

Analysis of the Vulnerability of Okra Cultivation to the Effects of Climate Change in the Urban Commune of N'Zérékoré (UCZ), Republic of Guinea

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Abstract

This study assesses the vulnerability of okra cultivation to climate variability in the Urban Commune of N'Zérékoré (CUZ), an area increasingly affected by climate-related disturbances that threaten food security. The analysis is based on surveys conducted with 52 farmers across 18 plots, complemented by qualitative field observations. The results reveal a strong dependence of okra production on climatic and environmental conditions. Cultivation relies largely on traditional practices, with broadcast sowing (73.8%) and fertilization dominated by mineral inputs (87.7%), while the use of organic manure remains limited. Mostly rainfed (98.2%), okra production is highly exposed to climatic hazards, and the use of chemical pesticides is relatively low (29.4%). Major constraints include water availability (42%), limited access to irrigation (58%), and the combined burden of high input costs and low household incomes (61%). Farmers employ several adaptation strategies, with adjustments to the sowing calendar being the most common (52%). The Climate Vulnerability Index (CVI) reveals notable spatial heterogeneity: four sites show high vulnerability, five medium vulnerability, and two low vulnerability. Overall, the findings underscore the need to strengthen agronomic practices, improve access to water and production inputs, and enhance farmers' adaptive capacities to boost the resilience of the okra sector to climate change.

Keywords

Okra Cultivation, Climate Change Impacts, Vulnerability Factors, N'Zérékoré

1. Introduction

Climate change now poses a significant threat to global food security, resulting in reduced agricultural yields, decreased crop diversity, and increased volatility in food prices [1] [2]. This crisis is further exacerbated by irregular rainfall patterns, more intense heat waves, and rising infestations of pests and diseases [3] [4]. Among agricultural products, vegetable crops are particularly vulnerable to these disruptions because of their strong dependence on temperature and water availability [5] [6]. Recent estimates indicate that extreme weather events can account for up to 70% of agricultural losses in some regions [7]-[9]. In response, farmers are increasingly adopting adaptation strategies and technological innovations to maintain productivity [10].

In West Africa, climate variability is leading to shorter rainy seasons, prolonged droughts, and increasingly intense heat waves [9] [11]. These changes profoundly affect rainfed agricultural systems, disrupting cropping calendars and reducing productivity [12] [13]. Vegetable crops, which are highly dependent on water availability, frequently experience heat and water stress [14] [15]. Climate instability complicates the management of production cycles and threatens farmers' incomes. Although adaptive practices such as crop diversification, drip irrigation, and the use of resistant varieties are promoted [16], their adoption remains limited by economic and institutional constraints.

In Guinea, the impacts of climate change are manifested through flooding, soil erosion, and localized droughts, with significant consequences for market gardening and, consequently, urban food security [7] [17] [18]. In the Urban Commune of N'Zérékoré (CUZ), these phenomena are exacerbated by demographic pressure and rapid urbanization, which reduce the land available for agriculture and intensify the degradation of water resources. Torrential rains lead to river siltation and the loss of fertile soil, resulting in a marked decline in vegetable productivity. These challenges underscore the need to transform agricultural practices to enhance farmers' resilience to climate-related hazards.

In this context, okra (*Abelmoschus esculentus*) cultivation plays a strategic role in the market gardening systems of the Urban Commune of N'Zérékoré (CUZ). As a crop with high nutritional and economic value, it serves as an important source of income for smallholder farmers while contributing to the food security of urban households. However, okra is highly sensitive to climatic variations, particularly temperature fluctuations, irregular rainfall, and soil degradation. These interrelated factors directly affect the growth, flowering, and fruiting of the plant, thereby compromising its yield and the stability of its production in the locality.

In addition, temperature fluctuations disrupt okra physiology, leading to developmental abnormalities, while irregular rainfall reduces water availability during critical growth stages. These water deficits result in recurrent water stress, early wilting, and premature flower and fruit drop, as reported by Asante [19], Challinor *et al.* [14], and Knox *et al.* [15]. Simultaneously, soil degradation (exacerbated by erosion, loss of organic matter, and overexploitation of land) undermines the fertility of growing environments and increases the vulnerability of okra cultivation to climate change. Together, these constraints reduce overall productivity and heighten the precariousness of farmers' livelihoods.

Despite its high nutritional value in the region (being rich in fiber, vitamins, and minerals) and its central role in urban food diversification, the productive potential of okra remains constrained by structural and technological limitations. The scarcity of irrigation infrastructure, limited adoption of agricultural innovations, and insufficient implementation of sustainable soil management leave farmers almost entirely dependent on natural rainfall. This reliance amplifies inter-seasonal yield variability and undermines the livelihoods of market gardeners. Moreover, the predominance of smallholder family farms, coupled with limited access to agricultural credit, quality inputs, and climate information, significantly restricts local adaptation capacities.

