

Variability of Maize Prices in Ghana: A Generalized Additive Mixed Model Approach

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ABSTRACT

Maize is grown throughout Ghana, and it is one most common cereal on every market; from A (Ashaiman market) to Z (Zebila Market). In this study, variability in prices of maize has been studied across 35 major markets in all 16 regions of Ghana. Data for this study were compiled weekly for a 5-year duration (2018–2022), except for a week when no maize was grown, i.e., the off-season. The location, week, and year were recorded, along with the price variations, to facilitate analysis. Generalized Additive Mixed Models were used to uncover patterns, trends, and potential factors influencing price. It is hereby established that the maize price increased smoothly from 2018 to 2020, and rapidly from 2020 to 2022. The Kotokuraba market, Dambai market, Ho Central market, Tarkwa market, and Goaso markets recorded the highest Maize prices within the 5 years. Further analysis reveals that the location of the market contributes more (51.7%) to price variability than the ‘week’. Again, the average trend of maize prices tends to increase from week 1 in January to 3rd week in June and decrease from the last week in June to 3rd week in December. The Government and other agribusiness interest groups may invest in storage facilities to store maize from June to December to help in price stabilization during the off-season from January to early June. Further research will be needed to explain in detail why market location, far or near the farm gate, accounts for more than 50% of price variability.

Keywords: Generalized Additive Mixed Models; Maize; Price variability; Markets

INTRODUCTION

Over 9000 years ago, maize first became a domesticated staple cereal in Southern Mexico, a region historically referred to as Mesoamerica (Erenstein et al., 2022). This agricultural development occurred several years after the domestication of wheat and rice in the Near East Fertile Crescent and the Yangtze Valley in China, respectively (Fei et al., 2020). Although maize was later domesticated, it has expanded rapidly across the world and has now become the second most widely cultivated crop after wheat (Erenstein et al., 2022; Padhan et al., 2024). In contemporary times, maize is classified as the primary food for one-third of the world’s population, with the United States of America being the leading consumer, followed by China (Ijaz, 2023; Wesz et al., 2023).

In Ghana, the importance of maize cannot be overemphasized, as it has become indispensable to both food security and economic activity (Amos et al., 2025). As of 2019, the production of maize stood at 2,900,000 metric tons, increasing significantly to 3,500,000 in 2021 (Baffour-Ata et al., 2023). Maize production is expected

to further expand due to population growth and rising per capita income (Santpoort, 2020). The per capita consumption of maize in Ghana in the year 2020 was 75.91kg per annum, which was an increase of 3% from the previous year (Ofori-Boateng, 2024). Also, apart from serving as a staple food for human consumption, maize is an essential element of poultry feed and supports numerous industrial functions (Saritha et al., 2020).

In recent times, maize prices have gained significant focus in existing literature due to the growing global demand in most countries. Since 2022, developments in the international grain market have been marked by significant changes. According to the United Nations Food and Agriculture Organization, there has been a drastic decrease in the prices of food on the global market, with a 5.6% decrease in grains since 2022 (Zereyesus et al., 2022). This was mostly caused by declining prices of maize in response to increased selling in Argentina by farmers (UNFAO, 2023).

During the same period between 2022 and 2023, food inflation in Ghana kept rising. The Ghana Statistical Service (2023) highlighted that food inflation increased consistently, reaching its peak in January 2023 at 61% per month, which is the highest in 22 years. Similarly, the World Food Programme (2023) also reported a 94.7% increase in the prices of wholesale and a 90% increase in retail prices for maize since January 2022 (WFP, 2023). The increase in maize inflation was attributed to the rise in fuel prices, currency fluctuations, global maize prices, and related factors. Additionally, in November 2023, the World Food Programme further estimated that 5.5 million Ghanaians, representing 18.4% of the population, had insufficient access to food due to rising consumer prices (Gersten, 2023).

Nonetheless, to promote sustainable development in food production, the government of Ghana has initiated a series of activities to maintain food security in the country. For instance, Ghana's National Stock Company (NAFCO) was primarily created to regulate grain supply and stabilize the price of grain (Armah et al., 2019). Additionally, the planting for food and jobs has been implemented to serve as an avenue to increase food production in Ghana (Pauw, 2022). Despite these efforts, the prices of maize are extremely high in most marketplaces in Ghana, although it is locally produced (Boadu et al, 2024). Adu (2024) indicated that maize prices have escalated from GH¢ 200 per 50 kg bag in January to around GH¢360 per bag as of 2024.

