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Climate variability and agricultural productivity: A time-series regression analysis of cassava, yam, and maize yields in Wenchi, Ghana

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ABSTRACT

This study examined the impacts of climate variability and cultivated land area on the yields of cassava, yam, and maize in Wenchi Municipality, Ghana, from 2000 to 2021. Using a quantitative approach, the study employed time-series data on rainfall, minimum and maximum temperatures, crop yields, and cultivated area. Multiple linear regression models with logarithmic transformations were used to assess the influence of climate variables and cultivated area on crop yields. Diagnostic tests confirmed the validity of model assumptions. The regression results revealed that temperature variables, especially minimum temperature, had a significant positive effect on all three crop yields. Maximum temperature also showed positive effects, although with varying levels of significance. Rainfall and cultivated area had no statistically significant impact on yields. The models explained 46.87%, 51.28%, and 61.57% of the variations in cassava, yam, and maize yields, respectively. Temperature played a more critical role than rainfall or cultivated land in influencing crop yields in Wenchi over the study period. These findings underscore the need for temperature-focused adaptation strategies and climate-smart agriculture to enhance food security and resilience in the transitional zones of Ghana.

Keywords: climate variability, rainfall trends, temperature trends, cultivated land area, crop yields, Wenchi Municipality, Ghana

INTRODUCTION

Human activities are among the primary drivers of environmental degradation, posing a significant threat to the planet's capacity to sustain a growing population (Holleman et al., 2020). These anthropogenic actions have profoundly influenced climatic conditions, particularly climate variability, which refers to fluctuations in seasonal and annual weather patterns relative to long-term climatic norms (Amikuzuno & Donkoh, 2012; Holleman et al., 2020). This variability has produced global consequences, including rising temperatures, altered precipitation patterns, and notable seasonal inconsistencies (Holleman et al., 2020). Elevated temperatures increase evapotranspiration rates in plants, thereby affecting water retention and photosynthetic efficiency (Dwyer et al., 2021). Conversely, lower temperatures can reduce metabolic activity, subsequently impeding plant growth (Abdul-Rahaman & Owusu-Sekyere, 2017). Precipitation plays a critical role in transporting nutrients essential for crop development, and fluctuations in both temperature and rainfall during the growing season can adversely affect soil moisture levels, ultimately undermining agricultural productivity (Gopalakrishnan et al., 2019).

Agricultural systems across the globe are significantly affected by climate variability, with the magnitude and nature of these impacts differing according to crop type, irrigation practices, and geographical location (Kukal & Irmak, 2018). As global temperatures continue to rise, both the frequency and intensity of climatic events, such as extreme temperatures and irregular rainfall, are projected to increase. This trend poses a substantial threat to the sustainability of agriculture and the security of global food systems, particularly in regions where economies are heavily dependent on agriculture (Holleman et al., 2020; Norbu & Basnet, 2022). In Africa, where agriculture remains central to economic livelihoods, concerns surrounding food insecurity are intensifying due to heightened vulnerability to climate fluctuations (Ayumah et al., 2020). In the absence of robust climate adaptation measures and targeted development interventions, projections indicate that extreme climate variability could exacerbate poverty across the continent by 2050, with particularly severe implications for countries such as Ghana (Jafino et al., 2020).

The agricultural sector remains a cornerstone of Ghana's economy, contributing approximately 23 percent of the national Gross Domestic Product (GDP) and providing employment for over 60 percent of the population (Akanni et al., 2020; Kwakye, 2023). Within this sector, the crop subsector holds particular significance, underpinning national food security and serving as the foundation for export activities and agro-industrial development. It accounts for roughly 65 percent of Ghana's agricultural GDP (Akanni et al., 2020). Between 1994 and 2013, the agricultural sector experienced consistent growth, averaging an annual rate of 4.5 percent. Cocoa, one of the country's primary export commodities, recorded a growth rate of 5.6 percent, while root and tuber crops grew by 4.9 and 5.6 percent, respectively (Diao et al., 2019). This sustained expansion has enabled staple food production to keep pace with demographic growth, which averaged 2.5 percent annually, alongside a 2.9 percent annual increase in per capita income (Diao et al., 2019). Ghana ranks among the world's leading producers of several key crops, including cassava, yam, plantain, maize, rice, oil palm, oranges, pineapples, groundnuts, and coconuts. Notably, the country was the fourth-largest producer of cassava globally in 2020, with an output of 22 million tonnes, and the second-largest producer of yam, with an annual production of 8.5 million tonnes (Akanni et al., 2020; Mabaya et al., 2022).

Empirical studies suggest that the primary driver of increased food crop production in Ghana since 1995 has been the expansion of cultivated land, surpassing the influence of other contributing factors (Diao et al., 2019; Essegbey & McCarthy, 2020). This land expansion has notably improved production per hectare, particularly for crops that experienced substantial increases in cultivated area during this period (Diao et al., 2019). A report by Ghana's Ministry of Food and Agriculture (MoFA) in 2019 indicated that the total cultivated area for major crops expanded from 2.4 million hectares in 1992 to over 4 million hectares by 2012 (Essegbey & McCarthy, 2020). Key staples such as groundnut, plantain, cowpea, yam, coconut, maize, rice, and cassava benefited from this growth, largely in response to rising food demand driven by population increases and higher per capita income (Diao et al., 2019). This expansion of arable land has not only contributed to increased crop output but has also reinforced food security initiatives and deepened the agricultural sector's contribution to national GDP, while providing employment and livelihood opportunities for a substantial segment of the population (Akanni et al., 2020).

Although recent improvements have been recorded in the yields of certain key food crops in Ghana, substantial declines persist in others, particularly yam, rice, sorghum, maize, and cassava. These crops have exhibited yield gaps of approximately 40 percent, 33.3 percent, 40 percent, 38 percent, and 57.5 percent, respectively (Arndt et al., 2015; Essegbey & Maccarthy, 2020). The primary cause of these yield reductions is climate variability and change, which continue to exert considerable pressure on Ghana's agricultural sector. A combination of environmental stressors-including inconsistent rainfall patterns, flooding, elevated temperatures, pest infestations, crop diseases, drought episodes, soil degradation, and altered wind patterns-has undermined crop productivity (Asante & Amuakwa-Mensah, 2014; Braimah et al., 2021). Climate projections further indicate that yields for crops such as cassava and maize are likely to decline in the future, due to continued temperature increases and reduced rainfall levels (Arndt et al., 2015; Braimah et al., 2021). Moreover, the incidence of complete crop failures is expected to rise, with an average occurrence estimated at once every five years across the country (Kasei et al., 2014).

