Discovery Agriculture

Impact of Climatic Variables on Tomato Production in Nigeria

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To Cite:
Anaso EU, Olafadehan OA, Chibuogwu JC, Addass PA, Zubairu H, Joel JO. Impact of Climatic Variables on Tomato Production in Nigeria. *Discovery Agriculture* 2025; 11: e11da3129
doi:

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Peer-Review History
Received: 27 December 2024
Reviewed & Revised: 18/January/2025 to 23/July/2025
Accepted: 29 July 2025
Published: 07 August 2025

Peer-Review Model
External peer-review was done through double-blind method.

Discovery Agriculture
pISSN 2347-3819; eISSN 2347-386X

ABSTRACT

Tomatoes are an excellent source of minerals and antioxidants (potassium, phosphorus, vitamins A, B, and C). Domestic consumption and demand are rising as a result of population increase and seasonal changes in output caused by climatic variability, both of which have grown prevalent in Nigeria. Hence, this study examined the impact of climatic variables on tomato production in Nigeria using time series data from 1980 to 2021 on tomato production. Data were analyzed using Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP), Johansen cointegration test, Vector Error Correlation Models (VECM), and Mann-Kendall test. Results from ADF and PP indicate that all the variables were stationary at the first difference orders. The Johansen cointegration result showed the presence of a long-run relationship, while VECM showed the short-run relationship of climatic factors on tomato production. Equally, the coefficient of Error Correction (EC2) confirmed the existence of a long-run relationship between tomato production and climatic variables. The Mann-Kendall test result showed that the Kendall tau (correlation coefficient) of temperature is positive and indicates increasing trend in temperature while that of rainfall was negative, indicating decreasing trend in rains as it affects tomato production in Nigeria. The study therefore recommended adoption of sustainable agricultural practices, efficient irrigation system and other climate innovative solutions for tomato production so as to increase and sustain tomato production in Nigeria.

Keywords: Climate change, Error Correlation, Mann-Kendall, Tomato production, VECM.

1. INTRODUCTION

Climate is a significant determinant of agricultural productivity and therefore affects the types of crops that can grow in a given area (Tawakalitu *et al.*, 2022). Agriculture is a complex sector involving several driving parameters such as: environmental, economic and social. It has become evident that crop production is susceptible to climate change, with its varying impacts across the globe (Osman *et al.*, 2021). According to the Intergovernmental Panel on Climate Change (2014), climate change can be defined as a change in climate conditions that can be detected by changes in time/or variability of its properties (using statistical tests), and that usually persists for an extended period of time, decades or more. The panel also recognized any

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change in climate over time, whether due to natural variability or as a result of human activity. This meaning has been established separately from the United Nations Framework Convention on Climate Change (UNFCCC), which defines it as climate change attributable directly or indirectly to human activity that alters the composition of the global atmosphere and, in addition, to natural climate variability observed over comparable periods. Ani and Anyika (2021) described climate variability as the long-term summation of atmospheric elements such as solar radiation, temperature, relative humidity, and precipitation, and their variations over time.

Literature is replete with numerous studies on climate variability and agricultural production in many developing countries (Tunde, 2019; Osman *et al*., 2021; Tawakalitu *et al*., 2022). Similarly, studies in Nigeria show that climate variability is mainly related to rainfall and temperature, and food crops (Ugonna *et al*., 2015; Ogbuchi, 2020; Nnadi *et al*., 2021). Therefore, food crops consist of various categories of crops, including vegetables, thus confirming the challenges these countries are facing concerning climate change. For instance, Cho (2018) asserted that the production of vegetables and legumes could decline by 35 percent by the year 2100 due to ozone depletion, water scarcity and increased salinity as long as greenhouse gas emissions continue on their current path. Nalik *et al.* (2017) showed that climate change affects vegetable production globally, but its nature and impact vary depending on the degree, geographic region, and agronomic practices employed.