Several studies have explored the determinants of food prices, considering various factors such as market integration, supply and demand dynamics, weather conditions, inflation, insufficient food supply, and global economic factors such as crude oil prices (Gebremedhin et al., 2023; Sitima and Mduma, 2023; 2025; Odojoma et al., 2025). Gebremedhin et al. (2023) pointed out temporal effects, including seasonality, weather conditions, and policy shifts, as pivotal elements that impact maize prices over time. Tryhubchenko (2025) also highlighted that adverse weather can lead to reduced supply of maize, which can influence prices. This argument was further justified by Sitima and Mduma (2023), who emphasised that climate change poses an additional risk to agricultural production, which requires adaptive agricultural practices to mitigate its impact on maize prices. Furthermore, Odojoma et al. (2025) found that inflation, exchange rate fluctuations, agricultural policies, and psychological behaviors were key microeconomic determinants of rising food prices in Nigeria. Similarly, Abdullah et al. (2024) highlighted the impact of GDP, exchange rates, and oil prices on food prices. The study further argued that rising oil prices significantly affect food commodity prices due to increased transportation costs. Other studies have also indicated that food price changes significantly impact household food security and diet quality (Mahare et al., 2025). For instance, Martey et al. (2025) highlighted that maize price shocks in Ghana reduce household consumption of purchased nutrient-dense and less nutrient-dense foods.

Although these studies contribute significantly to the variability of food prices, including maize, only a few have acknowledged the significance of the effect of location and time on food prices, but in different settings (Gilbert et al., 2017; Cedrez et al., 2020). There is limited literature that emphasizes the location-to-location or time-to-time variability of maize in Ghana (Baffour-Ata et al., 2021; Singh et al., 2025). The current studies on maize variability in Ghana focused on establishing the relationship between maize price variability and forest loss (Krah, 2023). Although the study of Krah (2023) is close Gebremedhin et al (2023) focused on Ethiopia and did not explore the amount of variability that is explained by the location and time, while this present study focuses on extending the variability of maize price by investigating the amount of variability that is explained by location representing some selected market places and time, specifically in Ghana.

Additionally, most studies that focused on analyzing the prices of agricultural food commodities adopted linear models (Wibowo et al., 2021; Guzmán Anaya, 2023). For instance, Guzmán Anaya (2023) used an autoregressive integrated moving average (ARIMA) to predict the price of maize in Mexico. Additionally, Wibowo et al (2021) employed a linear ridge regression to forecast food prices in DKI Jakarta, Indonesia. However, other studies have argued that nonlinear models are suitable for analyzing agricultural prices. Choudhary et al (2025) used a hybrid and advanced forecasting model that combined a genetic algorithm (GA), variational mode decomposition (VMD), and long short-term memory (LSTM) to forecast prices of agricultural commodities. They further justified that the results of the study revealed precise predictions compared to linear models because it was able to represent the nonlinear and non-stationary dynamics of the prices of agricultural food commodities, which included maize.

Therefore, to capture the nonlinearity between price changes and location and time, this study employed a Generalized Additive Mixed Model (GAMM) to examine the effect of location and time on the variability of maize prices in Ghana. GAMM allows for the inclusion of both fixed and random effects in the model, making it suitable for analyzing hierarchical data structures (Gomez-Rubio, 2018). It can incorporate various types of covariate effects, which include linear, nonlinear, random, and spatial effects, which ensures a more flexible model approach (da Silva et al., 2022; Cho et al., 2024). It can also accommodate multiple nested or crossed functional random effects with correlational structures, making it suitable for analyzing spatial, temporal, or longitudinal functional data (Scheipl et al., 2016). In this study, we have delved into the complexities of maize market dynamics, examining the intricate interplay of location-specific and temporal factors that influence maize price. This location-specific effect will help capture the inherent differences in maize markets across various geographical regions (Katchova et al., 2017). In other words, the extent to which local market characteristics contribute to maize price fluctuations can be assessed.

Consistent with previous evidence on the significance of seasonality, variation in weather, and policies, the GAMM incorporates these variables of time and location to provide a more precise analysis of the price changes of maize over time and location. This kind of methodology, GAMM as Kripfganz (2023) suggested, offers a comprehensive understanding of the factors driving maize price variability, considering both spatial and temporal dimensions. The findings of this study are significant for stakeholders, customers, and market analysts. This study will help professionals make more informed decisions and devise effective measures of controlling price by giving them a better organization of the determinants of maize price fluctuations.

MATERIALS AND METHODS

In this study, we employed the Generalized Additive Mixed Model (GAMM) to analyze the intricate relationship between Maize Prices and various factors. GAMM allows for a more flexible exploration of non-linear patterns over time and space, providing a robust framework to account for both fixed and random effects (Carignan et al., 2020). The study used the GAMM model because the data used contains both fixed and random variables.

Data Collection

Data for this study were compiled weekly for the 5-year duration, except for a week of no maize, ie. Off-season. Maize prices were collected from various marketplaces as listed in Table 1.4. Information on location, week, and year was recorded along with the price variations to facilitate the analysis.

