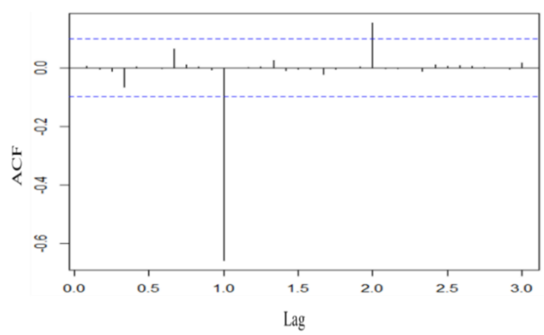

Figure 3A: ACF for 1st order and seasonal differencing time series of tomato production in Benue State

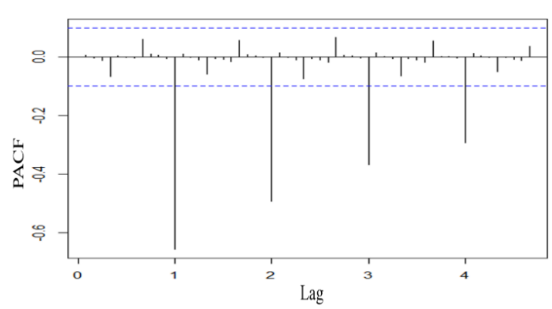

Figure 3B: PACF for 1st order and seasonal differencing time series of tomato production in Benue State

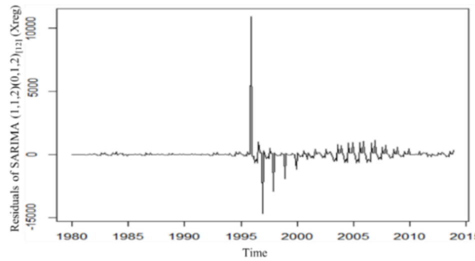

Figure 4: Residual plot of SARIMA (1,1,2)(0,1,2)$_{[12]}$ (Xreg) model

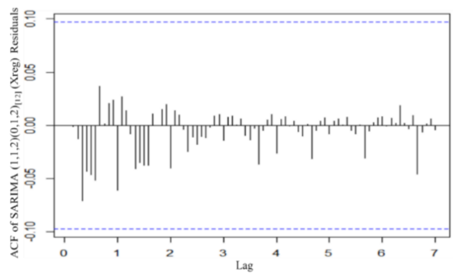

Figure 5A: ACF of SARIMA (1,1,2)(0,1,2)$_{[12]}$ (Xreg) residuals

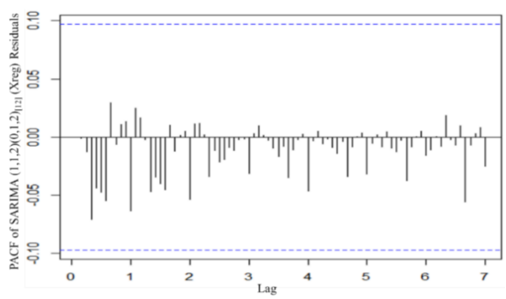

Figure 5B: PACF of SARIMA (1,1,2)(0,1,2)$_{[12]}$ (Xreg) residuals

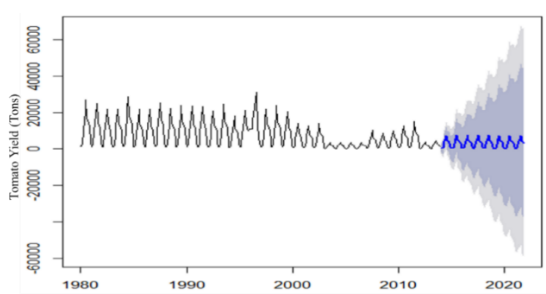

Figure 6: Forecast and original observations for Tomato production in Benue State.

