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# ASSESSMENT OF CLIMATE CHANGE IMPACT ON TOMATO (*solanum lycopersicum*) CULTIVATION QUALITY AND AGRARIAN SOCIOECONOMIC SUSTAINABILITY IN NIGERIA'S NORTHERN AGROECOLOGICAL ZONE

**BY**

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**Abstract**

This study examines the impact of climate change on tomato cultivation quality and agrarian socioeconomic security in Nigeria’s Northern Agroecological Zone, a region increasingly exposed to rising temperatures, erratic rainfall, and extreme weather events. Tomatoes are a key livelihood and food security crop in northern Nigeria, yet climate variability continues to disrupt production systems, farmer resilience, and public health outcomes. A descriptive cross-sectional design was employed, involving 406 tomato farmers and sellers across major producing states. Data were collected using structured questionnaires assessing climate change knowledge and awareness, perceived food security impacts, and public health risks. Statistical analyses were conducted using SPSS version 29, including descriptive statistics, chi-square tests, correlation, and regression analyses. Findings revealed very high awareness of climate change (97.3%) among respondents; however, depth of understanding was largely moderate, with only 14.8% demonstrating detailed knowledge. Education level and years of agricultural experience were significantly associated with climate change awareness ($p < 0.05$), while age and gender were not. Food security impact scores clustered around the mid-range (mean = 6.5), indicating moderate disruptions in availability and access, particularly among lower-income and rainy-season farmers. Public health impact perceptions were also moderate (mean = 3.63), with increased risk of waterborne diseases, heat-related illnesses, pesticide exposure, and water scarcity identified as key concerns. Correlation analysis showed a weak association between climate knowledge and food security ($r = 0.08$) and a stronger relationship between food security and public health impacts ($r = 0.27$). The study demonstrates that climate change significantly affects tomato farming livelihoods, food security, and public health in northern Nigeria, with knowledge alone insufficient to offset structural and environmental vulnerabilities. The findings highlight the need for integrated climate-smart interventions focusing on farmer education, supply chain resilience, and localized public health risk mitigation to sustain tomato production and improve agrarian wellbeing under changing climatic conditions.

**Keywords:** Climate Change, Tomato Farming, Food Security, Public Health, Farmer Awareness, Nigeria

## Introduction

Climate change poses profound environmental and socio-economic challenges worldwide, including rising temperatures, sea-level rise, and erratic rainfall. In Nigeria, environmental degradation through deforestation, erosion, desertification, and flooding continues to threaten infrastructure, water resources, and agricultural productivity. According to FAO, IFAD, UNICEF, WFP, and WHO (2017-2019), food crises arise primarily from conflicts, economic instability, and adverse weather conditions. Evidence of climate change in Nigeria includes increasing temperatures, inconsistent rainfall, desertification, and frequent flooding (Olaniyi *et al*., 2019; Udo, 2023). These events disrupt ecosystems and livelihoods, intensifying food insecurity. The Intergovernmental Panel on Climate Change (IPCC) and World Meteorological Organization (WMO) has identified Nigeria as one of the most vulnerable nations to climate risks (Landman, 2010; Getahun *et al*., 2020). Nigeria's vulnerability stems from widespread dependence on natural resources and fossil fuels. By 2018, total greenhouse gas emissions reached 336 million metric tons of $CO_2$ equivalents less than 1% of global emissions but local impacts remain severe (Castelein *et al*., 2022). Climate variability continues to exacerbate land degradation, floods, and biodiversity loss. Improper waste management, particularly of polyethylene terephthalate (PET) materials, further compounds these challenges by contributing to greenhouse gas emissions and urban flooding (Lase *et al*., 2023). Agriculture contributes significantly to Nigeria's emissions and remains among the most climate-sensitive sectors. The northern region, characterized by semi-arid conditions and erratic rainfall, faces intensified droughts and rising temperatures (Haider, 2019). Tomatoes, a major dietary and economic crop, are vital for household nutrition and income generation. With an annual demand of 2.3 million tons (Babadara, 2023), the sustainability of tomato farming under changing climate conditions is of national importance.

Despite several adaptation initiatives, including the National Adaptation Plan (NAP) and National Agricultural Resilience Framework (NARF) (Nwankpa, 2022), smallholder tomato farmers continue to face significant threats to productivity and livelihood. Understanding the intersection of climate impacts, crop quality, and farmer resilience is critical to ensuring sustainable food security in Nigeria. Climate change poses a severe threat to agricultural productivity in Nigeria, especially in the northern region where tomato farming predominates. Irregular rainfall, extreme heat, and frequent droughts have disrupted production cycles, reduced yields, and increased pest and disease outbreaks (Firoozzare *et al*., 2023; Singh *et al*., 2023). Rising temperatures degrade fruit quality, while water stress affects both yield and nutritional composition (Al-Sakkaf & Onaizi, 2023; Goossens *et al*., 2023). Socio-economically, smallholder farmers face limited access to adaptation technologies, credit, and extension services (Bavel *et al*., 2020). Broader issues such as inflation, poor infrastructure, and pandemic-related supply disruptions further constrain resilience (FAO, 2017; Tzachor *et al*., 2023). Despite the economic and nutritional relevance of tomatoes, few studies have examined climate change effects on this high-value crop. Bridging this gap is essential for developing targeted interventions that promote farmer security, food stability, and public health resilience in the face of climate change. This study bridges a critical knowledge gap on the intersection between climate change, food security, and agricultural resilience in Nigeria. By focusing on tomatoes, a high-value crop often overlooked in climate discourse it provides a more comprehensive view of climate risks beyond staple crops. Findings will inform policy and adaptation strategies to enhance food system resilience, improve farmer livelihoods, and strengthen national climate adaptation frameworks. The outcomes will guide government agencies, NGOs, and development partners in promoting sustainable agricultural practices aligned with food security and public health goals. The study focuses on tomato (*Solanum lycopersicum*) farming in Northern Nigeria, where climatic variability significantly affects agricultural production. The research is limited to smallholder farmers and rural communities, with analysis centered on post-harvest quality, food security implications, and public health dimensions of climate change. Socio-political and long-term economic factors are beyond the immediate scope of this study.