Data Analyses

Maize prices play a crucial role in the agricultural economy, and understanding their variations across different years, weeks, and market locations is essential for informed decision-making (Rutsaert and Donovan, 2020). This study analyzes maize prices using the Generalized Additive Mixed Models, aiming to uncover patterns, trends, and potential factors influencing price disparities (Muraya et al., 2017). We performed all statistical analyses using software packages such as Excel and R. These packages provide built-in functions to estimate GAMM models and conduct the necessary inferential tests (Jalal et al., 2017).

GENERALIZED ADDITIVE MIXED MODEL (GAMM)

Generalized Additive Mixed Models (GAMMs) are a statistical technique that exhibits a flexible extension of traditional linear models, accommodating non-linear relationships between predictors and the response variable (Simpson, 2018). GAMMs leverage smooth functions to capture complex patterns without imposing rigid parametric structures (Magazzino et al., 2023). The model is expressed as follows:

Where; μ_i represents the expected value of Maize Prices at time i , β_0 is the Intercept term, which signifies the baseline or average level of Maize Prices when all other predictors (Year, Week, Location) are zero or at their reference levels. s_1 is the Smooth term for the 'Year' variable. It implies that the relationship between Maize Prices and the Year is not strictly linear. The 's' denotes a smooth function, capturing potential non-linear trends or patterns over time. Similarly, s_2 is the Smooth term for the 'Week' variable. It implies that the relationship between Maize Prices and the Week is not strictly linear.

'Location' represents the effect of the spatial variable on Maize Prices. It is a categorical variable denoting different markets or regions, influencing prices in a non-linear manner, and The error term represents unobserved factors affecting Maize Prices that are not captured by the predictors in the model. It accounts for the variability in Maize Prices that cannot be explained by the model.

The equation models the expected value of Maize Prices as a combination of a baseline level a non-linear trend over time, and the linear effect of "Location". The random variation is captured by the error term. The smooth term for "Year" and "week" allows for capturing complex temporal patterns, while "Location" contributes linearly to the model. The intercept is the starting point, deviations from this baseline are accounted for by smooth and parametric terms. The equation is a representation of the Generalized Additive Mixed

Model (GAMM), which combines fixed effects (parametric terms) and random effects (smooth terms) to analyze the temporal and spatial variation of Maize Prices.

RESULTS

Summary of the Data

The data from 35 markets in Ghana are summarized in the table below (Table 1).

Table 1: Summary of the data

Market (Location)	Number of Observations	Market (Location)	Number of Observations
Agbogbloshie Market	140	Nalerigu Market	46
Bawku Market	135	Navrongo Market	84
Bechem Market	17	Nima Market	113
Bimbilla Market	58	Salaga Market	108
Bole Market	49	Sefwi Wiawso Market	21
Bolgatanga Market	122	Sekondi Market	81
Borae Market	48	Sunyani Market	202
Dambai Market	6	Takoradi Market	186
Damongo Market	111	Tamale Market	250
Ejura Market	36	Takwa Market	31
FUMBISI Market	84	Techiman Market	258
Goaso Market	92	Tumu Market	115
Gushiegu market	103	Wa Market	105
Ho Central market	46	Walewale Market	18
Kasoa, new market	134	Wenchi Market	244
Kintampo Market	72	Yeji Market	8
Kotokuraba Market	7	Yendi Market	73
Mankessim Market	81		

Data visualization

To implement any statistical model to model the data, it is very important to visualize the data to understand and discover the trends and variabilities that may persist. The plots below show the trend of the average price of maize across all the selected markets from 2018 to 2022. It can be observed from Figure 1 that, on average, the price increased from 2018 to 2020 and increased from 2020 to 2022. In terms of location, it can be observed (from Figure 2) that the average price of yellow maize varies across locations. Specifically, the price of yellow maize was very high at Kotokuraba market, Dambai market, Ho Central market, Tarkwa market, and Goaso market. These markets have extreme spikes, which show that there is variability of maize price in those marketplaces. This is very crucial for stakeholders to compare market stability, identify trends, and make informed decisions on where to buy or sell maize. Overall, the plot (Figure 2) also suggests that the price trend of maize across the various locations (markets) exhibits non-linear characteristics.