A substantial body of research has investigated the impact of climate variability on crop production, consistently highlighting significant threats to agricultural sustainability at both regional and global levels. In the United States Great Plains, Kukal and Irmak (2018) demonstrated that climate variability influences the yields of maize, sorghum, and soybean. Their findings indicate that while rising temperature trends benefit maize, they have adverse effects on sorghum and soybean. In contrast, precipitation trends were found to positively influence the yields of all three crops. In Nigeria's Delta State, Emaziye (2015) observed that rainfall variability negatively affects the yields of cassava, maize, and yam, and further noted that increasing temperatures and declining rainfall patterns reflect broader indicators of global warming. In Tanzania, climate variability has also been shown to significantly affect yields of maize, sorghum, and rice. Projections suggest that anticipated temperature increases by 2050 could reduce yields of these crops by 13 percent, 8.8 percent, and 7.6 percent, respectively (Rowhani et al., 2011). Similarly, in China, research by Shuai et al. (2013) revealed that the El Niño-Southern Oscillation (ENSO) plays a critical role in shaping the yields of rice, wheat, and corn, with intra-seasonal variations in rainfall and temperature serving as key determinants of agricultural performance.

Empirical studies conducted across various regions in Ghana underscore the complex and multifaceted impacts of climate variability on crop production. In the Ashanti Region, Dwamena et al. (2022) reported that elevated maximum temperatures were associated with reduced yields of cassava, maize, and yam, while increases in minimum temperatures had a specific adverse effect on maize. In the Lawra District, Ndamani and Watanabe (2015) found that annual rainfall exhibited varying effects on the yields of peanuts, maize, cowpea, sorghum, and millet, thereby illustrating the crop-specific sensitivity to rainfall variability. Similarly, Cudjoe et al. (2021), in their study of the Ejura-Sekyedumase Municipality, observed that while maize yields improved under conditions of well-distributed rainfall, they declined significantly in response to elevated temperatures. In the Akim Achiase area, Aninagyei and Appiah (2014) identified strong correlations between temperature and rainfall fluctuations and the production of rice and maize. Furthermore, in the Worobong ecological zone, Kyei-Mensah et al. (2019) linked reductions in the yields of tomato, cassava, plantain, and cocoyam to increasing rainfall variability, emphasizing the broader climatic pressures facing diverse agricultural systems in the country.

A substantial body of research has examined the intricate relationship between climatic conditions and agricultural productivity, demonstrating that the sensitivity and resilience of crops vary considerably across different regions and crop types (Cudjoe et al., 2021; Emaziye, 2015; Kukal & Irmak, 2018; Ndamani & Watanabe, 2015; Shuai et al., 2013). Despite these contributions, the role of cultivated land area in explaining variations in crop yields has often been underemphasized. This gap underscores the necessity for localized studies that take into account the specific environmental and agricultural contexts of individual regions. While extensive literature exists on the general impacts of climate variability on agricultural production in Ghana, there remains a noticeable scarcity of place-based investigations. In particular, the Wenchi Municipality has received limited scholarly attention, with few studies specifically analyzing the effects of temperature and rainfall variability on crop yields within this locale.

To address this gap, the study examined the impact of rainfall, temperature, and cultivated area on the yields of cassava, yam, and maize in Wenchi Municipality, Ghana. This area is recognized for its substantial production of staple crops, which are essential for local economic stability and food security (Adjei et al., 2020; Adjei-Nsiah, 2012). However, Wenchi experiences significant climatic challenges, including erratic and declining rainfall as well as increasing temperatures, which have resulted in shorter growing seasons and delays in planting (Quagraine et al., 2017). These climatic changes have adversely affected crop production and the livelihoods of farmers who rely on natural weather patterns (Adjei et al., 2020; Yarney et al., 2021). The study's findings are critical for informing strategies aimed at promoting sustainable crop production and facilitating effective climate change adaptation in Wenchi. A deeper understanding of how temperature, rainfall, and cultivated area influence crop yields can assist policymakers and agricultural practitioners in implementing targeted interventions to mitigate climate-related risks and strengthen agricultural resilience within the municipality.

MATERIALS AND METHODS

Study Site

Wenchi Municipality is situated in the western part of the Bono Region of Ghana, between latitudes 7°15' North and 7°30' South, and longitudes 2°17' West and 1°55' East (See **Figure 1**). It spans an area of approximately 1,145 square kilometers and shares boundaries with Bole and Kintampo South districts to the north, Techiman North to the east, Sunyani West to the south, and Banda and Tain districts to the west. The municipality lies within the transitional agroecological zone and experiences two distinct rainy seasons, which typically peak between June and July and again between September and October. The dry season occurs from December to March (Adjei et al., 2020). Wenchi was selected as the study site due to its extensive agricultural activity during both the wet and dry seasons (Adjei et al., 2020; Quagraine et al., 2017).

Data Collection

The study employed a quantitative research methodology, which involves the systematic collection and analysis of numerical data to quantify variables, identify relationships, test hypotheses, and make informed predictions. This approach is widely recognized for its capacity to produce statistically valid results that can inform decision-making processes and contribute meaningfully to the existing body of academic knowledge within a given field (Apuke, 2017).

