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ANALYSIS OF CLIMATE CHANGE EFFECTS ON CASSAVA PRODUCTION IN NIGERIA

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Abstract

This study ascertained how climate change affects cassava production in Nigeria. The study was done based on a 60-year dataset covering rainfall, temperature, relative humidity, and sunshine duration from 1963-2022, using multiple regression models, unit root, and co-integration tests for assessment of these climate variables' influence on the yield of cassava. The results indicated that temperature had the most substantial positive effect on cassava production (β=28,422,368.77, p=0.000), followed by relative humidity (coefficient = 147,217.28, p=0.000) and rainfall (β = 22,111.27, p=0.034). Sunshine duration, however, showed no significant effect (p=0.892). The model's high R-squared value (0.705) supported its robustness, and diagnostic tests confirmed no issues with serial correlation or heteroskedasticity. These findings highlighted the vulnerability of cassava production to climate variability and suggested the need for adaptive measures to sustain agri-food system in Nigeria.

Key words: *climate change, cassava production, Nigeria, rainfall, temperature*

INTRODUCTION

One of the staple crops that is essential to Nigeria's agri-food system is cassava. It is a significant source of carbohydrates and gives millions of smallholder farmers a way to earn money and ensure food security [15]. With production areas spanning the country's central and southern regions, Nigeria is the world's largest producer of cassava [22], [20]. However, in the last few years, the consequences of climate change have become a significant issue in both the production of cassava and the agricultural sectors [19]. Long-term changes in the average temperature, normal rainfall patterns, and other climatic variables brought on by natural processes and human activity like burning fossil fuels and deforestation are referred to as climate change [12]. Agriculture is greatly affected by climate change since each crop has specific weather requirements for its efficient growth. Cassava, although very tolerant to hostile environmental conditions, does not exclude vulnerability to impacts caused by climate change. Changes in the amount of rainfall and temperature can directly impact its yield, pest prevalence, and soil conditions [14], [18].

Cassava production is very important in Nigeria for food and economic security, adding immense value to the livelihood of rural households [17, 15]. Drought tolerance is one of the strengths of the crop, though the changing climate brings more uncertainty concerning its productivity. For example, irregularity in the rainfall season affects water availability and therefore water use efficiency during planting and growth of the crop, yield and farmers' income [5]. Similarly, extreme heat may reduce the potential of cassava to produce at optimal levels [2]. The climate of Nigeria varies, with the South being humid because of the coastal regions and the North being semi-arid. Rising temperatures, more frequent extreme weather events, and a shifting rainfall pattern over the last few decades have all demonstrated it [10]. These are anticipated to persist into the future, and it is necessary to assess these developments in relation to important crops like cassava. Different studies show that climate change is most likely to increase the occurrence of droughts, floods, and heatwaves in Nigeria [3].

The majority of earlier research from around the globe has shown how climate change affects agricultural output. For example, [2] discover that climate variability, particularly with regard to temperature increases and water availability, has a substantial impact on crop productivity in Nigeria. In the meantime, research on how climate change affects Nigerian agriculture's productivity with relation to staple crops like cassava has been conducted in [9] and [7]. Notwithstanding this growing corpus of research, it still seems unclear how exactly environmental factors like temperature, rainfall, relative humidity, and sunshine length impact cassava productivity in Nigeria over the long run.

The majority of the research tends to concentrate more on the broad effects of climate change on Nigeria's agri-food systems than on the special function of cassava, a crop that is both poor soil-tolerant and highly drought-tolerant [16]. While the works of [13], [6] and [18] suggested cassava as one of the crops that is suitable for climate adaptation, these studies have been mostly based on short-term assessments. This, therefore, makes the gap this study tries to address is very relevant concerning issues in detailed and long-term analysis of climate change effects on cassava production in Nigeria.

By addressing that gap, this study will help develop climate-smart agricultural methods and policies that will support cassava production even in the face of climate change.