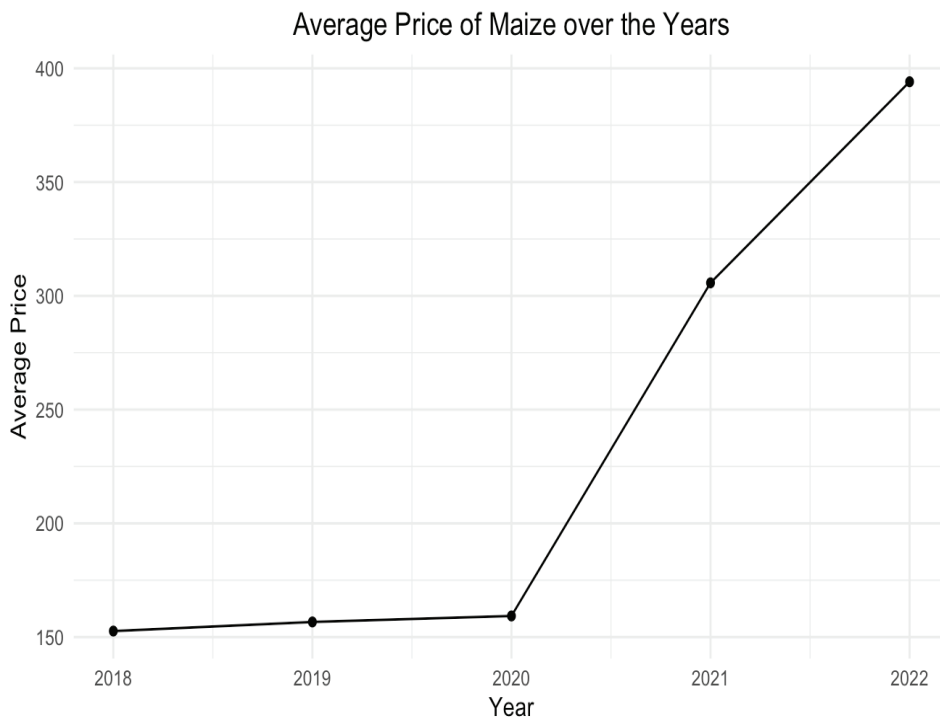


Figure 1: Average price of maize (2018-2022)

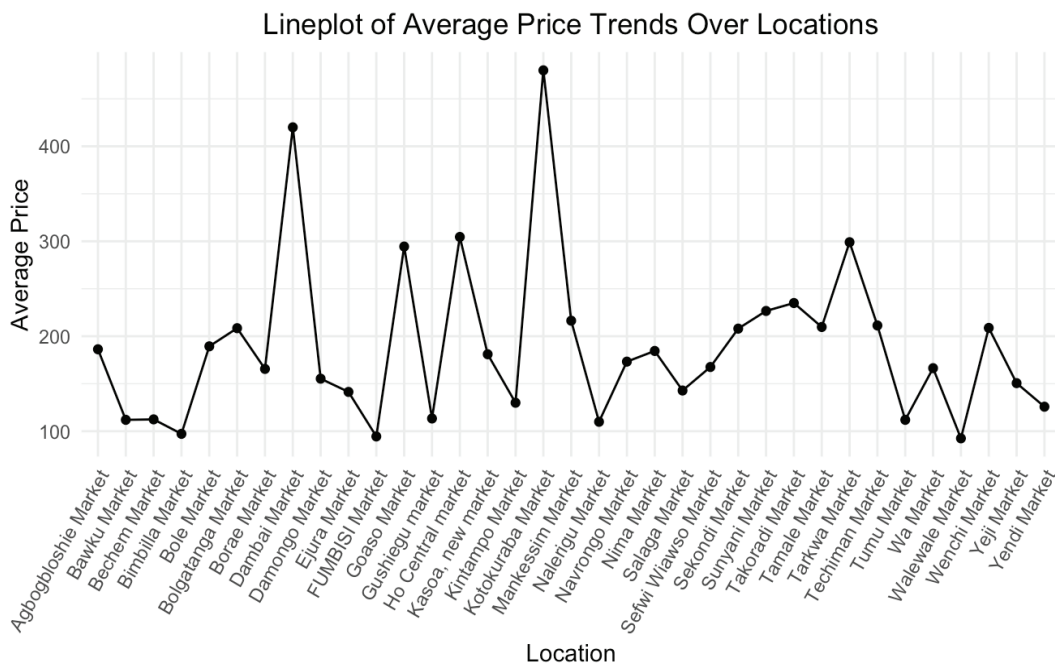


Figure 2: Average price trends over locations

In addition, the average trend of maize price over the weeks (Figure 2) and the distribution of price (Figure 4) were explored. It can be observed that, on average, the price of maize increased from week 1 to week 27

(that's, from the first week in January to the 3rd week in June) and decreased from week 27 to week 51 (that's, from the 3rd week in June to the 3rd week in December), and then increased in the last week in December. The histogram of the price (Figure 4) shows the spread or the variability of price, which seems quite wide, as indicated by the prices ranging from below GHC 100 to above GHC 600. The shape of the distribution appears to be right-skewed, which shows that the majority of maize prices are on the lower end of the price scale, and a minority have very high prices that pull the tail of the distribution to the right.