**Research Objectives**

The general objective of this study is to assess the impact of climate change on tomato (*Solanum lycopersicum*) cultivation and the security of farmers in Northern Nigeria. The specific objectives are to: (1) determine farmers' knowledge and awareness of climate change (2) examine the disruptions of food security pillars and their contributions to climate change risks in tomato (*solanum lycopersicum*) farming. (3) model the potential public health impacts of climate change on tomato farming.

## Methodology

The study was conducted in the northern cultivation region of Nigeria, which covers several states including Kano, Kaduna, Katsina, Sokoto, Kebbi, Zamfara, Jigawa, Bauchi, Borno, Yobe, Adamawa, and Gombe. The region lies between latitudes 9°N and 14°N and longitudes 4°E and 15°E, bounded to the north by Niger Republic, to the south by the Middle Belt, to the east by Lake Chad Basin, and to the west by the Republic of Benin (Nwoga *et al*., 2022). The area experiences a tropical savanna climate with distinct wet and dry seasons. The rainy season, typically from June to September, supports agricultural activities, especially tomato (*Solanum lycopersicum*) cultivation (Bjornlund *et al.*, 2020). The dominant ethnic groups are Hausa and Fulani, whose livelihoods largely depend on subsistence and commercial farming. Major tomato markets include local rural markets, urban centers, and cross-border export points. A descriptive cross-sectional design was employed using quantitative data. This design was considered appropriate for assessing the impact of climate change on tomato cultivation quality and farmers' livelihood security at a single point in time. It allows for the evaluation of relationships between climatic factors, agronomic variables, and socioeconomic outcomes (Johnson, 2014; Saunders *et al.*, 2019). The study incorporated both field survey and laboratory analyses to ensure comprehensive data coverage. The study population comprised tomato farmers across northern Nigeria who was actively engaged in cultivation and willing to participate. The sample size was determined using Slovin's formula with a 5% margin of error and a 95% confidence level, producing an estimated sample size of 400 respondents from a population of 201,430 farmers. Participants were selected using purposive sampling to ensure inclusion of experienced tomato farmers familiar with local climatic variations (Prior *et al*., 2020). A structured, self-administered questionnaire was designed to collect quantitative data on farmers' demographic characteristics, knowledge of climate change, perceived impacts on tomato cultivation, and adaptive strategies. The instrument was developed based on relevant literature and reviewed by experts for validity. Reliability was confirmed through a pilot test using 10% of the total sample (40 farmers) and analysis with Cronbach's alpha, where values between 0.70 and 0.90 were considered acceptable. Questionnaires were distributed to respondents across multiple northern states. Participation was voluntary, and informed consent was obtained. Ethical approval was secured from the institutional review committee. Respondents were informed of their right to withdraw at any stage, and all data were treated as confidential. Quantitative data from questionnaires were analyzed using SPSS version 29. Descriptive statistics (mean, frequency, percentage, and standard deviation) summarized the data, while inferential statistics including chi-square, correlation and regression analyses were used to assess relationships between climate factors, tomato quality, and farmer socioeconomic security. A p-value of $\leq 0.05$ was considered statistically significant. All ethical standards were upheld. Approval was obtained from the institutional ethics committee. Participation was voluntary, informed consent was obtained, and respondents were assured of anonymity and confidentiality.

## Results

Socio-demographic characteristics of tomato farming communities are essential in assessing their exposure to climate change risks and their capacity to adapt to disruptions in food security. Seasonal variation in tomato production between the dry and rainy seasons may influence who participates in farming and selling activities, how resources are accessed, and the nature of vulnerabilities experienced. The table below provides a breakdown of respondents' socio-demographic profiles across the two production seasons, offering insight into potential differences in adaptation capacity and livelihood outcomes. Findings reveal the socio-demographic characteristics of tomato farming respondents, disaggregated by the season of tomato production dry season (N = 321) and rainy