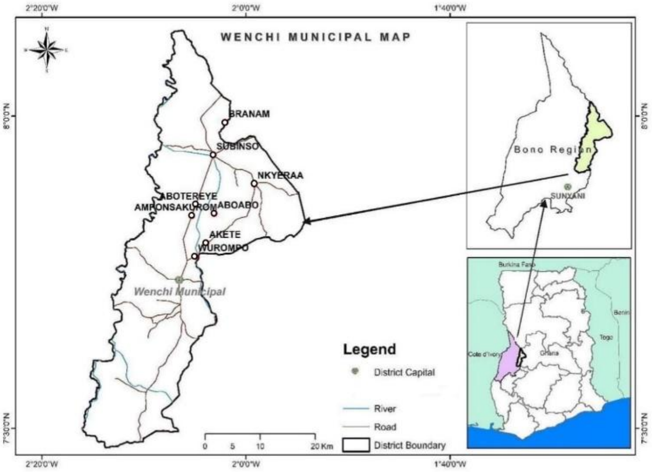

Figure 1. Map of Wenchi Municipality (Adjei et al., 2020)

Three distinct datasets were utilized in this study. The first consisted of a 22-year record, from 2000 to 2021, of average monthly temperature and rainfall data obtained from the Ghana Meteorological Agency (GMA). This dataset was critical for assessing long-term climatic patterns and their potential influence on crop production (Maharjan & Joshi, 2013). The second dataset included annual crop yield records for cassava, yam, and maize, gathered from the Ministry of Food and Agriculture (MoFA) over the same period. These crops were selected due to their widespread cultivation and importance to both household food security and local economies in the Wenchi Municipality (Adjei et al., 2020). The third dataset comprised information on the annual area of cultivated land for each of the selected crops, also sourced from MoFA. The inclusion of cultivated land area as a variable was essential, given its significant role in influencing yield outcomes and reflecting shifts in agricultural land use strategies (Diao et al., 2019).

The decision to use a 22-year dataset was informed by the methodological recommendation of Ayumah et al. (2020), who contend that data spanning a minimum of 15 years provides a robust basis for analyzing the effects of climate variability on agricultural productivity. This extended temporal scope enhances the reliability of the findings and allows for the observation of long-term trends and anomalies that shorter timeframes may obscure.

Data Analysis

Data analysis was conducted using tables and trend charts to facilitate the interpretation of results and enhance the clarity of observed patterns. Time series analysis was employed to assess trends in climatic variables, specifically temperature and rainfall, as well as the yields of major staple crops, including cassava, yam, and maize, over the 22-year period. This analysis was performed using the linear trendline and line chart functions available in Microsoft Excel. These tools enabled the visualization of long-term trends and fluctuations across the variables under investigation.

The slope of each trendline, representing the rate of change over time, was calculated using a statistical formula to determine whether the observed variables were increasing, decreasing, or remaining relatively stable. Estimating the slope offers a quantitative means of evaluating directional changes and is particularly useful for identifying persistent patterns or anomalies in time series data. As noted by Aswad et al. (2021), this method provides a reliable approach for interpreting long-term climate and agricultural trends. The slope was calculated using the formula below:

$$s = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2} \quad (1)$$

In this formula: "s" represents the slope of the trendline; "n" is the number of data points; $\sum x^2$ is the sum of the squares of the x values; $\sum xy$ is the sum of the product of the x and y values for each data; $\sum x$ is the sum of all x values; $\sum y$ is the sum of all y values; "x" values are the rainfall figures, and "y" values are the years under study.

The study employed conventional multiple linear regression models to evaluate the influence of cultivated area, annual minimum and maximum temperatures, and annual rainfall on the yields of three major crops: maize, yam, and cassava. The analysis was conducted using the Ordinary Least Squares (OLS) estimation method within STATA Statistical Software, version 17. Multiple regression modeling was selected due to its robustness in examining the relationship between multiple independent variables and a continuous dependent variable, a method supported by previous studies in the field (Ayumah et al., 2020; Onoja & Ajie, 2012).

To ensure the reliability and validity of the model's estimates, the analysis accounted for several critical assumptions, including the normal distribution of residuals, homoscedasticity (constant variance of errors), and the absence of serial correlation among residuals. Failure to meet these assumptions can result in biased coefficient estimates and misleading statistical inferences, thereby compromising the credibility of the findings (Ayumah et al., 2020; Beyer et al., 2015).

Diagnostic tests were conducted to confirm that these assumptions were satisfied. Specifically, the Breusch-Godfrey test was used to detect serial correlation, the Jarque-Bera test was applied to assess normality, and the Breusch-Pagan test was used to evaluate heteroscedasticity. The significance level for the analysis was established at $p \leqslant 0.1$, allowing for the detection of moderately strong effects. The standard multiple regression model utilized in the study is presented as follows:

$$Y = \alpha + b_1X_i + b_2X_i \ldots\ldots b_nX_n + e_i \quad (2)$$

In this context: "Y" is the dependent variable; "X" is the independent variable; "α" is the intercept; "b" is the regression coefficient (the coefficient of X); and "e" represents the stochastic error term.

To address the nonlinear relationships observed between crop yields, cultivated area, and climatic variables, a logarithmic transformation was applied to the data. This statistical transformation is widely used in regression analysis to normalize skewed distributions, minimize the influence of extreme values, and enhance the overall stability and reliability of the model's residuals. As noted by Curran-Everett (2018), applying logarithmic transformations can also improve the interpretability of coefficients in models where the relationships between variables are multiplicative rather than additive.

In this study, separate regression models were developed for each of the selected staple crops, which included cassava, yam, and maize, to account for their unique agronomic responses to climate and land-use variables. This approach allowed for more precise estimation of the individual effects of temperature, rainfall, and cultivated area on crop-specific yield outcomes.

$$PC_i = \alpha + b_1Rn_i + b_2MnT_i + b_3MxT_i + b_4AC_i + e_i \text{..log\_log Linear Model} \quad (3)$$

$$PY_i = \alpha + b_1Rn_i + b_2MnT_i + b_3MxT_i + b_4AC_i + e_i \quad (4)$$

$$PM_i = \alpha + b_1Rn_i + b_2MnT_i + b_3MxT_i + b_4AC_i + e_i \quad (5)$$

In this context: "Rn" is the yearly rainfall in millimeters (mm), "MnT" is the mean yearly minimum temperature in degrees Celsius (° C), "MxT" is the mean yearly maximum temperature in degrees Celsius (° C), "e" is the stochastic error term, " α " is the model's intercept, "PC" is the yearly cassava yield per hectare, "PY" is the yearly yam yield per hectare, "PM" is the yearly maize yield per hectare, and "AC" is the yearly area cultivated in hectares (ha).