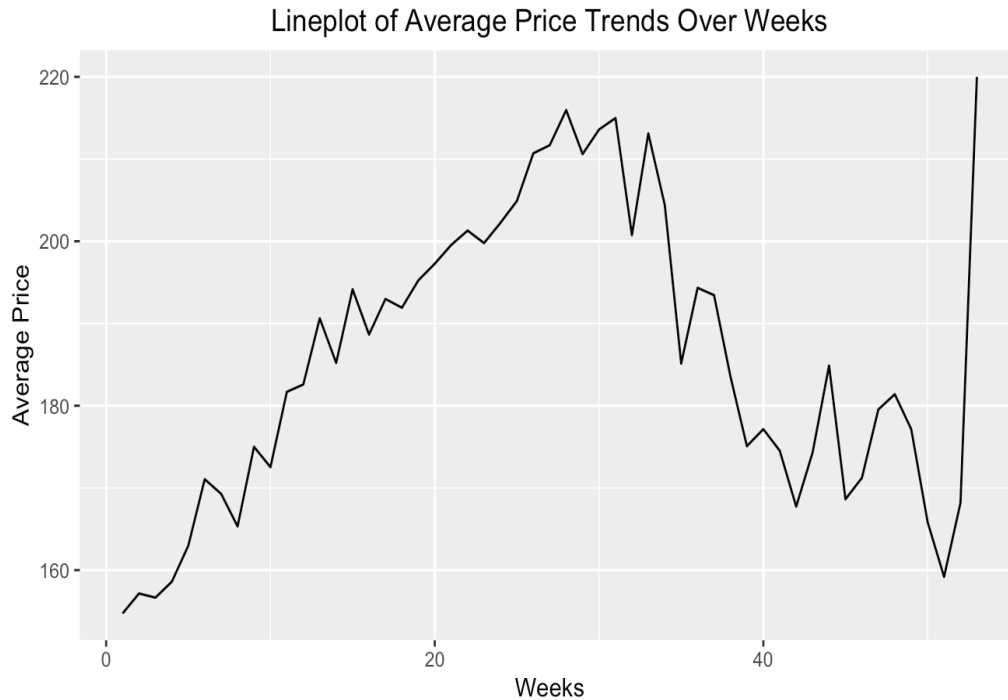


Figure 3: Average Weekly trend of maize price (2018-2022)

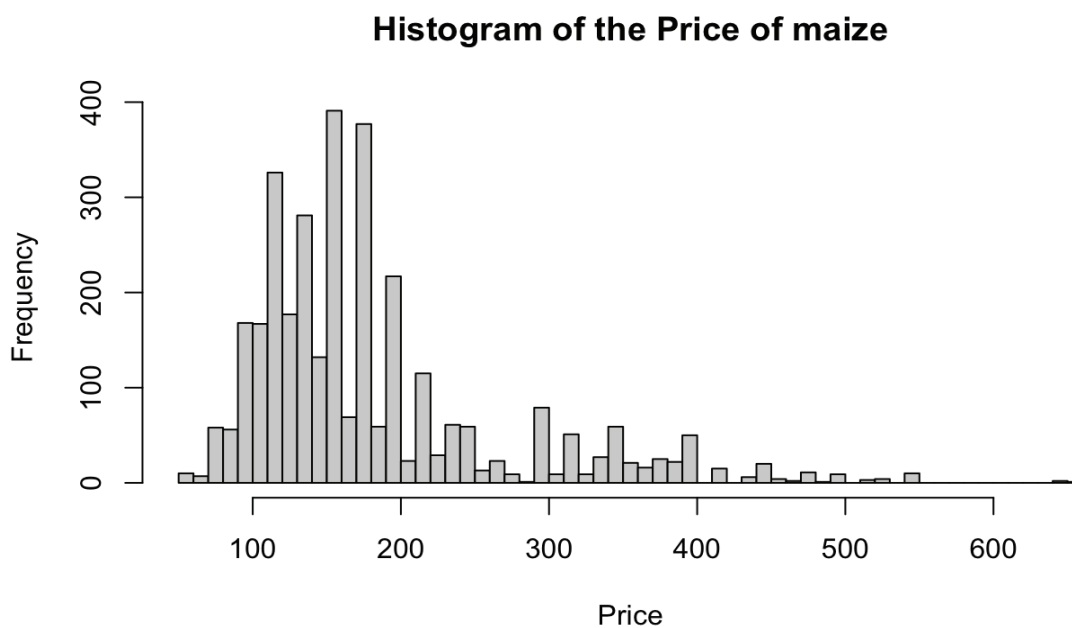


Figure 4: Histogram of the price of maize

The graph below shows the boxplot of the prices of yellow maize across the selected marketplaces in Ghana. Each box in the boxplot represents the interquartile range (IQR) of the data, which contains 50% of the values, and the horizontal lines inside the box represent the median price of maize at that location. Locations with higher medians are markets in which the price of yellow maize is high. Wider boxes indicate more variability in maize prices at that market, and the points beyond the whiskers (lines below and above the box) represent the outliers (that's the prices that are unusually high or low compared to the rest of the data).