A study by Abewoy (2018) revealed that changes in climatic elements since the 1960s have significantly affected agriculture in different ecological zones of Nigeria. As stated in the work of Ughelu (2017), Nigeria has been identified as one of the sub-Saharan African States that are vulnerable to changing climatic conditions. Some research works (Ikem, 2018; Uwazie, 2020) have shown that frequent environmental disasters in parts of Nigeria are attributable to unpredictable climatic variables, which invariably have worsened food productivity and human suffering over the decade. Changes in climatic variables brought about by climate change affect the six vegetative zones of Nigeria differently (Ughelu, 2017). In semi-arid Sudan and the Sahel savannah region, it brings low rainfall, drought and increased desertification; in the Northern and Southern Guinea Savannah belt, it changes rainfall patterns, often with late arrival of rain and a long dry season; the coastal zones experience severe flooding during the raining season (Ogbuchi, 2020). In rainforest zones, it delays the onset of rains, longer dry seasons, heat waves, and flooding around coastlines, while in mangrove swamps, it usually results in flooding of dry plains as continued sea level rise poses a threat to the natural environment (Berhanu & Wolde, 2019). Hence, these fluctuations in climatic factors not only affect the natural environment but also specifically hinder food crop production, which includes vegetables. Vegetable crops can be classified as fruit vegetables such as tomato, watermelon, garden egg, and cucumber. Vegetables contribute significantly to the caloric intake and nutrition as their consumption makes vitamins, minerals, and energy available to the human body (Nalik *et al*., 2017).

Tomato is one of the most important vegetable crops grown for its pulp (Tunde, 2019). The crop also contains potassium, iron, and calcium. Lycopene present in tomato fruit acts as an anti-carcinogen, which can prevent cancer, especially prostate cancer. Domestic consumption and demand for tomatoes are increasing due to population growth (Ochilo *et al*., 2019). Tomatoes are excellent healthy supplement and contain antioxidants such as ascorbic acid (Vitamin C), vitamin A, and tocopherol (Vitamin B). Tomatoes can be eaten fresh as a salad, used to cook in soups or stews, and to make fruit drinks, or pressed into a paste or puree, which are increasingly in demand in West Africa, where they form an essential part of the diet. It is among the major vegetable crops traded globally (Ajibare *et al*., 2022).

Data from Food and Agriculture Organization Statistical Database (2023) reveal that Nigeria is ranked 14th largest producer of tomatoes in the world and second only to Egypt in Africa, producing a total of 1.51 million metric tonnes (MMT) of tomatoes, valued at 87 billion naira and cultivated on 254,430 hectares of land. Its scarcity has become a common feature in Nigeria, which may be as a result of an increase in population and seasonal variations in output due to climate variability.

Climate variations affect tomato production because physiological, biochemical, and metabolic activities depend on temperature. Temperature can affect plants in several ways, ranging from plant growth time and viability, flowering, fruit development, and ripening (Lamin *et al*., 2022). Kondinya *et al.* (2014) reported that drought and salinity are two significant consequences of the temperature rise that impede vegetable production. Similarly, Abevoy (2018) pointed out that drought resulting from temperature rise influences the incidence of insect and disease host-pathogen interactions, thereby becoming a significant setback for tomato cultivation. Increase in temperature above recommended threshold levels usually results in viral diseases of fruit vegetables (Lamin *et al*., 2022) since the optimum temperature range for fruit set is 18 ^{o}C to 24 ^{o}C (Putland & Deuter, 2011). As stated by Ernest (2015), high temperatures would limit the yield of fruit vegetables because it increase developmental disorders in fruiting vegetables. With direct emphasis to the tomato crop, it has been depicted that it can compensate for temperature changes over a specific range and period, as well as thrive well in temperatures from 10 °C to 30 °C with an optimum temperature range of 21°C to 24 °C. However, daily mean temperatures between 27 °C to 29 °C can adversely affect tomato fruit set and yield (Malyse, 2021).

Available studies in Nigeria (Ugonna *et al*., 2015; Tunde, 2019; Tawakalitu *et al*., 2022; FAOSTAT, 2023) revealed evidence of fluctuating patterns in the trend of vegetable production. This could be connected to the change in climatic conditions. For example, Tunde (2019) observed that vegetable crops are generally susceptible to environmental extremes in the form of high temperatures, which is the leading cause of low yield. Ajibare *et al.* (2022) pointed out that an increase in temperature, a decrease in the availability of irrigation water, and flooding are the major limiting factors in sustaining and increasing tomato productivity. Similarly, Kalibbala (2011) reported that environmental factors such as temperature and rainfall affect tomato production. It was found that tomatoes are not tolerant to drought; hence, yields reduce significantly after any short period of water deficiency (Lamin *et al.,* 2022). Although, assessing the impact of climatic variables on crop yield can be mixed with so many complexities due to some underlying factors that affect productivity, such as improved technologies and management practices (Murenzi, 2018), determining the existence of any relationship between climatic elements and tomato productivity is fundamental in risk management (Osman *et al*., 2021).

Furthermore, the study is expected to give an in-depth insight into tomato crop production responses to the unpredictable rainfall patterns of the country, thereby providing helpful information for future agricultural planning and design of proactive measures against negative consequences of climate variability in Nigeria. Therefore, the question is: do the fluctuating patterns in tomato production in Nigeria deviate significantly from the past studies conducted over ten years ago? How do temperature and rainfall influence tomato production in Nigeria? It is against this background that this study analyses the effect of climatic factors on tomato production in Nigeria.