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season (N = 79), totalling 400 respondents. This comparison highlights patterns in employment type, age, gender, education, income, and farming experience, which have implications for exposure to climate change and adaptive capacity. The majority of respondents were farmers (83.8%), while sellers made up 16.3% of the total. Notably, a higher proportion of sellers (22.8%) participated in the rainy season than in the dry season (14.6%), suggesting a seasonal shift toward market engagement or possibly differing access to farmland or capital during wetter periods. Across all respondents, the dominant age group was 26–35 years (40.3%), followed by 18–25 years (32.0%). However, younger individuals (18–25) were more represented in the rainy season (38.0%) compared to the dry season (30.5%). Interestingly, the 46–55 ages group, largely absent from the dry season (0.9%), was notably more active during the rainy season (17.7%), possibly due to traditional or resource-based constraints that limit their participation in dry-season farming. In terms of gender, men made up 63.2% of the total sample. They were more dominant in dry season farming (65.1%) than in the rainy season (55.7%). Conversely, women constituted a larger share during the rainy season (44.3%) compared to the dry season (34.9%), suggesting that women may be more active in seasonal or home-based farming during the rains, possibly due to different household roles or constraints on land and labour access. Marital status was almost evenly split between single (49.5%) and married (49.0%) individuals. However, single respondents were more prevalent in the dry season (53.3%), while married individuals dominated in the rainy season (62.0%). This could reflect labour mobility, with younger, single individuals engaging in dry season farming, especially where irrigation or commercial farming is more common. Respondents generally had high levels of education. Over half (53.8%) held a bachelor’s degree, and 20.3% had postgraduate qualifications. Educational attainment was slightly higher among rainy season respondents, with 60.8% holding bachelor’s degrees, compared to 52.0% in the dry season. This suggests that both educated and less-educated individuals participate in tomato farming, but slightly more educated farmers may engage in rainy-season cultivation, possibly due to flexibility or interest in diversification. Agricultural experience was concentrated in the 5–10-year range (42.3%), followed by those with less than 5 years of experience (37.3%). This suggests that most participants are relatively new or mid-career farmers. The distribution of experience was consistent across both seasons, indicating that farming during the dry or rainy season is not necessarily a function of how long a person has been in agriculture. In terms of annual income, most respondents earned between N100,001 and N1,000,000, with the largest share (28.2%) falling into the N500,001–N1,000,000 bracket. However, higher earners (above N1,000,000) were more common in the dry season (21.2%) compared to the rainy season (3.8%), whereas those earning below N100,000 were disproportionately represented in the rainy season (26.6%). This suggests that dry season tomato production may be more profitable, potentially due to better pricing, access to irrigation, or reduced spoilage, while rainy season farming may face higher losses or lower market value.

**Table 1: Socio-Demographic Characteristics of Respondents by Season of Tomato**

| Variables | Dry Season (N=321) | Rainy Season (N=79) | Total (N=400) |
|---|---|---|---|
| Job | | | |
| **Farmer** | 274 (85.4%) | 61 (77.2%) | 335 (83.8%) |
| **Seller** | 47 (14.6%) | 18 (22.8%) | 65 (16.3%) |
| Age | | | |
| **18-25 years** | 98 (30.5%) | 30 (38.0%) | 128 (32.0%) |
| **26-35 years** | 139 (43.3%) | 22 (27.8%) | 161 (40.3%) |
| **36-45 years** | 64 (19.9%) | 13 (16.5%) | 77 (19.3%) |

| | | | |
|---|---|---|---|
| **46-55 years** | 3 (0.9%) | 14 (17.7%) | 17 (4.3%) |
| **> 56years** | 17 (5.3%) | 0 (0.0%) | 17 (4.3%) |
| Gender | | | |
| **Male** | 209 (65.1%) | 44 (55.7%) | 253 (63.2%) |
| **Female** | 112 (34.9%) | 35 (44.3%) | 147 (36.8%) |
| Marital Status | | | |
| **Single** | 171 (53.3%) | 27 (34.2%) | 198 (49.5%) |
| **Married** | 147 (45.8%) | 49 (62.0%) | 196 (49.0%) |
| **Divorced/Separated** | 1 (0.3%) | 1 (1.3%) | 2 (0.5%) |
| **Widow/Widower** | 2 (0.6%) | 2 (2.5%) | 4 (1.0%) |
| Highest Education Level | | | |
| **Below High School** | 5 (1.6%) | 0 (0.0%) | 5 (1.3%) |
| **High School** | 26 (8.1%) | 9 (11.4%) | 35 (8.8%) |
| **College/Technical School** | 54 (16.8%) | 10 (12.7%) | 64 (16.0%) |
| **Bachelor's Degree** | 167 (52.0%) | 48 (60.8%) | 215 (53.8%) |
| **Postgraduate Degree** | 69 (21.5%) | 12 (15.2%) | 81 (20.3%) |
| Agriculture Experience | | | |
| **Below 5 years** | 118 (36.8%) | 31 (39.2%) | 149 (37.3%) |
| **5-10 years** | 134 (41.7%) | 35 (44.3%) | 169 (42.3%) |
| **11-15 years** | 60 (18.7%) | 11 (13.9%) | 71 (17.8%) |
| **16-20 years** | 6 (1.9%) | 0 (0.0%) | 6 (1.5%) |
| **> 20years** | 3 (0.9%) | 2 (2.5%) | 5 (1.3%) |
| Annual Income | | | |
| **Below N100,000** | 40 (12.5%) | 21 (26.6%) | 61 (15.3%) |
| **N100,001-N300,000** | 70 (21.8%) | 15 (19.0%) | 85 (21.3%) |
| **N300,001-N500,000** | 45 (14.0%) | 25 (31.6%) | 70 (17.5%) |
| **N500,001-N1,000,000** | 98 (30.5%) | 15 (19.0%) | 113 (28.2%) |
| **More than N1,000,000** | 68 (21.2%) | 3 (3.8%) | 71 (17.8%) |