Based on these properties, we can observe from the plot below (Figure 5) that the Dambai market is an expensive market for yellow maize. In addition, the marketplaces that have high variability of maize prices are Goaso market, Dambai market, Tamale market, Wenchi market, Techiman market, Sunyani market, Ho Central market, Bolgatanga market, and Bechem market. Some of the marketplaces that mostly experience unusually high or low prices of maize are Takoradi Market, Navrongo Market, Nima Market, Wa Market, Techiman Market, Sunyani Market, Yendi Market, Kasoa New Market, Bolgatanga Market, Walewale Market, Damongo Market, Borae Market, Bawku Market, and Sefwi Wiawso Market.

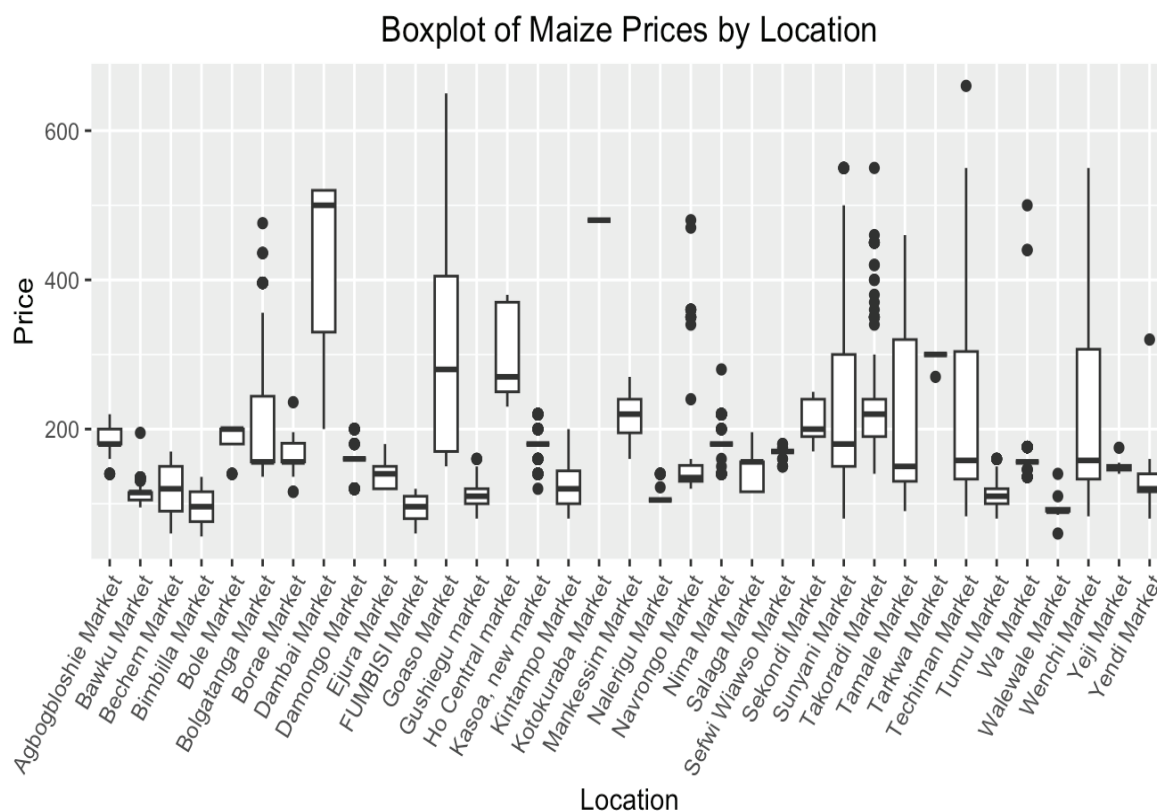


Figure 5: Boxplot of yellow maize prices by location

Relationship between Price and Location, Week, and Year

To establish the relationship between the response variable (price) and the predictors (year, week, and location), the Generalized Additive Model with random effect specification using the MGCV package in R was employed. It can be observed that (Table 1) there is a complex relationship between the predictors and the response variable since the edf values for all the smooth terms are significantly higher. The F-statistic for a smooth term is used to test the null hypothesis that the term does not improve the model fit. The significant p-values for all smooth terms show that they all contribute significantly to the model. This shows that price has a non-linear relationship with year, weeks, and locations.

Table 2: Significance of the smooth terms

Variables	Effective degrees of freedom (edf)	Reference degrees of freedom (Ref.df)	F-value	P-value
s(Year)	3.997	4	562386.3	0.000 ***
s(Weeks)	46.989	52	158.6	0.000 ***
s(Location)	33.807	34	4626.6	0.000 ***

Model Estimation

In analyzing the temporal and spatial variation of the price of maize, a generalized additive mixed model (GAMM) was employed. The model incorporated 'Year' as a smooth term to account for non-linear temporal trends, and random effects for both 'Week' and 'Location' (Markets) to capture unexplained variability. The intercept of the model was estimated at 5.3516 (SE = 0.1885, $t = 28.39$, $p < .0001$), suggesting a significant baseline level of the response variable. Temporal non-linearity was confirmed with an estimated degrees of freedom for the year smooth term of approximately 4 (edf = 3.999), indicating a complex relationship between Year and the response variable ($F = 2565$, $p < 0.001$).