MATERIALS AND METHODS

Nigeria, which lies between latitudes 4°N and 14°N off the equator and longitudes 3°E and 15°E of the Greenwich meridian, was the study's location. Legislatively, Nigeria is a democratic, secular country divided into 36 states, with Abuja as the Federal Capital Territory. Cassava is mainly grown in the Southern and Central Zones of the country prominently in States like Benue, Kogi, Edo, Delta, and Oyo where conditions are more favourable for its cultivation. These areas fall within the tropical and sub-tropical climates, having distinct wet and dry seasons. However, with the effect of climate change, there has been considerable change in the pattern of rainfall and temperature throughout the country. These States have become critically vulnerable to the unpredictable weather conditions of those zones traditionally known for cassava production.

Data Collection

A set of time series data were used which contained the mean annual temperature, relative humidity, rainfall, sunshine duration, and cassava production output from 1963 to 2022. Data were extracted from Food and Agriculture Statistics (FAOSTAT) and the Central Bank of Nigeria (CBN) database.

Data Analysis

The descriptive statistics of mean annual temperature, relative humidity, rainfall, and sunshine duration variations in Nigeria from 1963 to 2022 were used. In this regard, the series was subjected to a unit root test so that the time series data could check whether they were stationary or nonstationary. A co-integration test was conducted to study the long-run relationship among the variables. Multiple regression analyses were used to establish the effect of varied climate factors on the production of cassava.

Unit Root Test

The analysis began with a stationarity test to determine whether the variables were stationary and if the model specification was suitable. The regression equation used to assess stationarity, as described by [11] as cited by [21], is as follows:

$$\Delta lnCAS = \alpha_0 + \sum_{t-1}^{p} \alpha_1 \Delta lnRFL_{t-1} + \sum_{t-1}^{p} \alpha_2 \Delta lnTEMP_{t-1} + \sum_{t-1}^{p} \alpha_3 \Delta lnRH_{t-1} + \sum_{t-1}^{p} \alpha_4 \Delta lnSSD_{t-1} + \beta_1 lnRFL_{t-1} + \beta_2 lnTEMP_{t-1} + \beta_3 lnRH_{t-1} + \beta_4 lnSDD_{t-1} + U_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

The unit root problem was accessed through hypothesis as follows:

H0: $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0$ (the time series CAS has a unit root)

Ha: $\alpha_1<0$, $\alpha_2<0$, $\alpha_3<0$, $\alpha_4<0$ (the time series CAS has no unit root)

Where:

α_0= constant term

U_t =white noise

α_1- α_4 = coefficients of the first difference variables
β_1- β_4 = coefficients of the explanatory variables
p = lag length
CAS = Cassava production (metric tonnes)
RFL = Rainfall (millimetres)
TEMP = Temperature (ºC)
RH = Relative humidity (percentage %)
SSD = Sunshine duration (hours)

Co-Integration Test

The Johansen maximum likelihood co-integration test was used to ascertain the variables' long-term association. As described by [11] as cited by [21], co-integration identifies long-run equilibrium between variables, this is shown below:

$$\Delta lnCAS_t = \alpha_0 + \beta_1 lnRFL_{t-1} + \beta_2 lnTEMP_{t-1} + \beta_3 lnRH_{t-1} + \beta_4 lnSDD_{t-1} + u_t \dots\dots\dots\dots \quad (2)$$

Multiple Regression Model

The multiple regression model is as specifiedd below:

$$CAS_t = f(RFL_t, TEMP_t, RH_t, SDD_t) \quad (3)$$

The regression model can further be specified in linear form as follows:

$$CAS_t = \beta_0 + \beta_1 RFL_t + \beta_2 TEMP_t + \beta_3 RH_t + \beta_4 SDD_t + U \quad (4)$$

RESULTS AND DISCUSSIONS

Descriptive Statistics

The result in Table 1 shows the descriptive statistics summarizing variability and central tendencies related to cassava production and its associated climatic factors in Nigeria. On one hand, cassava production is highly concentrated, with a mean of over 28 million tonnes, and the difference between the minimum and maximum is large, which indicates considerable fluctuation over time. On the other hand, rainfall is similarly characterized by high means of 1,149.705 mm, with considerable variability that could be an influential factor in determining cassava yield. Meanwhile, other meteorological conditions, such as temperature, relative humidity, and sunshine duration, are relatively steady because their mean and median values are close, indicating stable conditions in general as also observed by [23].