2. MATERIALS AND METHODS

The climatic variables considered were the 41 years of annual averaged time-series data observed of rainfall and temperature, as well as tomato production in Nigeria. The data were gathered from the Food and Agriculture Organization of the United Nations (FAOSTAT) and the Macro Trends database for the period of 1980 to 2021. The mathematical model function adopted from Tshiala *et al*. (2010) is specified thus;

TomProd = f(Rainfall, Temp) (1)

Where TomProd is the tomato production in metric tonnes; Rainfall is in mm; and Temp is temperatures (°C).

Ordinary Least Squares OLS is expressed thus;

$$TomProd = \beta_0 + \beta_1 Rainfall + \beta_2 Temp + e \quad (2)$$

Where;

β_0= Regression constant

$\beta_1 - \beta_2$= Coefficients of independent variables

e = Error term

In logarithm form as;

$$LnFPI = \beta_0 + \beta_1 LnRainfall + \beta_2 LnTemp + e \quad (3)$$

Where Ln is the natural logarithm

In order to conquer the non-stationarity occurrence and other restraining elements associated with the time-series analysis, Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests were used to test the stationarity of the data. The ADF model expressed as;

$$\Delta y_t = \mu_t + \varphi y_{t-1} + \sum_{i-1}^{p} \gamma_i \Delta y_{t-i} + \epsilon_t \quad (4)$$

Where;

Δy_t = Short-run persistence

p = Number of lags

Phillips-Perron (PP) model is expressed as;

$$d_{\alpha} = t_{\alpha}\left(\frac{\gamma_0}{f_0}\right)^{1/2} - \frac{T(f_0-\gamma_0)(se(\hat{\alpha}))}{2f_0^{1/2}S} \quad (5)$$

Where;

$\hat{\alpha}$ = Estimate

t_{α} = t-ratio of α

$se(\hat{\alpha})$ = Coefficient of standard error

S = Standard error

γ_0 = Consistent estimate of the error variance

f_0 = Estimate of the residual spectrum at frequency zero

In agreement with the result of ADF and PP unit root tests, Johansen cointegration test was employed to test the long-run relationship while the Vector Error Correlation Models (VECM) was used to estimate the short-run changeability of the data to equilibrium trend. The VECM model is expressed as:

$$\Delta y_t = \Pi y_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta y_{t-1} + \mu + \epsilon_t \quad (6)$$

Where;

Δy_{t-1} = First difference operator of (n x 1) vector of the n variables

y_{t-1} = Lagged values of Y_t

Δ = Difference operator

Π = (n x n) coefficient matrix

Γ = (n x (k-1)) matrix of short-run coefficients

μ = error term

ϵ_t = (n x 1) vector of white noise disturbances

The linear trends function of temperature on tomato as used by Tshiala *et al*. (2010) is expressed as;

$$f(X,t) = aX\,(t) + b \quad (7)$$

Where;

t(corresponding year) = 1, 2, … n

X(t) is the yearly average temperature

a is the linear trend ^{o}C/year)

Furthermore, the trends were examined using the Mann-Kendall test, as used by Capodici *et al*. (2008) and Aswad *et al.* (2020). The Mann-Kendall test was used to examine the increasing or decreasing trends (monotonic) of the dataset considered over time. The n time series values (X_1, X_2, … X_n) are substituted by their relative ranks (R_1, R_2, … R_n). The data were analyzed using Excel, Eviews, and gretl software. The Mann-Kendall (S) is expressed as;

$$S = \sum_{i-1}^{n-1} \sum_{j=i-1}^{n} sgn(X_j - X_i) \quad (8)$$

Where;

n = Number of data set points

X_j and X_i = Annual data values obtained in years' j and i, (j > 1)

Sgn (X_j – X_i) is estimated using the equation:

$$\mathrm{Sgn}(X_j - X_i) = \begin{cases} +1\ for\ (X_j - X_i) > 0 \\ 0\ for\ (X_j - X_i) = 0 \\ -1\ for\ (X_j - X_i) < 0 \end{cases} \quad (9)$$

Sgn (X_j –X_i) indicates the individual sign fitness that takes on the values (+1, 0, or -1). A positive sign (S) implies a regularly increasing trend, while a negative value suggests a downward trend.