The random effects analysis revealed that while both 'Week' and 'Location' contributed to the variability, the impact of 'Location' was more pronounced (variance = 0.0721, SD = 0.2685) compared to 'Week' (variance = 0.0014, SD = 0.0380). In other words, the location of the market contributes more to the variability in the price of maize than the week. The adjusted R-squared value of 0.517 indicates that over half of the variability in the response variable is accounted for by the model.

Table 3: Model estimates

Parametric coefficients	Estimate	Std. error	T-value	Pr (> t)
Intercept	5.3516	0.1885	28.39	0.000
Approximate significance of smooth terms:				
	Edf	Ref.df	F	P-value
s(Year)	3.999	4	2565	0.000
R-sq.(adj) = 0.517		Scale est. = 0.0206		
Random effect:				
Group		Variance	Std. Deviation	
Week		0.0014	0.0380	
Location		0.0721	0.2685	

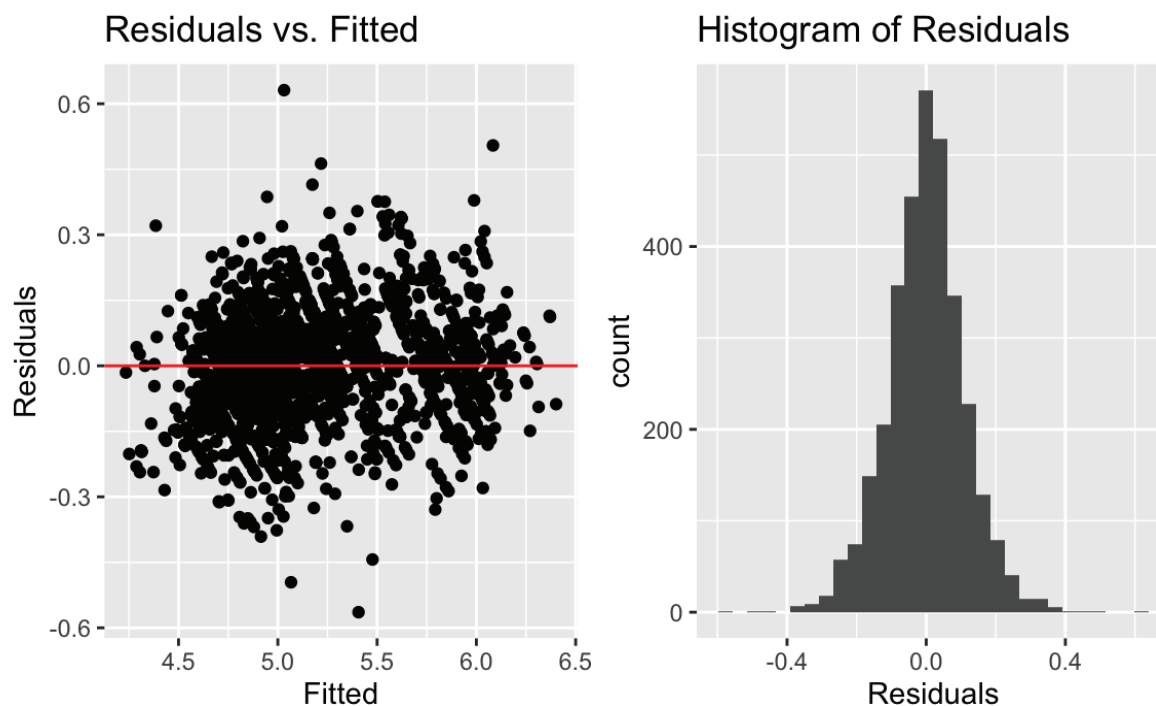


Figure 6: Diagnostics plots on generalized additive mixed model

Model Diagnostics

The diagnostics plots from the generalized additive mixed model with a gamma distribution and log link function were evaluated to assess the fit of the model. The Residuals vs. Fitted plot did not exhibit any clear trends or patterns, which shows that the model captured the systematic variation in the data effectively. However, a slight increase in the spread of residuals at higher fitted values was noted, indicating potential heteroscedasticity, which warrants further exploration. The histogram revealed nearly symmetric distribution around zero, which is unexpected for the gamma model, suggesting that the transformation applied (log link function) has effectively stabilized the variance of the residuals. These plots suggest that the GAMM with a gamma distribution provides an adequate fit to the data, capturing the essential patterns and trends.