Standard deviations further emphasize variability, especially in cassava production and rainfall. The standard deviation of cassava production is high, indicating high variability across the years, probably because of climatic or socioeconomic factors. Rainfall indicates a medium variation due to the value of its standard deviation-a result that could be impactful since cassava growth is sensitive to water. The lower variabilities in temperature, humidity, and duration of sunshine indicate very stable climatic conditions that are quite generally favourable to cassava production because most extreme values are few, disrupting such aspect of production.

Table 1. Descriptive statistics

Statistics	CAS	RFL	TEMP	RH	SSD
Mean	28152837	1149.705	27.089	57.626	6.251
Median	29656000	1160.655	27.110	57.386	6.237
Maximum	65350850	1335.280	27.860	61.770	8.800
Minimum	7783000	872.040	26.270	53.950	4.500
Std. Dev.	18341552	86.056	0.388	1.494	0.901
Skewness	0.468	-0.539	-0.208	0.268	0.419
Kurtosis	1.856	3.600	2.293	3.109	3.415
Jarque-Bera	5.460	3.805	1.679	0.749	2.186
Probability	0.065	0.149	0.432	0.688	0.335
Sum	1692847315.428	68982.286	1625.362	3457.567	375.049
Sum Sq. Dev.	19812475938624157.277	436932.771	8.888	131.656	47.866
Observations	60	60	60	60	60

Source: Made by authors based on Data Analysis, 2024.

There is a slight positive skewness of cassava production, indicating that the yield was extremely high in some years. The rainfall data have a mild negative skewness, with kurtosis just a little above 3, indicating a peaked distribution with extreme low values of rainfall. Temperature, humidity, and duration of sunshine have distributions near normal. The Jarque-Bera test results in confirming normality approximation for all climatic variables; this will further enable the analysis, such as regression modelling, for any assessment of their impacts on cassava yield. This analysis thus suggests that rainfall might be an important variable driving cassava production variability, whereas temperature, humidity, and sunshine provide relatively stable cultivation conditions over the observed period.

Trend of Climatic Variables and Cassava Production in Nigeria

The long-term trend in Nigeria's climate and cassava production is depicted in Fig. 1, which also demonstrates the sudden shifts in both variables between 1963 and 2022. According to the data set, Nigeria's cassava production increased from 7.8 million tonnes to nearly 60 million tonnes between 1963 and 2022. This probable long-term growth emanates from improved agronomic practices, government supports and initiatives for the crop, and farmers' adaptation to climatic conditions. However, periodic declines-most notably in the early 1980s, 2009-2010, and 2015 indicate sensitivity of this production to fluctuating climate and other external factors. While cassava production has been resilient, recent fluctuations might insinuate that emerging challenges are linked to the impacts of climate change on the staple crop.

The temperature is slowly rising from year to year; the average annual temperature increased from about 26.6°C in the early 1960s to over 27.5°C in recent years. Such a warming-up trend is in line with the global pattern promoted by climate change and thus may affect cassava physiology and yield. Cassava is normally resistant to moderate temperature increases, but very high temperatures or continuous rise may stress the plants, thereby reducing production. Indeed, slight cassava production has been seen during periods of temperature increases or variability, as in the early 1980s and 2000s, which suggests that temperatures could play a factor in its production.