The variance (S') equation is expressed as;

$$Var(S') = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right] \quad (10)$$

Where;

n = Number of data set points

g = Zero difference between the compared value numbers

t_p = Number of data set points in the P^{th} group

A standard measure test statistic for the Mann-Kendall (Z_{mk}) equation is expressed as;

$$Z_{mk} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, if\ S < 0 \\ 0\ if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, if\ S > 0 \end{cases} \quad (11)$$

The standardized Z_{mk} values adhere to the distribution of normal variance with "0" and "1"; it is used as a measure of trend significance. The intensity of the probability function of a normal distribution with a mean of 0 and a standard deviation of 1 is given as;

$$f(z) = \frac{1}{\sqrt{2\pi}^{e}} - \frac{z^2}{2} \quad (12)$$

The trend is held to be *decreasing* when the Z is negative and the computed probability is greater than the level of significance. The trend is held to be *increasing* when the Z is positive and the computed probability is greater than the level of significance. A situation where the calculated probability is less than the level of significance indicates that, there is *no trend*.

3. RESULTS AND DISCUSSION

Table 1 shows the unit root results using Augmented Dickey-Fuller [ADF] (Dickey & Fuller, 1979) and Phillips-Perron [PP] (Phillips & Perron, 1988) to investigate the stationarity properties of the variables. The ADF test checks for the constancy of the mean of the time series data over time, while the PP test checks for the equality/constancy of variance of the time series data over time. The result shows that rainfall is stationary (constant) at both levels and the first difference of the ADF and PP tests. The constancy of the annual average and variance of rainfall implies that the annual rainfall patterns over the years are relatively predictable. On the contrary, temperature was non-stationary at the ADF test (at ordinary level) but estimated to be stationary at first difference. However, temperature was stationary at the PP test both for the ordinary level and the first difference. This shows the possibility of variations in temperature over the years. The plausible explanation might be due to an unsustainable approach to agricultural expansion and intensification emanating from deforestation and indiscriminate farming practices. On the other hand, the non-variability of the result of the first difference suggests that the previous year's temperature has no traceable impact on the current year's temperature. Furthermore, the results reveal that tomato production is not stationary for both ADF and PP tests, but becomes stationary at first difference. This is an indication that variability in climatic conditions may have altered tomato production in the past four decades.

Table 1: Stationarity: Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) Unit Root Tests

Variables	ADF test Level	First difference	PP test Level	First difference
TomProd	0.123119 (0.9635)	-6.792735 (0.0000)***	-0.077831 (0.9451)	-8.967659 (0.0000)***
Rainfall	-6.652249 (0.0000)***	-7.229744 (0.0000)***	-6.629649 (0.0000)***	-16.18879 (0.0000)***
Temp	-1.415292 (0.5650)	-8.769029 (0.0000)***	-3.171057 (0.0291)**	-16.42075 (0.0000)***

Note: *** and ** indicate significance at 1% and 5% respectively

Source: Authors' Computation, 2023

Table 2 shows the Johansen Cointegration test of tomato production. Johansen Cointegration is generally used to determine the number of cointegrating relationships (r). The result indicates that the Trace test is two (2) cointegrating equations at the 0.05 level, while the Max-eigenvalue test indicates no cointegration at the 0.05 level. This denotes that the null hypothesis of no cointegrating equation (r = 0) is rejected while the alternative hypothesis of having one (1) cointegrating equation (r = 1) is recognized at the 0.05 level. This result agrees with Osman *et al.* (2021), who opined in their study in Gadaref State, Sudan, that the existence of any relationship between climatic elements and tomato production is fundamental in determining the risk management to adopt. Therefore, it is established that long-run relationships exist among the variables used in this study.

Table 2: Johansen Cointegration results of tomato production

Hypothesized No of CE(s)	Eigenvalue	Trace statistic	Prob.	Max-Eigen statistic	Prob.
None*	0.428406	47.02838	0.0184	21.81375	0.1551
At most 1*	0.288917	25.21463	0.0062	13.29767	0.3046
At most 2	0.263292	11.91696	0.0629	11.91696	0.0629

Note: * denotes rejection of the hypothesis at the 0.05 level; Lag interval (in first differences): 1 to 1; Log likelihood: -985.6952
Source: Authors' Computation, 2023

The Fully Modified Least Squares (FMOLS) model for the cointegrating regression has the advantages of correcting endogeneity bias and serial correlation. This necessitated its use in this paper to overcome the problem of serial correlation and endogeneity among the variables. Table 3 shows a long-run relationship of tomato production in Nigeria using FMOLS. The result shows that temperature is statistically significant at 1%, thus; has a long-run effect on tomato production in Nigeria. This is consistent with the findings of Tunde (2019), which affirmed that vegetable crops are vulnerable to extreme climatic conditions such as high temperatures because they lead to low yield. The result also agrees with Kalibbala (2011), who reported that environmental factors such as temperature affect tomato production in Rakai District, Uganda.