DISCUSSION

The research used a generalized additive mixed model (GAMM) to test the intervals of nonlinearity in location and time for maize prices in Ghana. This model was selected because an analysis of food prices in various places and times revealed the existence of a non-linear trend. The underlying data were analyzed to get more insight into the correlation between these variables and to investigate the difference in price of maize due to location and time. The results of Figure 1 showed that the prices of maize increased over the years considered. This finding corresponds to the work by Adu (2024), who stressed the increase in the maize prices in Ghana. Concerning geographically determined variability, the prices of maize tend to become non-linear in the various regions (Figure 2). Also, the trend in the average maize price is expected to increase between the first week of January and the third week of June and decrease between the last week of June and the third week of December (Figure 3). Maize prices have increased between January and June because of low production in these seasons, as the majority of the cultivation is done in these seasons, and harvest is usually done at the end of June. In the harvest season, a lot of maize is available in most areas, and this lowers the prices in

the market (Cedrez et al., 2020; Krah, 2023).

The research indicated that there was a high degree of variability in maize prices in the various marketplaces. The maize price variability is high in marketplaces like the Goaso market, Dambai market, Tamale market, Wenchi market, Techiman market, Sunyani market, Ho Central market, Bolgatanga market, and Bechem market. That is, the price of maize is either very high or very low in these marketplaces. The reason is that most of these markets are located in areas where the production of maize is high, and the demand for maize is likely to rise since most customers will relocate to such areas to purchase maize. This finding aligns with the findings of Katchova et al. (2017) and Gilbert et al. (2017), who reported spatial variations in the prices of foodstuffs in markets. Moreover, this result is consistent with Tryhubchenko (2025) and Sitima and Mduma (2023), who associated the variability of prices of maize with the production factors and supply variations in the regions. Nonetheless, this study indicates that the cost of maize has a high rate of variability in the various markets within the Ghanaian market.

The result of the test of significance of the smooth terms indicated that there is a significant non-linear correlation between the price of maize and year. This indicates that the maize price does not increase or decrease at a steady rate with time. Alternatively, it may have high growth or decline rates at some point in time, given the alteration of demand and supply, inflation, or policy adjustments. The non-linear relationship between price and weeks suggests that the price of maize trends higher at some particular periods in the year because of the high demand during holidays, or it is supplied less because of the growing seasons. The non-linear reaction between price and location demonstrates that various locations (markets) are impacted by various reasons, including the transportation prices, local taxes, availability of local maize compared to imported maize, or seller rivalry.

These non-linear relations are very important to the stakeholders and consumers. It allows the stakeholders to know at what times and where to interfere in order to stabilize the price e.g., subsidies at times of high growth and investing in infrastructure to lower the cost of delivering food to the market. The latter assists them in anticipating a better price and amending the supply chain and inventory levels to match the estimated seasonal and local price changes, which may result in their cost-saving and more efficient operations. In the case of consumers, it helps them to plan their purchases or budget on food expenditure by knowing when and where food prices may be high.

The Generalized Additive Mixed Model (GAMM) was employed to examine the complex relationship between maize price and year, week, and location, with location and week treated as random effects. The results indicate that location ($SD = 0.26$) explains a greater proportion of maize price variability compared to weekly effects. This finding reflects the Ghanaian context, where maize production is largely concentrated in rural areas with poor transportation infrastructure. When the plantation is done on a large scale, farmers in those areas incur a lot of loss. High transportation costs and logistical constraints may restrict the movement of maize to urban markets, thereby contributing to price variation across locations, especially during periods of high demand. This explanation is also in line with Abdullah et al. (2024), who also highlighted the importance of transportation costs in determining the dynamics of food prices.

The adjusted R-squared, which is equal to 0.51, shows that the model can explain about 51 percent of the variability in maize prices. This implies that there are other variations that may contribute significantly to

price fluctuations in maize in Ghana, which are not contained in the model like inflation, exchange rate, supply and demand forces, market integration, and climatic conditions. This point is consistent with Odojoma et al. (2025), who also found macroeconomic factors to be significant determinants of food price fluctuations, and Sitima and Mduma (2023), who also noted the impact of risks associated with climate on the prices of agricultural products. Further studies on this topic must thus include these other determinants to give a more detailed analysis of the maize prices in Ghana.

CONCLUSION

This study hereby establishes that the maize price increased smoothly from 2018 to 2020, and rapidly from 2020 to 2022. Also, the model output showed that location and weeks significantly contribute to the variability of maize price in Ghana. However, location ($SD = 0.26$) tends to explain much of the variability in maize price as compared to weeks, with the Kotokuraba market, Dambai market, Ho Central market, Tarkwa market, and Goaso markets recording the highest Maize price variability within the 5 years. Again, maize prices tend to increase from week 1 in January to 3rd week in June and decrease from the last week in June to 3rd week in December. The Government and other agribusiness interest groups may invest in storage facilities to store maize from June to December to help in price stabilization during the off-season from January to early June. Further research is needed to explain in detail why market location, far or near the farm gate, accounts for more than 50% of price variability.

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