**Knowledge and awareness of tomato (*Solanum lycopersicum*) farming communities on climate change**

Understanding the level of awareness and knowledge of climate change among agricultural communities is critical, particularly for crops sensitive to climatic variations such as tomato (*Solanum lycopersicum*). Farmers' perceptions and comprehension of climate-related changes play a vital role in shaping their adaptive capacity, influencing how they respond to environmental stressors and implement climate-smart practices. Therefore, this section explores the extent to which tomato farmers and sellers are aware of climate change, their perceived indicators of change, and the sources from which they acquire related information. Table 2 presents the summary of responses assessing the knowledge and awareness of climate change among tomato farming communities. The findings indicate a very high level of awareness, with 97.3% (n = 389) of respondents affirming that they had heard about climate change. Only 2.8% (n = 11) reported a lack of awareness, suggesting that climate change as a concept is widely recognized within the study population. Regarding the depth of understanding, the majority (65.3%) reported a *moderate* level of understanding, while 20.0% reported having *little* understanding and only 14.8% reported a *detailed* understanding. These results imply that although awareness is high, in-depth comprehension of the causes, mechanisms, and long-term implications of climate change may still be limited among a substantial proportion of respondents. In terms of perceived signs of climate change, respondents most frequently cited *rising temperatures* (32.8%) and *droughts* (29.0%) as the main indicators, followed by *severe storms* (22.8%) and *changes in plant and animal behaviour* (15.5%). These perceptions align with empirical climate data trends in Nigeria and reflect the farmers' lived experiences and environmental observations, reinforcing their recognition of climate variability. The sources of information on climate change varied, with the most commonly reported being *social media* (34.3%), followed by *television* (24.3%) and *other informal sources* (23.3%). Notably, only 8.0% cited *government sources*, and a small percentage relied on *radio* (6.0%) or *friends* (4.3%). This pattern suggests a heavy reliance on non-institutional and often unregulated information channels, which may contribute to partial or inconsistent understanding of the issue.

**Table 2: Summary of Knowledge and Awareness of Climate Change among Tomato Farming Communities**

| **Variable** | Category | Frequency | Percentage (%) |
|---|---|---|---|
| **Heard of Climate Change** | Yes | 389 | 97.3 |
| | No | 11 | 2.8 |
| **Understanding Level** | Little | 80 | 20.0 |
| | Moderate | 261 | 65.3 |
| | Detailed | 59 | 14.8 |
| **Most Common Sign Observed** | Rising Temperatures | 131 | 32.8 |
| | Droughts | 116 | 29.0 |
| | Storms | 91 | 22.8 |
| | Changes in plant and animal behaviour | 62 | 15.5 |
| **Main Information Source** | Friend | 17 | 4.3 |
| | Radio | 24 | 6.0 |
| | Television | 97 | 24.3 |
| | Social media | 137 | 34.3 |
| | Government source | 32 | 8.0 |
| | Others | 93 | 23.3 |

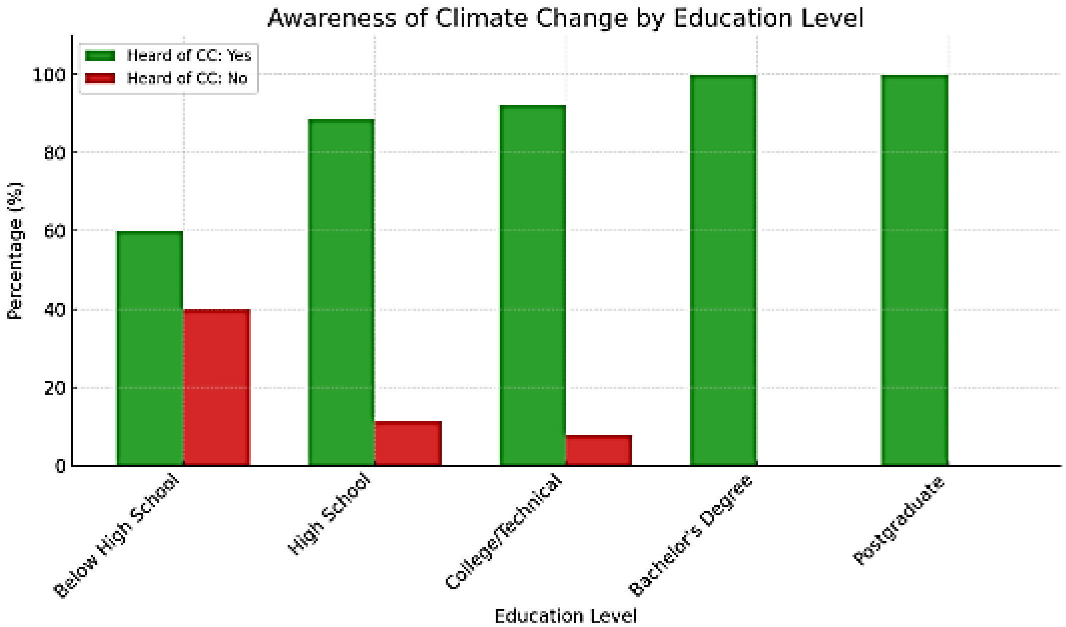


Figure 1: Climate Change by Education Level

As shown in Figure 1, there is a clear and positive association between education level and awareness of climate change among tomato farming communities. Respondents with postgraduate (100.0%) and bachelor's degrees (100.0%) all reported awareness of climate change. Awareness remained high among those with college or technical education (92.2%) and high school education (88.6%), although a small percentage in these groups (7.8% and 11.4%, respectively) indicated no awareness. By contrast, among respondents with below high school education, only 60.0% reported awareness, while 40.0% indicated that they had not heard about climate change. This suggests a significant information gap among less educated farmers and highlights the critical role education plays in environmental awareness.