The presence of a cointegrating relationship between the dependent and independent variables, as shown by the Johansen cointegration test, obliged the assessment of the short-run operational deviation between the variables in the cointegrating relationship equation by assessing the Error Correlation Model.

Table 3: Cointegrating equation, deterministic: Long-run covariance estimate

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Constant	-1.42E+10	3.03E+09	-4.673507	0.0000***
Rainfall	160220.1	369682.9	0.433399	0.6672
Temp	5.22E+08	1.07E+08	4.879658	0.0000***
Long-run variance		4.16E+16		

Note: Dependent Variable: TomProd; Method: Fully Modified Least Squares (FMOLS); Sample (adjusted): 1981 2020; Cointegrating equation deterministics: C; Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth = 4.0000
Source: Authors' Computation, 2023

The Vector Error Correlation Models (VECM) are frequently used in situations when the cointegrating relationship (r) is greater than zero (0) and less than the number of variables in the model. Table 4 shows the VECM of tomato production. The result indicates that rainfall (d_Rainfall_1) coefficient (−0.0004) is negative; thus not statistically significant. This confirms the proof of negative impacts of the climatic factors on tomato production in both short-run and long-run in Nigeria. The Error Correction (EC) term proposes the long-run relationship. The coefficient of EC is negative and statistically significant. This shows the presence of a long-run causative relationship. The coefficient EC2 (-0.812332) is also negative (which is consistent with general expectations) and statistically significant at 1%. This confirms the existence of a long-run relationship between dependent and independent variables (tomato production with climatic variables of temperature and rainfall, *ceteris paribus)*. This shows the rate of correction to the previous year's short-run variability from the long-run constancy rate of the independent variables. In other words, this confirms that rainfall and temperatures, like other tropical countries sharing similar climatic variability, affect tomato production in Nigeria. The coefficient of the Error Correlation (EC) parameter (0.812) is significant at 1%, and consistent with the theoretical and statistical criteria in terms of sign and size of the estimate. This implies that 81.2% of the disequilibrium in tomato production due to short-run disturbances in the previous years is adjusted to the long-run equilibrium in the current year. In other words, the adjustment parameter (EC-1) depicts that short-run deviations were getting larger and larger as tomato production moved towards the long run at a convergence speed of 81.2% per year.

The coefficient of multiple determination (R-squared) is 0.492. This indicates that about 50% of the total deviations in the dependent variable (tomato production) were jointly influenced by the climatic variables included in the model. The Adjusted R-squared is 0.416, which implies that a reduction in the degree of freedom as a result of additional explanatory variables may not change considerably the goodness of fit of the regression equation, giving reliability to the variables incorporated in the model. Durbin-Watson value range of 1.5–2.5 implies there is absence of autocorrelation discovered in the disturbances. From Table 4, the Durbin-Watson estimation (1.9) was obtained. This means that the extraneous factors (such as management system, level of technology, improved seeds, and labour among others) – which invariably show up as the components of the disturbance term in this case, do not weigh much influence as to cause a significant change in the climatic factors of the subsequent year or current year.

Table 4: Vector Error Correction Models (VECM) of tomato production

Variables	Coefficient	Std. Error	t-ratio	p-value
Constant	22.6230	6.11074	3.702	0.0008***
d_TomProd_1	−4.07197e-010	5.47460e-010	−0.7438	0.4623
d_Temp_1	0.0107821	0.164292	0.06563	0.9481
d_Rainfall_1	−0.000375673	0.000441577	−0.8508	0.4010
EC1	1.05085e-09	2.77536e-010	3.786	0.0006***
EC2	−0.812332	0.215391	−3.771	0.0006***
Mean dependent var	0.013590	S.D. dependent var		0.299319
Sum squared resid	1.728004	S.E. of regression		0.228831
R-squared	0.492435	Adjusted R-squared		0.415531
Rho	0.043076	Durbin-Watson		1.910672

***, ** and * represent 1%, 5% and 10% respectively; Lag order 2

Source: Authors' Computation, 2023

The Mann-Kendall statistical test for trend analysis is employed to examine whether a given set of data values is at an increasing or decreasing trend (monotonic) over time, as well as to ascertain whether the trend is statistically significant or not. It is a non-parametric test, which means it can be used for all distributions. However, the data set should not be serially correlated. The null hypothesis suggests that there is no monotonic trend in the time series data collected, while the alternative hypothesis suggests that a trend exists. Table 5 shows the Mann-Kendall test results. The p-value (0.0001) for both tomato and temperature and tomato and rainfall is less than alpha (0.01) [0.0001 < 0.01]. This is an indication that the null hypothesis is in fact not true, thereby leading to the rejection. However, the alternative hypothesis, which suggests that there is a statistically significant trend in time series of tomato production and temperature as well as tomato and rainfall, taking into account the 41 years' time series data, is accepted.