RESULTS AND DISCUSSION

Variation and Trends in Rainfall

Figure 2 presents the annual rainfall patterns in the Wenchi Municipality from 2000 to 2021. The data reveal that annual rainfall generally remains below 1,600 millimeters, with an overall average of approximately 1,231.5 millimeters. Certain years recorded particularly high rainfall levels, peaking at 1,549 millimeters, while others experienced significantly lower amounts, ranging between 948 and 987 millimeters. These fluctuations reflect considerable interannual variability. The highest annual rainfall was documented in 2010, whereas the lowest was observed in 2015. A trendline analysis indicates a modest but consistent decline, with a slope of -4.99, suggesting an average annual reduction of approximately 4.99 millimetersAlthough this decline appears minor in absolute terms, its potential long-term impact on agricultural productivity should not be underestimated. These findings are consistent with previous research conducted by Quagraine et al. (2017) and Holleman et al. (2020), both of which observed declining and erratic rainfall patterns in the Wenchi Municipality.

Figure 3 further illustrates standardized rainfall anomalies, showing that the years 2000, 2001, 2006, 2009, 2011, 2012, 2013, 2015, 2016, 2017, and 2020 experienced negative deviations from the long-term average. These negative anomalies signal the occurrence of meteorological

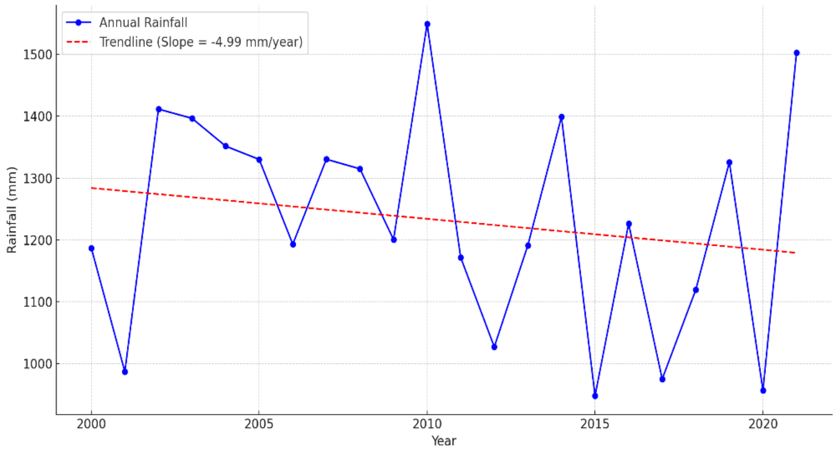

Figure 2. Annual rainfall data for Wenchi GMA (2000-2021) (Source: Authors' own elaboration)

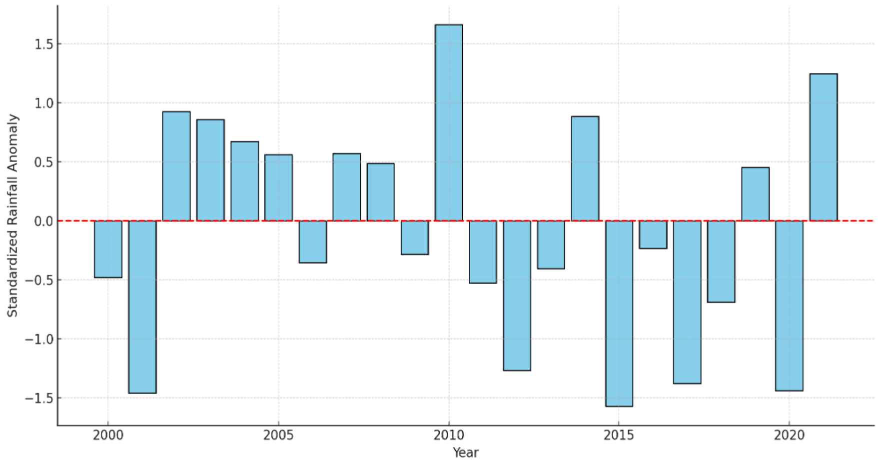

Figure 3. Standardized anomalies for the annual rainfall data (2000-2021) (Source: Authors' own elaboration)

droughts, indicating below-average rainfall and the likelihood of moisture stress during the growing season. In particular, the years 2001, 2012, 2015, 2017, and 2020 were notably affected. In contrast, the remaining years exhibited positive anomalies, reflecting relatively wetter conditions. Supporting these observations, Braimah et al. (2021) identified a decreasing trend in seasonal rainfall across agroecological zones in Ghana from 1901 to 2010. Similarly, Asante and Amuakwa-Mensah (2014) as well as Adjei and Kyerematen (2018) emphasized the evolving impacts of climate change in Ghana, including the extension of dry seasons and a reduction in the length and intensity of wet periods. The observed inconsistency and long-term decline in rainfall across the Wenchi Municipality presents a growing concern for agricultural communities, as these changes threaten both crop performance and the stability of rural livelihoods.

Variability and Trends in Temperature

Minimum temperature

Figure 4 presents the mean annual minimum temperatures in the study area from 2000 to 2021, which ranged between 19.9°C and 22.9°C, with a calculated average of approximately 21.8°C over the 22-year period. Notably, the years 2005 and 2011 recorded minimum temperatures that closely aligned with this long-term average. The highest

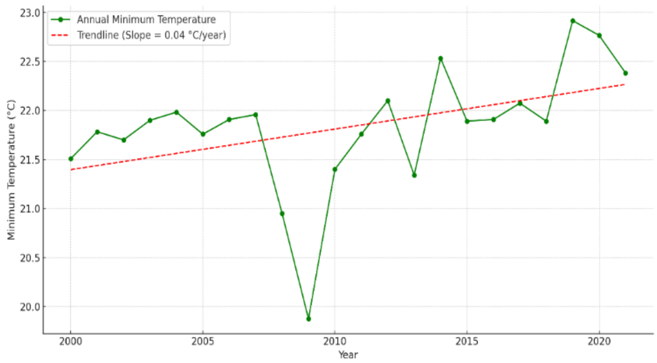

Figure 4. Annual minimum temperature data for Wenchi GMet (2000-2021) (Source: Authors' own elaboration)

minimum temperature occurred in 2019, reaching 22.92°C, while the lowest was observed in 2009 at 19.88°C. The overall trend analysis indicates a gradual increase in minimum temperatures, with a computed slope of 0.04. This suggests an average annual rise of approximately 0.04°C. Although the rate of increase appears modest, it reflects a persistent warming trend that is consistent with global climate change patterns documented in the literature (Adjei & Kyerematen, 2018; Holleman et al., 2020).