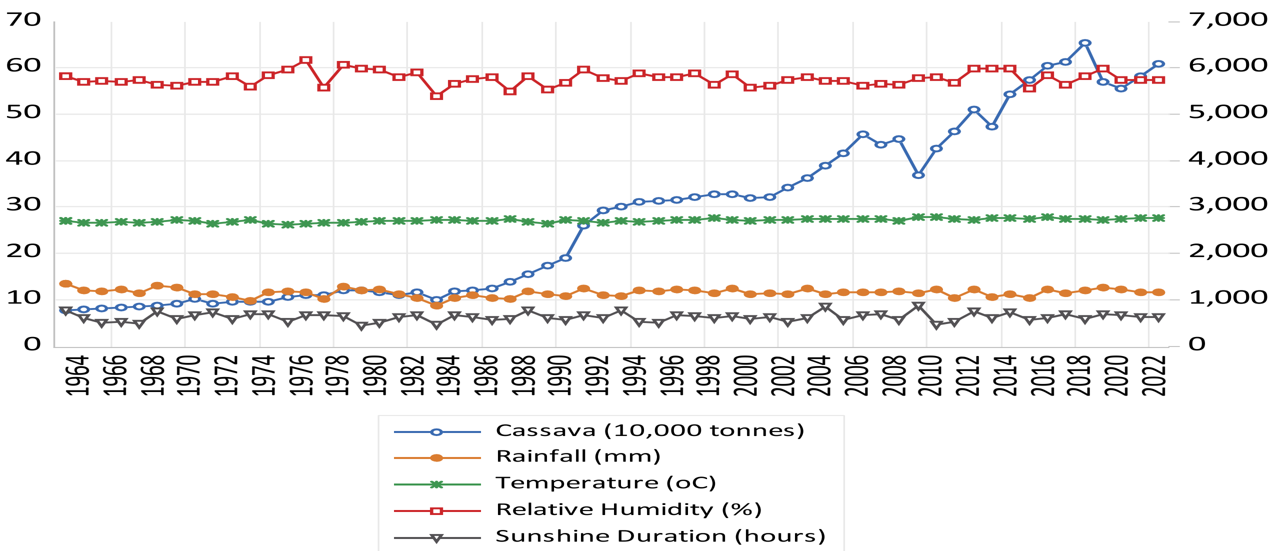

Fig. 1. Trend of climatic variables and cassava production in Nigeria
Source: Made by authors based on Data Analysis, 2024.

Other climate parameters such as relative humidity, rainfall, and sunshine duration vary from year to year and thus show a positive correlation with some aspects of production variation. For instance, rainfall is very inconsistent between years, and this may be reflected by poor production in dry years such as 1983 and 2010.

Variations happened in relative humidity and sunshine duration, and those would probably have effects on production through their influence on cassava growth and yield. These climatic factors are interrelated in such a way that they expose cassava producers in Nigeria to a myriad of challenges toward adapting to climate variability. With the persisting current climate movements of rising temperature and unpredictable rainfall patterns, cassava output may reach a breaking point beyond which adaptation measures have to be taken to sustain its productivity levels.

Unit Root Test

The data were subjected to Unit Root Tests, namely the Augmented Dickey-Fuller (ADF) Test, in order to deduce their stationarity and their order of integration for the annual data ranging from 1963 to 2022.

In this regard, results show in Table 2 that all the variables are integrated of order 1 (1^{st} difference).

Table 2. Unit root test

Variable	Level difference	prob	1^{st} diff	prob	Order of integration
CAS	0.372	0.980	-7.965	0.000	I (1)
RFL	-6.161	0.000	-12.879	0.000	I (1)
TEMP	-1.298	0.625	-11.145	0.000	I (1)
RH	-7.061	0.000	-13.868	0.000	I (1)
SSD	-7.287	0.000	-9.612	0.000	I (1)

Source: Made by authors based on Data Analysis, 2024.

Lag Order Selection Criteria

Table 3 displays the results for the selected lag order based on the criterion used. In this model, Lag 1 was chosen, as all selection criteria indicated a significant probability level of 5% at this lag.

Table 3. Lag Order Selection Criteria

Lag	Log L	LR test	Final prediction error	Akaike information criterion	Schwarz information criterion	Hannan-Quinn information criterion
0	-1538.44	NA	228473692158264915.382	54.156	54.335	54.225
1	-1403.36	241.719*	4803527916284735.649*	50.293*	51.369*	50.711*
2	-1386.4	27.374	6504193287561842.317	50.576	52.547	51.342
3	-1368.33	26.002	8741658392475216.853	50.819	53.686	51.934
* Shows lag order chosen by the criterion						

Source: Made by authors based on Data Analysis, 2024.

Cointegration Test

Table 4 results show that the null hypothesis (H_0) of no co-integrating equation is rejected, revealing at least one co-integrating equation at the 5% significance level.