Table 5: Mann-Kendall (MK) test/ Two-tailed test

	TomProd/Temp	TomProd/Rainfall
Kendall's tau	0.490	-0.149
U (standardized)	7.886	0.000
Expected value	882	861
S'	183856278	178807207

Var (S)	0.1009	9348.16
Pooled Variance	1.69016E+16	1.71102E+16
p-value (Two-tailed)	**<0.0001**	**<0.0001**
Alpha	0.01	0.01

Correlation is significant at the 0.01 level (2-tailed).
Source: Authors' Computation, 2023

The Kendall tau (rank correlation coefficient) is usually used to determine the monotony of the slope. Kendall tau (correlation coefficient) ranges between -1 and 1; a positive correlation coefficient indicates an increasing trend, while a negative correlation coefficient shows a decreasing trend. The Kendall tau (correlation coefficient) of temperature is positive (0.490), which signifies an increasing trend of temperature as it affects tomato production. This finding is consistent with Figure 1. Similarly, the Kendall tau (correlation coefficient) for rainfall is negative (-0.149), which signifies a decreasing trend of rainfall as it affects tomato production in Nigeria. (Figure 2). This negative sign of rainfall agrees with Aswad *et al*. (2020), whose finding was adverse in their study of the trend analysis of rainfall in Sinjar District, Iraq.

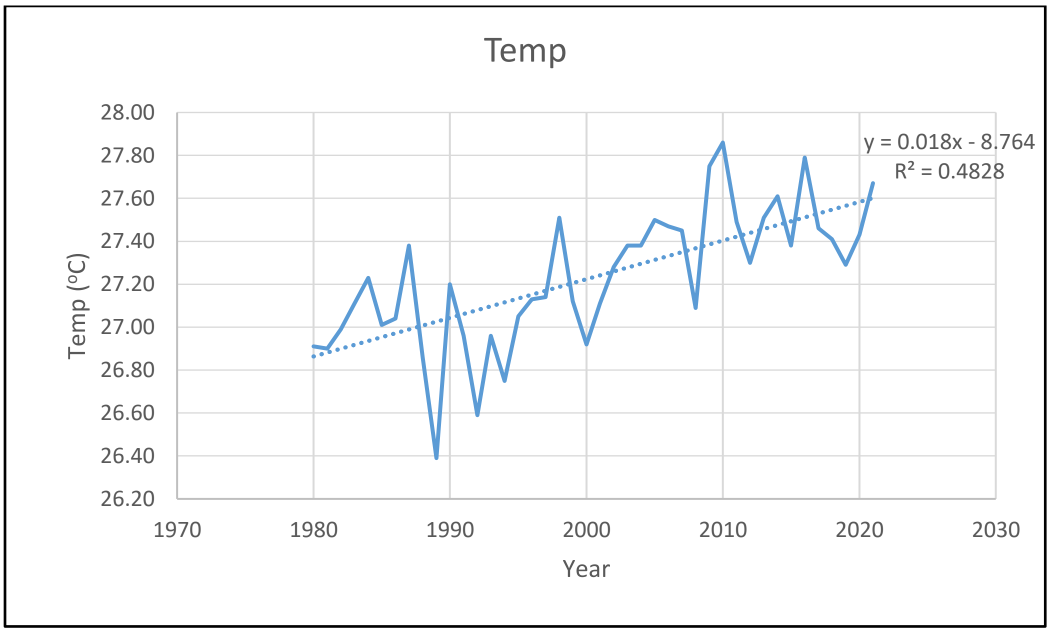

Figure 1: Temperature trends in Nigeria (Source: Authors' Computation, 2023)

Figure 1 shows the graphical representation of temperature trends in Nigeria for the year considered. It revealed the linear trendline temperature. From Figure 1, the temperature was at 27.20 ºC in 1990 while in 2010, the temperature was above 27.80 ºC before it declined to about 27.40 ºC in 2020. Nigeria has a mean temperature of 27.2 ºC over the years (1980 – 2021) considered in this research. Hence, the graph confirmed the existence of an undulating trend in temperature in Nigeria.