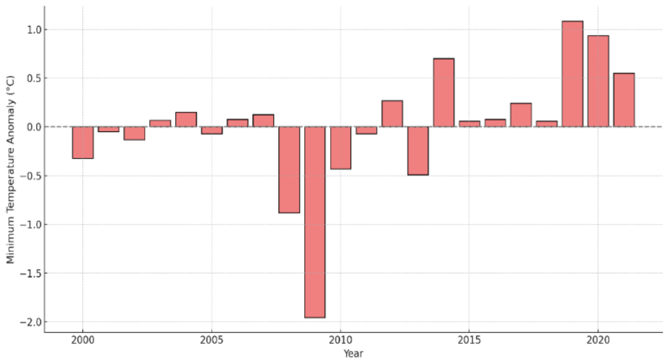

Figure 5. Standardized anomalies for annual minimum temperature data (2000-2021) (Source: Authors' own elaboration)

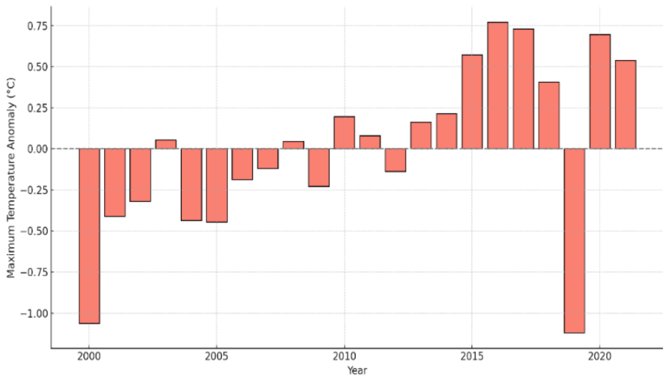

Figure 7. Annual maximum temperature data for Wenchi GMet (2000-2021)

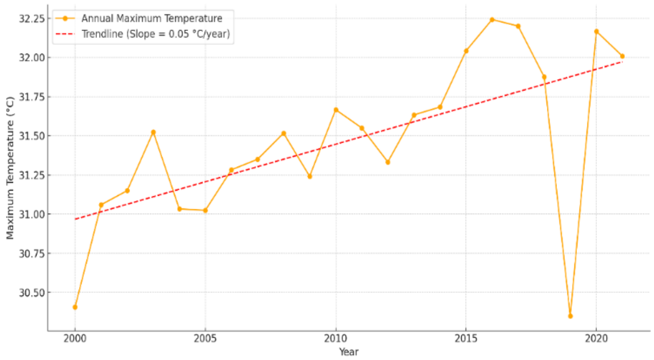

Figure 6. Annual maximum temperature data for Wenchi GMet (2000-2021)

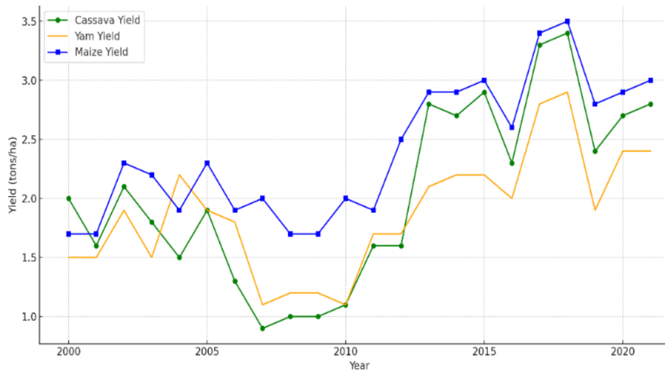

Figure 8. Annual Cassava, Yam, and Maize Yield data for Wenchi MoFA (2000-2021) (Source: Authors' own elaboration)

Figure 5 illustrates the standardized anomalies in annual minimum temperature, revealing periods of deviation from the long-term mean. Negative anomalies, such as −2.4 in 2008, −4.86 in 2009, −0.7 in 2010, and −1.31 in 2013, represent cooler-than-average years. In contrast, the years 2014, 2019, 2020, and 2021 exhibited positive anomalies of 2.36, 3.92, 3.04, and 1.87, respectively, indicating warmer-than-average conditions. The frequency and magnitude of positive anomalies in recent years underscore a concerning upward shift in minimum temperature levels. This warming trend has significant implications for agriculture in the Wenchi Municipality. As noted by Hatfield and Prueger (2015), elevated night-time temperatures can accelerate plant respiration rates, thereby reduce net carbon assimilation and ultimately leading to diminished crop yields. These findings suggest that rising minimum temperatures may pose a growing threat to crop productivity and food security in the region, necessitating adaptive strategies for climate-resilient agriculture.

Maximum temperature

Figure 6 illustrates the annual mean maximum temperature recorded in Wenchi Municipality from 2000 to 2021, reflecting the average of the highest temperatures observed each year. The data reveals considerable interannual variability. For instance, the years 2000, 2004, and 2019 exhibited maximum temperatures that fell noticeably below the long-term average of 31.5°C, with recorded values ranging between 30.4°C and 30.35°C. In contrast, warmer years such as 2016, 2020, and 2021 experienced maximum temperatures exceeding 32.0°C, with the highest value of 32.2°C observed in 2016. These fluctuations suggest the influence of a complex interplay of factors, including solar radiation intensity, atmospheric circulation patterns, and changes in land use and vegetation cover, as reported by Holleman et al. (2020).

Figure 7 presents the standardized anomaly, which quantifies the extent of deviation from the long-term average. Negative anomalies recorded in 2000, 2001, and 2019 indicate relatively cooler periods, whereas positive anomalies observed in 2016, 2017, 2020, and 2021 reflect warmer conditions. The computed warming trend, with an average slope of 0.05, demonstrates a gradual increase in temperature over time, despite interannual fluctuations. This trend is consistent with global studies documenting rising temperatures across West Africa as a result of climate change, as reported by Holleman et al. (2020). Studies report that high temperatures are associated with decreased germination rates and stunted plant development, which often result in increased crop mortality and lower yields (Kwakye, 2023). These challenges highlight the urgent need for proactive and adaptive strategies to manage climate variability.