Table 4. Cointegration Test

Cointegration Test				
Endogenous variables: CAS, RFL, TEMP, RH, SSD				
Johansen-Hendry-Juselius: Cointegrating				
Unrestricted Cointegration Rank Test (Trace)				
Hypothesized		Trace	0.05	Prob.**
No. of CE(s)	Eigen value	Statistic	Critical Value	Critical Value
None *	0.602	118.057	69.819	0.000
1* at most	0.462	64.667	47.856	0.001
2 at most	0.246	28.688	29.797	0.067
3 at most	0.189	12.300	15.495	0.143
4 at most	0.003	0.175	3.841	0.676
Trace test shows 2 cointegrating equation(s) at the 0.05 level				

Source: Made by authors based on Data Analysis, 2024.

Regression Analysis

The effect of several climatic parameters on Nigeria's cassava output from 1963 to 2022 is displayed in Table 5's regression analysis results. According to this result, the rainfall coefficient at 22,111.266 has a p-value of 0.034, making it significant at the 5% probability level. As a result, a one-millimeter increase in rainfall over the preceding time has resulted in a very significant rise in cassava yield of almost 22,111 tonnes. In an agri-food system that relies only on rainfall, such as Nigeria, this positive link serves as further evidence that rainfall is the primary driver in cassava production, especially when it comes to providing the moisture needed for crop growth. [22] also reported the positive influence of rainfall on cassava production and food security in general in Nigeria and suggested the use of irrigation facilities in the areas with low rainfall as the surest way of maintaining the level of productivity of cassava. The result therefore calls for water management mechanisms in the form of water use efficiency, especially in cases where climatic variability has increased erratic rainfall patterns.

On the one hand, temperature also explains a strong beneficial influence on cassava production, with a high coefficient of 28,422,368.765 and statistical significance of p=0.000. The result shows that such a case indicates that with an increase in temperature by one degree Celsius from the previous period, there is the possibility of an increase of about 28 million tonnes of cassava. These findings agree with those of [1], who indicate that temperature is indeed an essential determinant of cassava yield and sometimes outweighs the impact of rainfall on production. However, this relationship might be complicated, as too much heat can evaporate the moisture and thus make the conditions unfavourable for growth. On the other hand, increased temperature may have benefited cassava to a point but could be expected to be eventually reversed by extreme fluctuations or too much heat. This would again create a need to breed cassava for the adaptation of heat and drought tolerance. Another climate variable, relative humidity, has a positive and significant coefficient with a value of 147,217.280 (p=0.000) showing increasing levels of humidity are positively linked with increased yields of cassava. This finding finds support in [20], which postulated that humidity played a significant role in cassava production, given its predominant contribution to an environment suitable for growth due to low evaporation rates, hence the maintenance of soil moisture. Highly humid conditions may be quite favourable in that there could be a reasonably assured supply of moisture that the cassava plants would require for their good development. The findings give more strength to the notion that there should be an integrated perception of temperature, rainfall, and humidity for sustainable cassava production under a changing climate.

The effect of sunshine duration on cassava output, however, does not reach statistical significance (p = 0.892), suggesting that the variation in sunshine hours during the preceding period is not very important for cassava yield in this investigation. Indeed, [8] discovered that while the length of daylight may have an impact on agricultural output, other climate factors like humidity and rainfall have a greater impact on cassava productivity. The insignificance in sunshine could therefore mean that cassava is a hardy crop and less responsive to changes in sunshine than to water availability and temperature.

The estimated Error Correction Model (ECM) coefficient is -0.589, with a p-value of 0.000, highly significant, hence indicating rapid adjustment speed toward long-run equilibrium in response to any disequilibrium in cassava production. This negative value of the ECM coefficient justifies the fact that any deviation from the long-term trend of cassava production, due to external shocks or climate variability, has been corrected by about 58.9% every year. This finding is concurrent with that of [9], who found that the ECM coefficient indicates the resilience of cassava production to climate-induced shocks. This rapid adjustment shown suggests adaptability by farmers of cassava in Nigeria, who might have embraced certain practices to minimize the impacts of climatic variation, change on cassava, hence ensuring stability in the levels of output.