VOL. 5 (2), DECEMBER, 2025
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**Table 3: Inferential Statistics on Factors Associated with Climate Change Awareness among Respondents**

| Hypothesis | Test Used | $\chi^2$ Value | df | p-value | Decision |
|---|---|---|---|---|---|
| **Education level is associated with awareness** | Chi-Square | 50.302 | 4 | 0.000 | Reject $H_0$ (Significant) |
| **Gender is associated with awareness** | Chi-Square | 3.518 | 1 | 0.062 | Do not reject $H_0$ |
| **Years of experience in agriculture is associated with awareness** | Chi-Square | 17.454 | 4 | 0.002 | Reject $H_0$ (Significant) |
| **Age is associated with awareness** | Chi-Square | 8.670 | 4 | 0.070 | Do not reject $H_0$ |

The Chi-square test revealed a statistically significant association between education level and awareness of climate change ($\chi^2 = 50.302$, df = 4, $p < 0.001$). This finding supports earlier descriptive evidence and reinforces the role of formal education in enhancing climate literacy. Respondents with tertiary education (bachelor's and postgraduate degrees) demonstrated near-universal awareness, highlighting education as a strong predictor of climate change knowledge. A significant association was also found between years of agricultural experience and awareness ($\chi^2$ = 17.454, df = 4, p = 0.002). This suggests that farmers with longer exposure to agricultural practices may be more familiar with climatic shifts affecting crop production, possibly through experiential learning and informal knowledge exchange. In contrast, gender (p = 0.062) and age (p = 0.070) were not significantly associated with awareness at the 0.05 level. Although marginally close to the threshold, these results suggest that awareness of climate change is broadly distributed across gender and age groups within the study population and not significantly differentiated by these attributes.

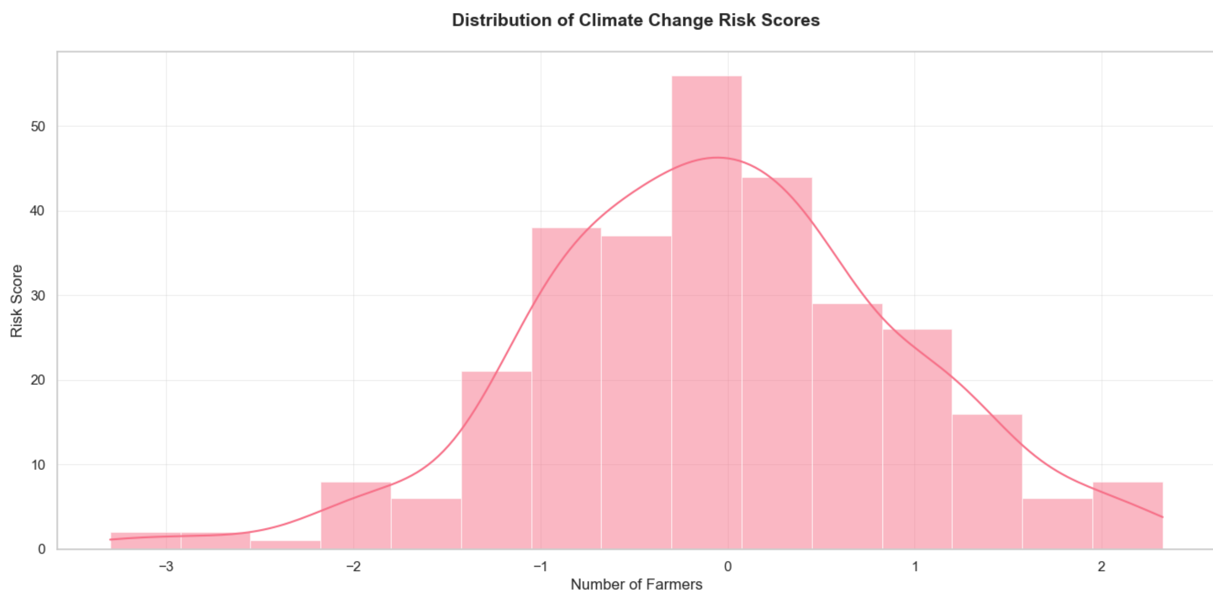


**Figure 2: Distribution of Climate Change Risk Scores**

From figure 2, most farmers fall into the lower risk categories (scores 0 and 1), with very few in the highest risk group (score 2). This suggests that the majority of the surveyed farmers perceive climate change risks as relatively low.

**Food Security Impact Scores**


**Figure 1: Distribution of Food Security Impact Scores**

From figure 3, the histogram displays food security impact scores (0-10 scale) among farmers, with a mean score of 6.5. Scores are concentrated around the middle range (4-8), indicating moderate perceived impacts on food security. The distribution also shows some farmers experience higher impacts.