Figure 2 shows the graphical trends of rainfall in Nigeria over the years considered (1980 – 2021). It shows that the rainfall in Nigeria is above 800mm and less than 1400mm with mean of 1093.31mm. Between 2000 and 2010, rainfall assumed an average of 1000mm as shown in the graph while between 2010 and 2020 it exhibits increasing and decreasing patterns in subsequent order. This establishes the existence of a slightly unstable trend in rainfall in Nigeria.

Figure 3 shows the graphical trends of tomato production in Nigeria over the years (1980 – 2021) considered. It shows that between 1980 and 1990, production of tomato seems to be equal as increase in production of tomato rise from 1990 to about 200MMT in 2000 and increased further till 2005 before it experienced downward production till around 2011. Tomato production was highest around 2015, as shown on the graph. This production is a result of adequate rainfall and temperature. The optimum temperature for tomato production is between 26 ºC and 29 ºC Figures 1 and 2. Nigeria has a mean of tomato production of about 222MMT over the years (1980

– 2021) considered in this study. Therefore, climatic variables (rainfall and temperature) are very essential in tomato production in Nigeria, *ceteris paribus*.

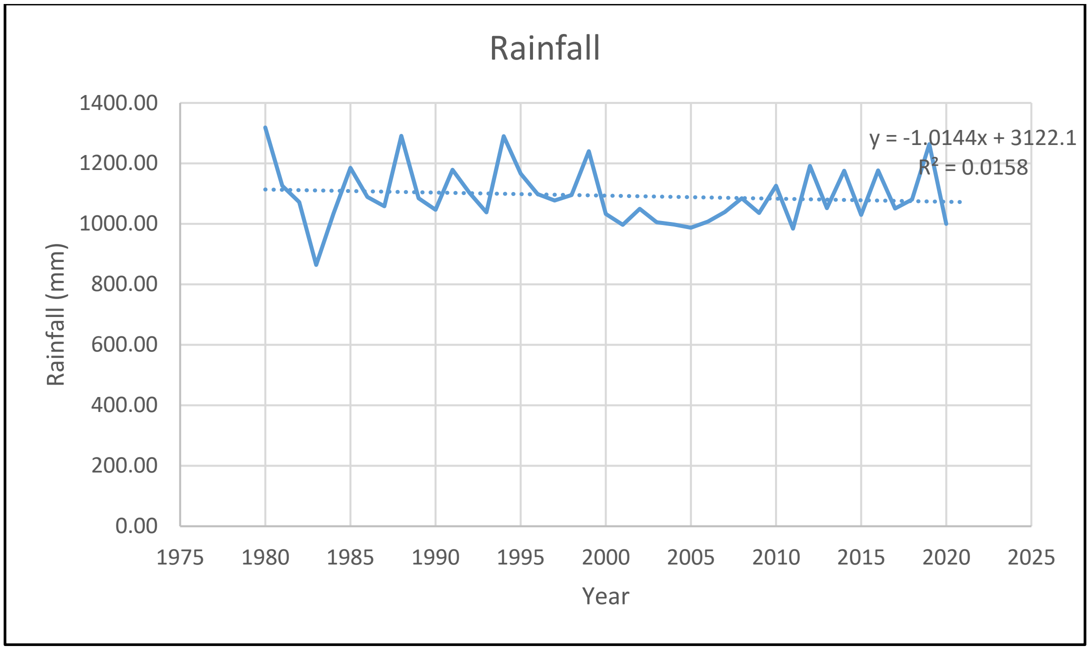

Figure 2: Rainfall trends in Nigeria (Source: Authors' Computation, 2023)