5. DISCUSSION

Incorporating temperature and rainfall as exogenous variables significantly improved model performance, with SARIMA (1,1,2)(0,1,2)$_{[12]}$ (Xreg) emerging as the best-fit model for tomato production in Benue State. Compared to the SARIMA model, the SARIMAX counterpart achieved a markedly lower AIC (8126.02 vs. 8464.2) and improved forecast accuracy (RMSE: 6528.52 vs. 7575.78; MAPE: 74.09% vs. 87.13%), confirming temperature and rainfall as key determinants of tomato output. It is noted in literature that temperature and rainfall in the study area closely match optimal values that best suit conditions for tomato production (Naika *et al*., 2009). This is pointing to the fact that there is no need waiting for rainfall to return before tomato is cultivated in Benue State. A simple provision of constant watering of 3cm to 5cm deep for the cultivation period (from planting to harvesting) with optimum temperature range of 25-35 degrees Celsius for vegetation growth will be enough for the crop to do relatively well (Hartz *et al*., 2017; Kürklü et al., 2025). This temperature, of course, will not be difficult as Kürklü et al (2025) argue that Benue State fall within the major tomato producing areas in Nigeria with temperature range of 25-34°C. The seasonal cultivation of tomato means that cultivation of the crop is chiefly controlled by climatic factors hence, the reason Nigeria ranks in the highest tomato producing nations keep fluctuating year in year out depending on how climate is favorable (Mira *et al*., 2013; Ugonna *et al*., 2015; Umar et al., 2025). Most researchers have pointed out so many reasons for postharvest loses of tomato which is linked to microorganisms (Ugonna *et al*., 2015; Umar et al., 2025). Some have claimed postharvest loses are much because the state lacks facilities such as roads, transportation vans, market and processing facilities (Ayandiji and Adeniyi, 2011; Akinola et al., 2023). It was found in this research that the seasonal nature of cultivating the crop is also one of the reasons postharvest loses of the crop is on the high-end year in year out in Benue State. This is confirmed in our discovery that temperature and rainfall have significant effect on tomato production in the light of facts already established that cultivating the crop during the hot-wet season in tropical and subtropical climates suffers high incidence of disease (Naika *et al*., 2009). More so, an eight-year forecast using the SARIMA (1,1,2) $(0,1,2)_{[12]}$ (Xreg) model revealed that no important changes will occur in tomato yields up to the end of 2021 if nothing is done to change the rainfall or water supply for the crop as the temperature would keep fluctuating within the optimal range.

6. CONCLUSION

The application of time series in analyzing the agricultural variable (tomato) using climatic variables (temperature and rainfall) was able to indicate that both temperature and rainfall affects tomato production in Benue State. Since excesses of the two variables have earlier been proven to cause some level of damage to the crop (Naika *et al*., 2009), it becomes crystal clear that part of the postharvest losses is caused by temperature and rainfall. This calls for swift actions to be taken about the seasonal nature of producing tomato and if possible, similar crops that suffer damage from excesses of temperature and rainfall. The time series model, SARIMA (1,1,2)$(0,1,2)_{[12]}$ (Xreg) is parsimonious for tomato production and will be a very good tool for forecasting future tomato production in the state. Prediction of agricultural produce in the state using time series models that incorporate exogenous variables that are suspected to have effects on these crops will provide so much information as regards cultivation and postharvest loses and this will help in the control of these loses. Hence, it is recommended that;

(i) Tomato farmers should focus on a controlled system of cultivating the crop in Benue State instead of keeping all attention on open field cultivation that expose the crop to adverse weather conditions. Establishing a greenhouse for tomato farming will be more appropriate in the state.

(ii) Farmers should focus more on cultivating tomatoes all year round to ensure steady supply since it is conducive to do so, provided they can afford a steady water supply of 3cm to 5cm deep during the cultivation period. This is possible because all other conditions remain within control throughout the year, only rain/water ceases completely for a while before returning again.

(iii) Business inclined people should establish standard tomato farms within the state. The farm should have a workable irrigation system that will pick up the challenge of steady water supply when rain is gone so as to ensure steady production of tomato throughout the year. This will be more profitable and generate more income especially during the dry season when fresh tomato fruits become scarce.

(iv) Time series SARIMA (1,1,2)$(0,1,2)_{[12]}$ (Xreg) model is appropriate for forecasting short term tomato production in Benue State. The inclusion of other factors such as soil fertility, fertilizers, cultivation practices and others which could likely have effect on tomato production in the study area was also recommended. This would improve the model performance and provide a more accurate forecast for tomato production in Benue State.

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