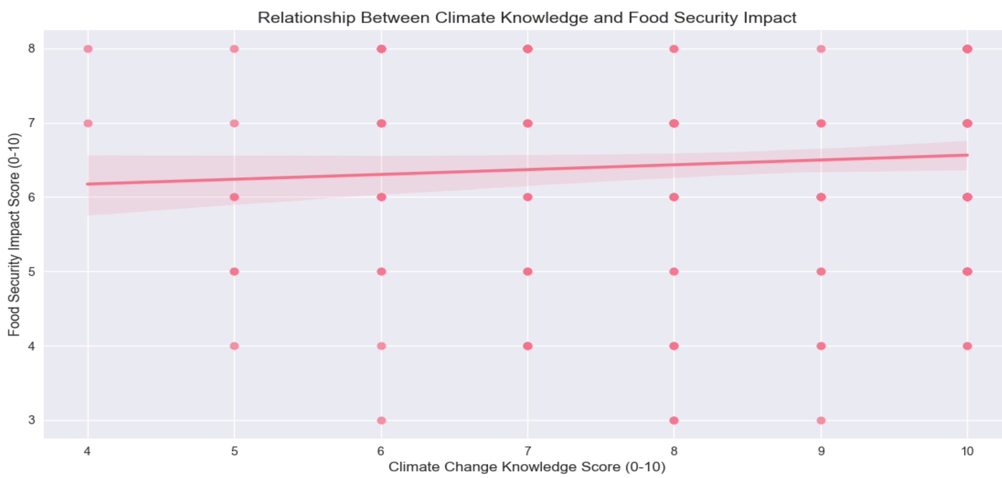


**Figure 4: Relationship Between Climate Knowledge and Food Security Impact**

From figure 4, the scatterplot explores the relationship between climate change knowledge scores and food security impact scores. There is a weak positive trend, implying that higher knowledge may correlate with slightly better food security outcomes.

**Public Health Impact of Climate**

**Table 9: Public Health Impact of Climate Change on Tomato Farmers (n = ~290)**

| Statement | Mean | Max | Interpretation |
|---|---|---|---|
| Increased pesticide exposure due to pest outbreaks | 3.55 | 5.0 | Moderate-to-high health concern |
| Water scarcity impacting irrigation quality and health | 3.59 | 5.0 | Moderate-to-high risk |
| Extreme weather and increased risk of waterborne diseases | 3.76 | 5.0 | Highest perceived public health impact |
| Heat-related illnesses among farm workers | 3.58 | 5.0 | Moderate-to-high |
| Nutritional quality reduction in tomatoes affecting health | 3.67 | 5.0 | Notable public health concern |

Table 4 highlights the perceived public health risks associated with climate change among tomato farmers. The highest rated concern was the increased risk of waterborne diseases due to extreme weather conditions (Mean = 3.76), indicating strong awareness of indirect health impacts. This was closely followed by concerns over nutritional quality reduction in tomatoes (M = 3.67), heat-related illnesses among farm workers (M = 3.58), and pesticide exposure from pest outbreaks (M = 3.55). Water scarcity also posed a significant concern (M = 3.59). Overall, the scores suggest that farmers perceive climate change as a moderate-to-high public health threat, particularly through its effects on food safety, water access, and disease exposure.

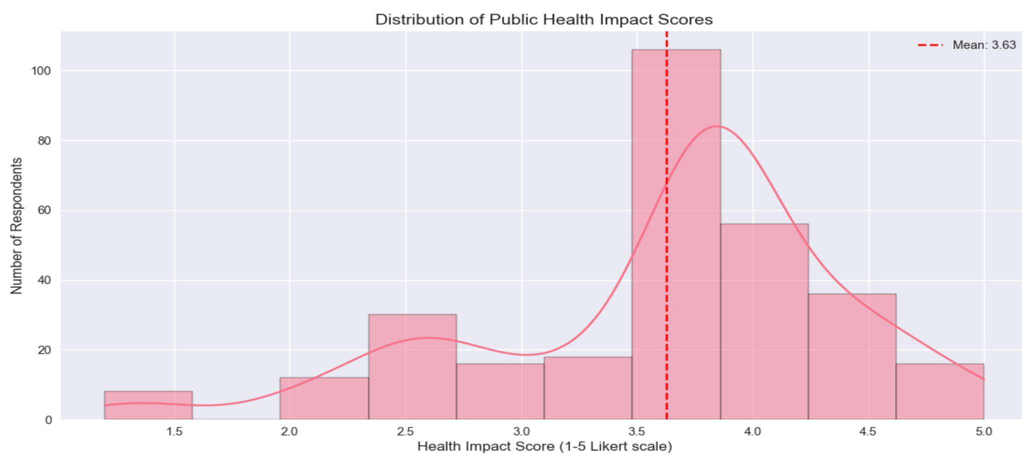


**Figure 2: Distribution of Public Health Impact Scores**

Figure 5 presents public health impact scores on a 1-5 Likert scale, with a mean of 3.63. Scores are clustered around 3-4, reflecting moderate perceived health impacts. The tail toward higher scores suggests a subset of respondents' experiences more severe health effects.