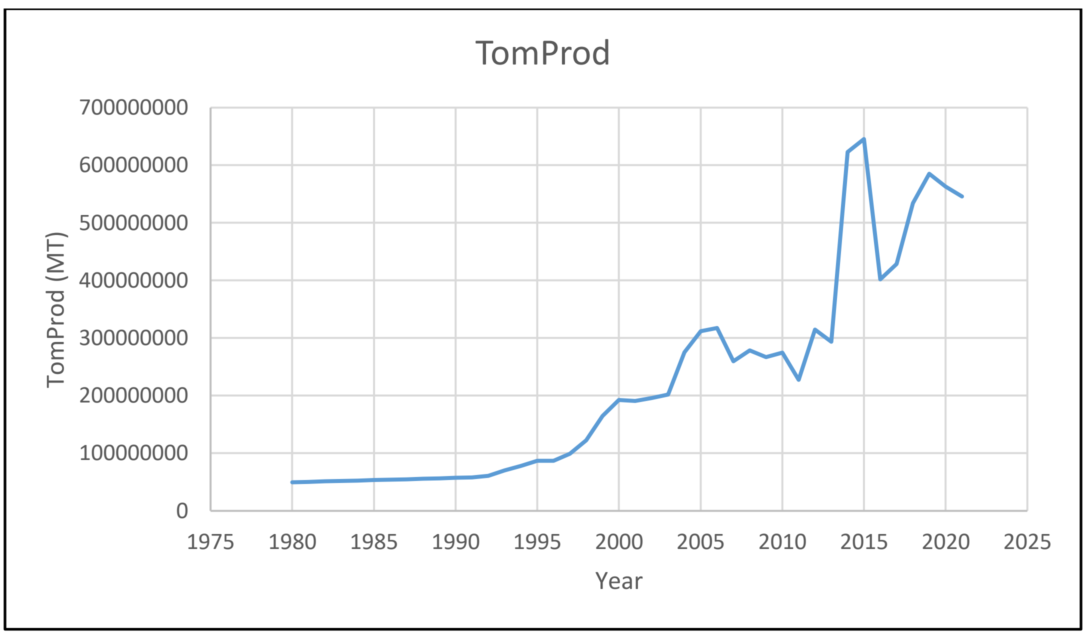

Figure 3: Tomato trends in Nigeria (Source: Authors' Computation, 2023)

4. CONCLUSION

This research examined the impact of climatic variables on tomato production in Nigeria. Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests were used to test the stationarity of the data; Johansen cointegration test was used to test the long-run relationship; The Vector Error Correlation Model (VECM) was used to test the short-run trend; Mann-Kendall test was used to ascertain the trend of correlation of climatic factors which include: the effects of temperature and rainfall on tomato production.

The results of the ADF and PP unit root tests indicate that all the variables were totally stationary at first difference orders for both ADF and PP. The Johansen cointegration result shows the presence of a long-run relationship among the variables used in this study. The VECM result indicates that rainfall coefficient is negative; buttressing the proof of the negative impacts of climatic factors on tomato production in both short-run and long-run in Nigeria. The coefficient of Error Correction (EC2) is negative, thus; confirming the existence of long-run relationship between tomato production and the climatic variables. The Mann-Kendall test results shows that Kendall tau (correlation coefficient) of temperature is positive, which invariably indicates increases in trend of temperature. However, rainfall is negative, showing a decreasing trend in rainfall patterns as it affects tomato production in Nigeria. Hence, the research recommends that:

i. The findings in this research would be of a great help when designing national climate-resilient development plan for increased food production by policy makers of agricultural sector in Nigeria.
ii. Farmers and other relevant stakeholders should shift attention to sustainable agricultural practices as well as increase investment in climate-smart solutions in tomato production so as to increase and sustain tomato production in Nigeria.
iii. The results revealed a significant influence between temperature and tomato production in Nigeria. This means that climatic variables, specifically temperature, indicate some ample proofs to conclude that agricultural operations, particularly tomato production could be affected by extreme heat waves, which brings about shortage in underground water. It is expected that relevant government stakeholders should give urgency to the need to ensure that proper irrigation facilities are installed and made accessible for increased tomato production so as to compensate for the loss of water due to drought, as well as stimulate proper biochemical and metabolic processes for optimum yield.
iv. It is possible that the dependence observed from the analysis does not account for all other environmental and management factor systems. Therefore, these results could be too optimistic because they are based on climatic factors of temperature and rainfall only, hence, other agricultural systems like capital, security, seeds, among others, could be incorporated to substantiate the significance of adaptive capacity.
v. Gridded data of climatic factors simulating likely future conditions are essential inputs for forecasts. Global circulation models (GCMs) are valuable sources of information commonly exploited to assess the potential impacts of climate change. There is an urgent need to encourage more institutions to engage in creating such datasets to provide dozens of possible choices as input.

Acknowledgement

We thank the Food and Agriculture Organization of the United Nations (FAOSTAT) and the Macro Trends for making the database accessible to us.

Author contributions

Conceptualization: ARA and EMEI; Methodology: ARA; Data gathering and curation: ARA; Formal analysis: ARA; Investigation and Supervision: EMEI, ARA, and OGC; Validation: EMEI and OGC; Visualization: ARA; Resources: OGC, EMEI, and ARA; Writing original draft: OGC, EMEI, and ARA; Review: ARA and EMEI; Editing of the manuscript: ARA, EMEI, and OGC. All authors have read and agreed to the published version of the manuscript.

Funding

The research did not receive any external financial support.

Conflict of interest

The authors declare that there are no conflicts of interests.

Ethical approval

Not applicable.

Informed consent
Not applicable.

Data availability
All data associated with this study will be made available based on the reasonable request to corresponding author.

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