In this model, the constant term, C, has a negative sign and is statistically significant;

this may suggest that fluctuations in the level of cassava produced in Nigeria are determined by other non-climatic factors. Probably, the significant negative constant captures the structural problems inherent in the agricultural sector of Nigeria, such as input non availability, inadequate market linkage, and land degradation, which over time may be affecting cassava yield adversely, irrespective of climate conditions. Ajayi [4] also identified farm size, farmer experience, and the cost of inputs as significant determinants in cassava production, suggesting that the productivity level may, otherwise, be shaped by non-climatic variables. This further buttresses the fact that policies for sustainable cassava production should aim at both the climatic and non-climatic aspects.

The R^2 value of 0.705, which indicates that 70.5% of the variation in cassava production is explained by the included climate variables, therefore reflects a very strong model fit. The F-statistic stands at 25.387 and is statistically significant, thus generally confirming the reliability of the model in explaining cassava production trends. In addition, the Durbin-Watson statistic is 1.784, showing no problem of autocorrelation and further enhancing these findings for robustness.

Table 5. Regression Analysis

Variable	Coeff.	Std. Error	t-Statistic	Prob.
RFL (-1)	22111.266**	11647.522	1.898	0.034
TEMP (-1)	28422368.765***	3801758.251	7.476	0.000
RH (-1)	147217.280***	45493.437	3.236	0.000
SSD (-1)	213838.862	1561085.660	0.137	0.892
ECM (-1)	-0.589***	0.127	-4.657	0.000
C	-776493119.311	126972699.454	-6.115	0.000
R^2	0.705	F-statistic		25.387
Adjusted R^2	0.678	D.W. Stat.		1.784

Where *** and ** are significant at 1% and 5% respectively.
Source: Made by authors based on Data Analysis, 2024.

Normality test

Normality test of residuals in Fig. 2 indicates that the model behaves well and meets some important regression assumptions. According to the Jarque-Bera test statistic of 0.401 (p-value = 0.818), residuals are normally distributed, with their mean effectively at zero at 6.50e-09 and standard deviation of approximately 9.93 million units. The negligible negative skewness of -0.151 and a near-normal kurtosis of 2.73 reflect a minimal deviation from normality, and the symmetry around zero suggests an unbiased model. All that put together points to the model demonstrating the link between climate variables and cassava output reliably.

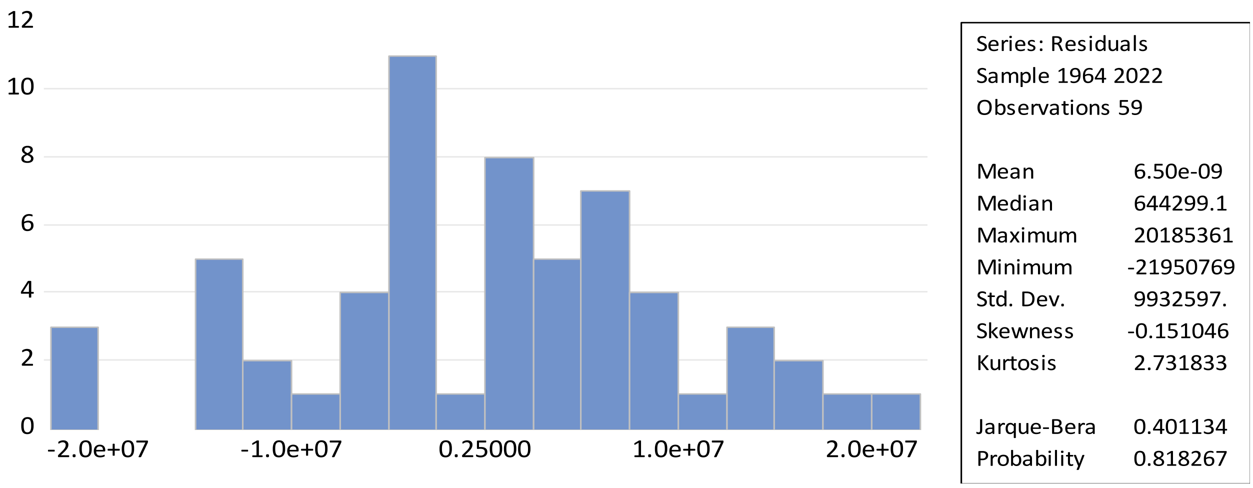

Fig. 2. Normality test
Source: Made by authors based on Data Analysis, 2024.