Table 10: Pearson Correlation Matrix

| | Knowledge Score | Food Security Index | Health Impact Score |
|---|---|---|---|
| Knowledge Score | 1.00 | 0.08 | 0.19 |
| Food Security Index | 0.08 | 1.00 | 0.27 |
| Health Impact Score | 0.19 | 0.27 | 1.00 |

From table 6, the correlation analysis explores relationships between knowledge scores, food security index, and health impact perception. A weak but positive correlation exists between knowledge score and health impact score (r = 0.19), suggesting that more knowledgeable respondents tend to perceive greater health risks from climate change. The correlation between knowledge and food security is very weak (r = 0.08), implying little to no association. Meanwhile, food security and health impact scores have a slightly stronger correlation (r = 0.27), indicating that farmers perceiving greater health impacts also tend to be more food-insecure. While none of the correlations are strong, they suggest potential patterns linking knowledge, perceived health risk, and food security status.

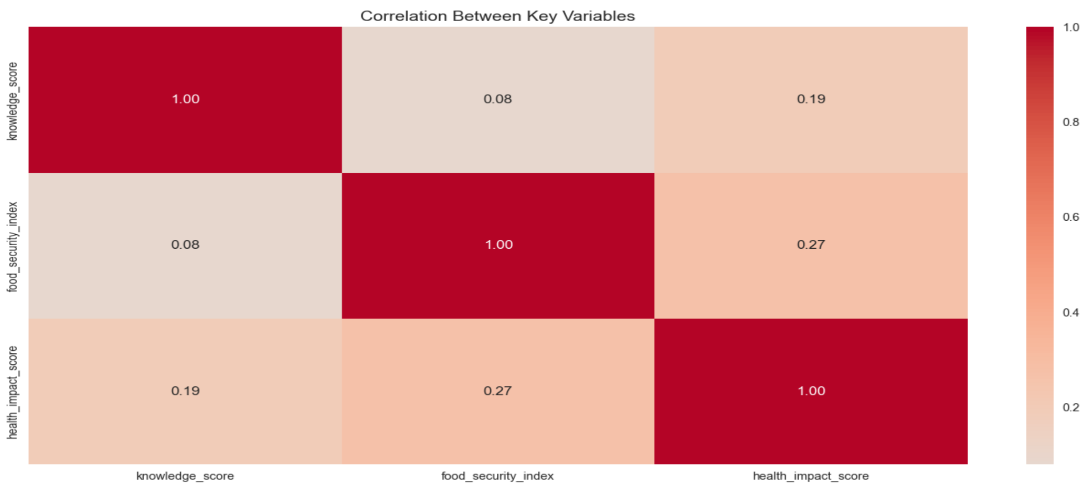


**Figure 3: Correlation Between Key Variables**

From figure 6, the correlation matrix reveals relationships among knowledge scores, food security, and health impact scores. Knowledge score shows a weak positive correlation with food security (0.27) and health impact (0.19). Food security and health impact have a stronger correlation (0.27), suggesting interconnected challenges. The low correlations indicate that while these variables are related, other unmeasured factors significantly influence outcomes.

The study provides a comprehensive analysis of Climate change knowledge was moderate (scores 4–6), increasing with education (postgraduates at 9.54, below high school at 6.00, p < 0.001), and correlated weakly with health impacts (r = 0.19) and food security (r = 0.08), with food security and health impacts showing a slightly stronger link (r = 0.27). Farmers perceived moderate public health risks (mean 3.63), with waterborne diseases (3.76) as top concerns, reflecting the interconnected challenges of climate change, food security, and health in the tomato farming community. Awareness of climate change was very high (97.3%), but depth of understanding was largely moderate (65.3%), with only 14.8% reporting detailed understanding, indicating a gap between awareness and comprehensive knowledge among farmers.

**Discussion**

The assessment of farmers' knowledge and awareness showed moderate levels (scores 4–6), with education significantly influencing understanding ($p < 0.001$; postgraduates 9.54, below high school 6.00). Anyaoha *et al.* (2023) noted genotype awareness among Nigerian researchers, suggesting potential for local education, while the socio-demographic profile (44.7% aged 26–35, 64.0% male, 51.3% with bachelor's degrees) supports targeted training, as Rangaswamy *et al.* (2021) noted. The rejection of the null hypothesis ($H_0$) of no significant knowledge differences highlights the need for local climate education. Education level and years of agricultural experience were statistically associated with awareness ($\chi^2 = 50.302$, $p < 0.001$; $\chi^2 = 17.454$, $p = 0.002$), while gender and age were not significant predictors, confirming education and experiential learning as key drivers of climate awareness. Although 97.3% of respondents had heard of climate change, only 14.8% had detailed understanding, indicating shallow knowledge depth despite high awareness. Food security impact scores (mean 6.5, range 4–8) showed a weak knowledge correlation (r = 0.08) and stronger health link (r = 0.27). Rainy season farming (82.0%) and modest incomes (52.3% below ₦100,000) suggest climate variability affects availability and access, as Abolusoro & Audu (2024) identified yield variability among 20 cultivars (e.g., Cobra F1 yielding 15 tons/ha). The rejection of the null hypothesis (H0) of no relationship with climate risks calls for local supply chain enhancements. Food security impact scores were concentrated in the mid-range (4–8), with a mean of 6.5, indicating moderate perceived impacts on food availability and access. The weak positive trend between climate knowledge and food security suggests that awareness alone is insufficient to buffer food security risks without structural and economic support systems. Modelled public health impacts showed moderate risks (mean 3.63), with waterborne diseases (3.76) and nutritional quality reduction (3.67) as concerns. A weak knowledge-health correlation (r = 0.19) and stronger food security-health link (r = 0.27) suggest vulnerabilities, with heavy metals (e.g., 0.30 mg/kg Cd in Sokoto) and microbial loads (3 log CFU/g) posing risks. Salem et al. (2016) noted Cd and Fe accumulation, while the rejection of the null hypothesis (H0) of no significant impacts underscores the need for local health modeling. Public health impact scores clustered around 3–4 on a 5-point Likert scale, reflecting moderate perceived health risks, with extreme weather-related waterborne diseases rated highest (Mean = 3.76)