Variation and Trends in Crop Yield

Figure 8 illustrates the yield trends of cassava, yam, and maize in Wenchi Municipality from 2000 to 2021, revealing distinct patterns and degrees of variability for each crop. Cassava yields displayed considerable fluctuations, with the highest yield of 3.4 tonnes per hectare recorded in 2018 and

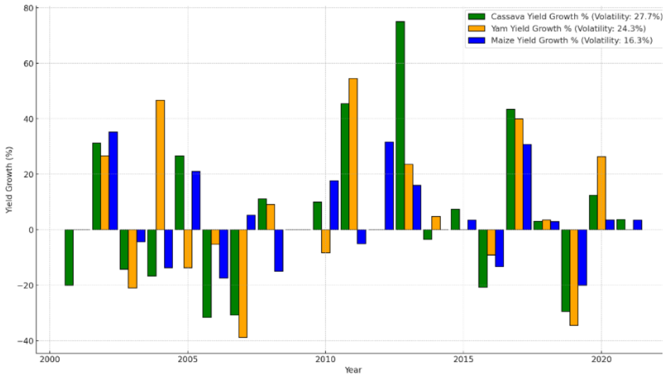

Figure 9. Annual yield percentage growth for Cassava, Yam, And Maize (Source: Authors' own elaboration)

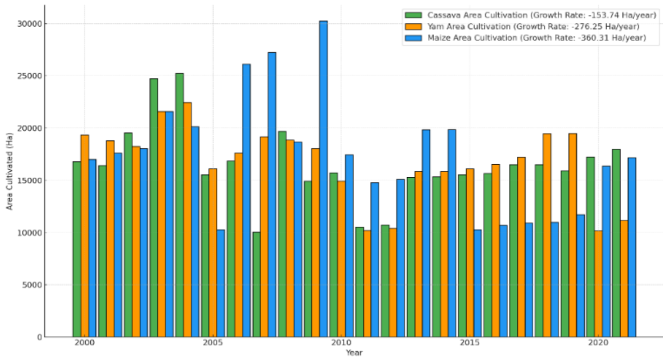

Figure 10. Annual area cultivation data for Wenchi MoFA (2000-2021) (Source: Authors' own elaboration)

the lowest of 0.9 tonnes in 2007. Between 2007 and 2018, a notable upward trend was observed, with cassava yields increasing at an average rate of approximately 0.075 tonnes per hectare per year. Despite this positive trajectory, cassava exhibited the greatest level of yield volatility among the three crops, reflected in a standard deviation of approximately 27.7 percent. This high degree of variability is further confirmed in **Figure 9**, which presents the annual percentage growth anomalies, indicating more pronounced fluctuations in cassava yields relative to other crops. These findings are consistent with national data, which report a significant rise in cassava output, positioning Ghana as the fourth-largest producer globally with an estimated 22 million tonnes in 2020 (Akanni et al., 2020; Mabaya et al., 2022).

Yam production, by contrast, showed relatively stable yield levels throughout the period under review. The highest yield of 2.9 tonnes per hectare was achieved in 2014, 2015, and 2020, while the lowest, at 1.1 tonnes, was recorded in 2007. Yam yields increased at a slower average rate of approximately 0.047 tonnes per hectare per year. The standard deviation of about 24.3 percent suggests moderate variability in yam production, which is less severe than that of cassava. **Figure 9** further illustrates this moderate fluctuation, with yield anomalies indicating consistent, though subdued, annual percentage growth. The relative stability in yam production is aligned with Ghana's national profile, where the country ranks second in global yam production, reporting a total output of 8.5 million tonnes in 2020 (Mabaya et al., 2022). The slower yield growth may be attributed to yam's sensitivity to environmental factors and differences in agronomic practices.

Maize yields in Wenchi Municipality also demonstrated year-to-year variability but followed a generally upward trend from 2007 to 2018. The highest recorded yield was 3.5 tonnes per hectare in 2018, whereas the lowest, approximately 1.7 tonnes, occurred in several years including 2000, 2001, 2008, and 2009. The average growth rate for maize yield was approximately 0.071 tonnes per hectare per year, which closely parallels the growth trajectory of cassava. Among the three crops, maize exhibited the lowest yield volatility, with a standard deviation of about 16.3 percent, indicating relatively stable performance. This trend is further supported by the yield anomalies presented in **Figure 9**, which show more consistent annual percentage growth for maize compared to cassava and yam. The observed yield improvements are consistent with national agricultural trends, which have been influenced by strategic policy initiatives.

According to Pauw (2022), food crop yields in Ghana have increased by approximately 40 percent since 2017, largely due to the implementation of the Planting for Food and Jobs program. This initiative, administered by the Ministry of Food and Agriculture (MoFA), has provided farmers with subsidized agrochemicals, fertilizers, quality seeds, and other essential inputs. Monitoring these yield trends is essential for guiding sustainable agricultural development in Wenchi Municipality, as crop performance directly influences household livelihoods and the resilience of the local food system.

Variations in Lands Used for Cassava, Yam, and Maize Cultivation

Figure 10 depicts the annual cultivation area for maize, cassava, and yam in Wenchi Municipality from 2000 to 2021, highlighting distinct trends and fluctuations for each crop. Among the three, maize cultivation exhibited the most pronounced variability. Beginning at 26,001 hectares in 2000, the area under maize peaked at 28,050 hectares in 2002. However, significant declines followed in subsequent years, particularly in 2003 and 2005, when the cultivated area fell to 21,580 and 21,276.2 hectares, respectively. A resurgence was observed in 2007, with the area increasing to 27,238 hectares, followed by a secondary peak of 27,443.8 hectares in 2010. After this point, a general downward trend emerged, culminating in a reduction to 19,193 hectares by 2021. With an annual rate of decline estimated at 360.31 hectares, maize records the steepest decrease in cultivated area among the three crops, reflecting a substantial contraction in land allocation.

In comparison, cassava cultivation showed less dramatic variability. The area began at 16,800 hectares in 2000, experienced a slight decline to 16,427 hectares in 2001, and peaked at 19,693 hectares in 2008. A notable decrease occurred in 2010, when the area dropped to 12,712 hectares. From 2011 onward, cassava cultivation stabilized, reaching 17,968.4 hectares in 2021. The overall annual decline of 153.74 hectares indicates a relatively mild downward trend. This pattern may reflect evolving crop preferences, reallocation of farming inputs, or environmental constraints affecting cassava cultivation in specific locations. Nonetheless, the relative consistency in cassava area suggests that it continues to serve as a critical staple crop in the municipality.