Ramsey reset Test

The Ramsey RESET test results in Table 6 indicate that the model used is appropriately specified, with no evidence of functional form misspecification. Both the t-statistic (1.338) and F-statistic (1.790) yield p-values of 0.187, which are above conventional significance levels, suggesting that there is no need to reject the null hypothesis of correct specification. The likelihood ratio result (1.997, p=0.158) further supports this conclusion, reinforcing that the model does not suffer from omitted nonlinearities or interaction terms that would improve its fit. Consequently, the results suggest that the significant climatic factors such as rainfall, temperature, and relative humidity are well-captured in the model, affirming the reliability of its findings on climate impacts on cassava production.

Table 6. Ramsey reset Test

Statistic	Value	df	P-value
t-stat.	1.338	52	0.187
F-stat.	1.790	(1, 52)	0.187
Likelihood ratio	1.997	1	0.158

Source: Made by authors based on Data Analysis, 2024.

Breusch-Godfrey Serial Correlation LM Test

Table 7 presents results that surpass standard significance standards (e.g., 0.05), including an Obs*R^2 value of 1.869 with a p-value of 0.172 and an F-statistic of 1.701 with a p-value of 0.198. According to these findings, there is insufficient data to rule out the null hypothesis that there is no serial association at up to one lag. This suggests that the model's residuals are not significantly autocorrelated, supporting the reliability of the regression model and reinforcing that the estimated effects of climate variables on cassava production are not distorted by serial correlation.

Table 7. Breusch-Godfrey Serial Correlation LM Test

F-Stat.	Obs*R^2	Prob. F(1,52)	Prob. χ^2 (1)
1.701	1.869	0.198	0.172

Source: Made by authors based on Data Analysis, 2024.

Heteroskedasticity Test: Breusch-Pagan-Godfrey

The test results in Table 8 assess for heteroskedasticity, or non-constant variance, in the residuals of the regression model analysing climate change effects on cassava production. The null hypothesis of homoskedasticity is supported by the F-stat. (1.663, p=0.160) and Obs*R^2 (7.999, p=0.156), which both produce p-values above accepted significance limits. Additionally, the scaled explained sum of squares result (5.590, p=0.348) indicates that the model does not contain heteroskedasticity.

Table 8. Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-stat.	Prob. F(5,53)	Obs*R^2	Prob. χ^2 (5)	Scaled explained SS	Prob. χ^2 (5)
1.663	0.16	7.999	0.156	5.59	0.348

Source: Made by authors based on Data Analysis, 2024.

CONCLUSIONS

has analysed the effect of climate change on cassava production in Nigeria based on how variations in rainfall, temperature, relative humidity, and length of sunshine affect cassava output. The estimated results indicate that rainfall, temperature, and relative humidity positively and significantly affect cassava production, while sunshine duration is insignificant. According to these findings, cassava will be impacted by climate variability, mostly through the adoption of water use efficiency and a slight increase in temperature, even though it is resistant to these changes. Extreme weather beyond these, meanwhile, would put cassava's tolerance and higher output per hectare to the test. The study therefore promotes the implementation of climate-smart agricultural techniques that will guarantee the sustainability of Nigeria's cassava output, given that the country's climate change estimates show an increase in the frequency of extreme weather events. Since cassava is a staple commodity that is associated with food security, these results from the study call for immediate adaptation in agriculture to ensure livelihoods at the level of smallholder farmers, hence ensuring food security at a national level. In the light of the importance of rainfall in cassava, it is hereby recommended that irrigation systems should be invested in, especially in areas that experience unpredictable rainfall patterns. It will address the risk associated with water shortages in critical growth phases.

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