This study advances knowledge on tomato production, quality, and climate-smart agriculture in northern Nigeria.
The research also links tomato quality to farmers' socio-demographic characteristics and climate change awareness. Higher education levels corresponded with greater understanding of climate risks, while climate knowledge modestly correlated with perceptions of health and food security impacts. Farmers identified waterborne diseases and reduced nutritional quality as pressing climate-related threats. This integration of production outcomes with human and social factors provides insight into how knowledge, experience, and resource access influence the resilience of smallholder farming systems. By situating these results within the framework of climate-smart agriculture, the study demonstrates how CSA practices can address observed vulnerabilities. Climate-resilient crop varieties, efficient irrigation, improved post-harvest handling, soil and water conservation, and renewable energy.

The findings offer evidence for designing CSA interventions tailored to local conditions, supporting farmers in adapting to climate variability while maintaining food quality and safety. Finally, the study informs policy and development strategies. It provides empirical evidence for targeted capacity-building, extension services, and financial support through national and international climate funding. The results underline the need for coordinated action to improve tomato production quality, strengthen climate adaptation, and enhance food security. Additionally, knowledge and Awareness revealed moderate levels (scores 4–6), with education significantly influencing awareness ($p < 0.001$; postgraduates 9.54 vs. 6.00 below high school). Anyaoha *et al.* (2023) noted genotype awareness, supporting targeted training, as per Rangaswamy *et al.* (2021). The rejection of the null hypothesis ($H_0$) of no significant knowledge differences calls for local climate education. This is supported by significant associations between awareness and education ($\chi^2 = 50.302$, $p < 0.001$) and farming experience ($\chi^2 = 17.454$, $p = 0.002$). Food Security Impact Scores showed a mean of 6.5 (range 4–8), with a weak knowledge correlation ($r = 0.08$) and stronger health link ($r = 0.27$). Rainy season farming (82.0%) and low incomes (52.3% below ₦100,000) suggest climate impacts on availability and access, as Abolusoro & Audu (2024) noted yield variability. This rejects the null hypothesis (H0) of no relationship with climate risks, advocating for supply chain enhancements. Histogram distributions confirm moderate perceived food security impacts. Public Health Impact of Climate modeled moderate risks (mean 3.63), with waterborne diseases (3.76) and nutritional quality reduction (3.67) as concerns, linked to food security ($r = 0.27$) and weakly to knowledge ($r = 0.19$). The rejection of the null hypothesis ($H_0$) of no significant impacts highlights the need for local health modeling. Likert-scale distributions and correlation matrices support these relationships.

## Conclusion

The study on the quality and security of tomato cultivation in Nigeria's Northern Cultivation Region has provided critical insights into the impacts of climate change on this vital agricultural sector. The assessment of farmers' knowledge and awareness revealed a moderate understanding of climate change, strongly correlated with education levels, indicating a foundation for capacity building that could bolster adaptive practices. Food security impact scores indicated moderate disruptions, with climate variability affecting availability and access, particularly in resource-constrained communities, while public health modelling identified risks from waterborne diseases and nutritional quality reduction, linked to heavy metal and microbial issues. Collectively, these findings illuminate the complex relationship between environmental, logistical, and socio-economic factors shaping tomato quality and security. The study's rejection of all null hypotheses affirms the significant influence of climate change and related factors on tomato cultivation. It highlights the resilience of local cultivars and the potential for intervention at multiple stages which stern from soil management to transport and farmer education to mitigate adverse impacts. The study concluded that these insights provide a robust foundation for policy and practice, urging a holistic approach to sustain tomato production amidst evolving climatic challenges.

## Recommendations

Based on the study's findings, the following tailored recommendations are proposed:

i. The study recommends launching targeted climate change education programs that leverage the observed educational influence (e.g., postgraduates scoring 9.54 vs. 6.00 for those below high school), to enhance farmers' awareness and adoption of adaptive practices like drought-resistant varieties. Partnering with local agricultural extension services to deliver workshops in Kano, Zaria, and Sokoto.

ii. Government should strengthen the supply chain resilience by supporting rainy season farming with irrigation infrastructure and income diversification programs, addressing the 82.0% reliance and 52.3% of farmers earning below ₦100,000. Encouraging cooperative marketing to stabilize access and availability, mitigating the moderate food security impact.

iii. Developing a localized health risk model. Collaborating with public health authorities like Environmental Health Officers to implement soil remediation and hygiene campaigns, reducing the moderate perceived risks.

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