Table 1. Results of diagnostic tests for the crops

	Cassava		Yam		Maize	
Diagnosis-Type	**T-Statistics**	**Probability**	**T-Statistics**	**Probability**	**T-Statistics**	**Probability**
Heteroscedasticity	0.04	0.8441	0.090	0.7595	0.019	0.6618
Autocorrelation	1.017	0.3133	0.116	0.7334	0.651	0.4196
Normality	0.9471	0.6228	0.947	0.6228	1.143	0.5647

Table 2. Multiple regression analysis for Cassava

log_Cassava	Coefficient	Standard Error	t	P-value
log_Rainfall	-0.0011354	0.0008153	-1.39	0.182
log_Temperature (Mn)	0.5423479	0.2173871	2.49	0.023*
log_Temperature (Mx)	0.5098747	0.2674254	1.91	0.074*
log_AreaCultivated	0.0000327	0.0000381	0.86	0.403
_Constant	-24.9938	9.506246	-2.63	0.018

Note: $R-squared\ (R^2) = 0.4687$; Adjusted $R-squared\ (R^2) = 0.3436$; and F-statistics = 3.75 (Prob > F = 0.0231). The regression shows significance at the 5% significance level.

Yam cultivation followed a similar trajectory of early expansion followed by stabilization. Starting at 19,333 hectares in 2000, yam reached its peak at 21,582 hectares in 2003, indicating a period of increased focus on yam production. This was followed by declines, with significant reductions to 16,116.2 hectares in 2005 and 14,932.9 hectares in 2010. After 2011, the cultivated area fluctuated but remained generally stable, ultimately decreasing to 11,181.5 hectares by 2021. With a negative growth rate of 276.25 hectares annually, yam experienced a more pronounced reduction in land area than cassava. This decline may be linked to yam's heightened sensitivity to climatic variability and the resource demands associated with its cultivation, which affect its long-term viability as a staple crop.

These trends in staple crop cultivation in Wenchi Municipality may be attributed to multiple interrelated factors. Research by Adjei and Kyerematen (2018) and Bannor et al. (2022) points to a shift among farmers toward cashew cultivation, reducing emphasis on traditional staples such as maize, cassava, and yam. Furthermore, Adjei-Nsiah (2012) and Zubairu et al. (2021) have noted that crop diversification and rotational practices in transitional agroecological zones, including Wenchi, influence farmers' decisions regarding crop selection and planting. Additionally, the unpredictability of rainfall, exacerbated by ongoing climate change, deters large-scale planting during the rainy season and further impacts the allocation of land for these essential crops (Owusu et al., 2018; Zubairu et al., 2021).

Effect of Temperature and Rainfall Variability on Crop Yields

The results of the diagnostic tests conducted for cassava, yam, and maize indicate that the assumptions underlying the multiple regression model were adequately satisfied. Specifically, the Breusch-Pagan-Godfrey test revealed no evidence of heteroscedasticity or serial correlation in the residuals at the 5 percent significance level. Furthermore, the Jarque-Bera test confirmed that the residuals are normally distributed. These findings suggest that the regression models for all three crops are statistically valid and free from major specification issues. The outcomes of the diagnostic tests for cassava, yam, and maize are summarized in **Table 1**.

Impact of climatic variation on cassava yield

The multiple regression analysis examines the factors influencing cassava yield, with a specific focus on rainfall, temperature, and cultivated area. The results indicate that temperature-related variables exert a significant influence on yield, while rainfall and cultivated area exhibit comparatively weaker relationships. In particular, minimum temperature has a positive and statistically significant coefficient (0.5423479, $p < 0.05$), suggesting that increases in minimum temperature are associated with improvements in cassava yield. Maximum temperature also presents a positive coefficient (0.5098747), with marginal statistical significance ($p < 0.10$), indicating a weaker yet relevant association with yield performance. These results underscore cassava's general adaptability to warmer conditions, although sustained exposure to extreme temperatures may still pose agronomic challenges (see **Table 2**).

By contrast, annual rainfall is associated with a negative coefficient (−0.0011354) that is not statistically significant ($p > 0.10$), implying a limited direct effect on cassava yield in the study context. Similarly, the coefficient for cultivated area is positive but negligible (0.0000327, $p > 0.10$), suggesting that increases in cultivated land alone do not lead to substantial gains in yield. This may reflect the presence of other constraints, such as soil quality or limited input availability. The model accounts for 34.36 percent of the variation in cassava yield, as indicated by the adjusted R-squared value (0.3436), and is statistically significant overall (F-statistic = 3.75, $p < 0.05$). These findings highlight the critical role of temperature in determining cassava yield outcomes, while suggesting that rainfall and cultivated area contribute minimally under current conditions.

Impact of climatic variation and area cultivation on yam yield

The multiple regression analysis examines the factors influencing yam production, focusing on rainfall, temperature, and cultivated area as predictor variables. The results indicate that temperature-related factors significantly affect yam yields, while rainfall and cultivated area exhibit weaker associations. The coefficient for minimum temperature is positive (0.4060022) and statistically significant ($p < 0.05$), suggesting that increases in minimum temperature are

Table 3. Multiple Regression Analysis for Yam

log_Yam	Coefficient	Standard Error	t	P-value
log_Rainfall	-0.0007202	0.0005078	-1.42	0.174
log_Temperature (Mn)	0.4060022	0.1401204	2.90	0.010*
log_Temperature (Mx)	0.4135149	0.1824331	2.27	0.037*
log_AreaCultivated	0.0000214	0.0000228	0.94	0.362
_Constant	-19.48259	6.656781	-2.93	0.009

Note: R − squared (R^2) = 0.5128 ; Adjusted R − squared (R^2) = 0.3982; and F-statistics = 4.47 (Prob > F = 0.0119). The regression shows significance at the 5% significance level.

Table 4. Multiple Regression Analysis for Maize

log_Maize	Coefficient	Standard Error	t	P-value
log_Annual Rainfall	-0.000131	0.0005205	-0.25	0.804
log_Temperature (Mn)	0.3197132	0.1561565	2.05	0.056*
log_Temperature (Mx)	0.4993277	0.1734049	2.88	0.010*
log_AreaCultivated	-0.0000309	0.0000184	-1.68	0.112
_Constant	-19.59633	6.575584	-2.98	0.008

Note: *R − squared (R^2) = 0.6157; Adjusted R − squared (R^2)= 0.5253; and F-statistics = 6.81 (Prob > F = 0.0018).* The regression is significant at the 5% level.

associated with higher yam yields. Similarly, maximum temperature displays a positive and statistically significant coefficient (0.4135149, $p < 0.05$), indicating that yam production improves with rising maximum temperatures, provided these remain within agronomically acceptable limits (See **Table 3**).

In contrast, the coefficient for rainfall is negative (−0.0007202) and not statistically significant ($p > 0.10$), implying that rainfall has minimal direct influence on yam yields within the study period. The coefficient for cultivated area is also positive but very small (0.0000214), and lacks statistical significance ($p > 0.10$), suggesting that an increase in cultivated land does not lead to a substantial increase in yield. This may be attributed to other limiting factors, such as soil fertility, input constraints, or variations in farming practices. The model explains 39.82 percent of the variation in yam production, as indicated by the adjusted R-squared value (0.3982), and is statistically significant overall (F-statistic = 4.47, $p < 0.05$). These findings underscore the critical role of temperature in determining yam yield while confirming the relatively limited influence of rainfall and cultivated area in this context.

Impact of climatic variation and area cultivation on maize yield

The multiple regression analysis investigates the factors influencing maize production, with particular emphasis on annual rainfall, temperature, and cultivated area. The findings highlight the significant role of temperature variables, while rainfall and cultivated area exhibit weaker or negligible effects. The coefficient for maximum temperature is positive (0.4993277) and statistically significant ($p < 0.05$), indicating that higher maximum temperatures positively affect maize yields, provided the heat levels remain within agronomic thresholds. Similarly, the coefficient for minimum temperature is positive (0.3197132) and marginally significant ($p < 0.10$), suggesting that warmer minimum temperatures contribute to improved maize growth (See **Table 4**).

In contrast, annual rainfall is associated with a negative coefficient (−0.000131) that is not statistically significant ($p > 0.10$), implying minimal direct influence on maize yields in the context of this model. The coefficient for cultivated area is also negative and very small (−0.0000309), and it too lacks statistical significance ($p > 0.10$). This suggests that expansion in the cultivated area does not necessarily enhance production, potentially due to issues such as declining input quality or land degradation. The model accounts for 52.53 percent of the variation in maize production, as reflected by the adjusted R-squared value (0.5253), and is statistically significant overall (F-statistic = 6.81, $p < 0.01$). These results underscore the critical influence of temperature on maize yield, while reaffirming the limited role of rainfall and cultivated area under the conditions observed.

The findings provide important insights into the influence of climate variability on crop yields in Wenchi Municipality, Ghana. The results demonstrate that higher minimum temperatures are consistently associated with increased yields for cassava, yam, and maize. This outcome aligns with prior research by Dwyer et al. (2021) and Abdul-Rahaman and Owusu-Sekyere (2017), which suggests that warmer temperatures can enhance key plant physiological processes, including photosynthesis and nutrient uptake, thereby contributing to greater productivity. Maximum temperatures also exerted a positive effect on all three crops, although the effect on maize was only marginally significant. This indicates that while elevated temperatures may benefit crop yields, the magnitude of this effect differs by crop and environmental context, as observed in studies by Emaziye (2015) and Shuai et al. (2013). Overall, the temperature patterns recorded in Wenchi between 2000 and 2021 appear to have created relatively favorable conditions for the crops under investigation.

In contrast, rainfall did not exhibit a statistically significant effect on crop yields in this study. This finding diverges from broader regional evidence, which identifies rainfall variability as a major determinant of crop performance in Ghana and other parts of sub-Saharan Africa (Dwamena et al., 2022; Kukal & Irmak, 2018). The absence of significant impact in Wenchi may be attributed to the resilience of cassava, yam, and maize to rainfall fluctuations. Additionally, local environmental factors, such as soil moisture retention capacity and underlying hydrological conditions, may have moderated the direct influence of rainfall on crop performance in the area.

Furthermore, the analysis indicates that cultivated area did not significantly influence the yields of cassava, yam, or maize. This result contrasts with findings from previous studies, which have emphasized the role of land expansion in enhancing agricultural output in Ghana (Akudugu et al., 2013; Diao et al., 2019; Essegbey & Maccarthy, 2020). The limited role of cultivated area in this context suggests that other variables, including soil fertility, farming techniques, resource availability, and broader non-climatic influences, may have played a more decisive role in shaping yield outcomes in Wenchi during the study period.

CONCLUSION AND RECOMMENDATIONS

This study provides empirical evidence on the effects of climate variability and cultivated land area on the yields of cassava, yam, and maize in Wenchi Municipality, Ghana, over a 22-year period. The analysis demonstrates that temperature, particularly minimum temperature, is a key driver of yield variability for all three crops. These findings are consistent with global and regional studies emphasizing the beneficial effects of moderate warming on plant physiological processes. Although maximum temperatures also positively influenced yields, their effects were less consistent, particularly for maize.

In contrast, rainfall and cultivated area did not exhibit statistically significant effects on yield outcomes, highlighting the complexity of climate-agriculture relationships at the local scale. The lack of significance for rainfall challenges broader assumptions about its uniform impact across regions, suggesting that crop-specific traits, soil characteristics, and local water retention capacities may buffer against precipitation deficits. Similarly, the minimal impact of cultivated area implies that expanding farmland alone is insufficient for boosting productivity without addressing other structural constraints such as soil fertility, farming practices, and input availability.

The findings underscore the importance of designing location-specific climate adaptation strategies that emphasize temperature-resilient agricultural interventions. Policymakers and agricultural practitioners should prioritize climate-smart technologies, resilient seed varieties, and localized support systems to improve productivity under shifting climatic conditions. Future research should build on these insights by incorporating socio-economic variables, exploring farmer adaptation behaviors, and employing mixed-method approaches to deepen understanding of climate-crop dynamics in vulnerable agroecological zones.

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