This study, therefore, aims to analyze the vulnerability of okra cultivation to the effects of climate change in the Urban Commune of N'Zérékoré, to propose realistic and sustainable adaptation measures to enhance the resilience of local market gardening systems and support urban food security.

2. Materials and Methods

2.1. Knowledge of the Urban Commune of N'Zérékoré

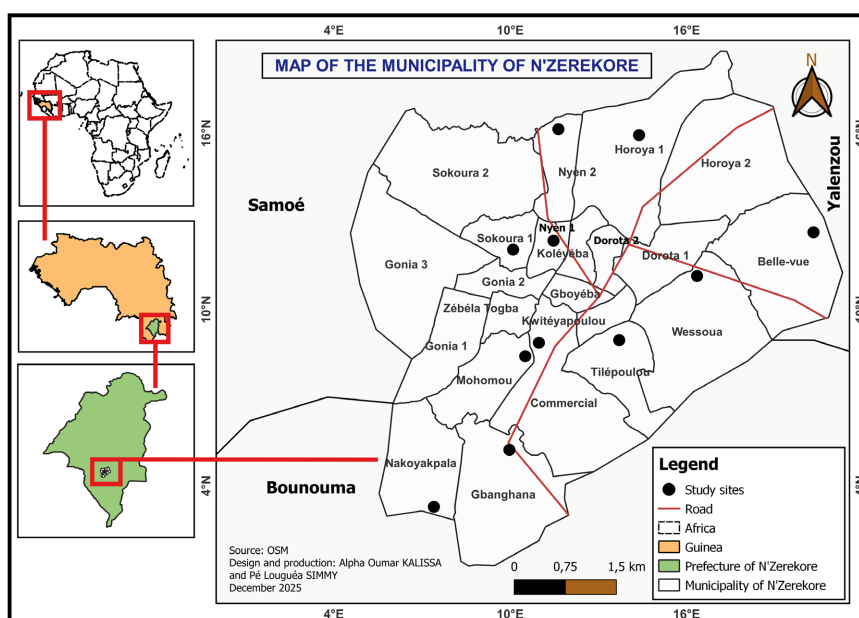


Figure 1. Location map of the study sites in the Urban Commune of N'Zérékoré.

Located in Southeastern Guinea, the Urban Commune of N'Zérékoré (CUZ) is the largest city in Guinea's forest region, covering an area of 47.3 km² with an estimated population of 250,000 according to the 2018 census. It is made up of 22 neighborhoods divided into 96 sectors and bordered by several rural communes (CR), including Samoé, Bounouma, Yalenzou, Koulé, Guécké, and Kobéla (**Figure 1**).

Geographically, the CUZ is located between 7°32' and 8°22' north latitude and at 9°04' west longitude. The commune experiences a sub-equatorial high-altitude climate, influenced by surrounding mountains, which favors a long rainy season lasting approximately nine months, followed by a short dry season. This climate, combined with high humidity, supports intensive agricultural production. Physically and ecologically, the municipality is traversed by the Tilé River, which plays a crucial role in draining water from the area. Once covered by dense forest, the CUZ has experienced significant vegetation loss due to demographic pressure, leaving only a few sacred forests intact. Wildlife, particularly large game, is also threatened by poaching and habitat degradation. Despite these environmental challenges, the CUZ retains high agricultural potential, particularly for crops such as rice, coffee, kola, and palm oil. This potential not only ensures local food self-sufficiency but also allows for the export of surplus to other regions.

2.2. Data Collection Methods

The methodology used to achieve the objectives of this study includes the following steps: Bibliographic research, Selection of Resource Persons (RP), Semi-structured interviews, Direct observation, Determination of the climate vulnerability index, and finally, data processing.

2.2.1. Bibliographic Research

Two categories of documents were used: geo-historical archives of the CUZ and online resources. The geo-historical archives were consulted at the N'Zérékoré Environmental Research Center (CREDEZ), the CUZ town hall, the N'Zérékoré Prefectural Directorate of Agriculture (DPAZ), and the University of N'Zérékoré (UZ) library. Online resources included the websites of the Convention on Biological Diversity (CBD), the United Nations Development Programme (UNDP), and the Food and Agriculture Organization of the United Nations (FAO). Additionally, discussions with field specialists provided relevant information. Data obtained from these sources helped to define the research problem, delimit the study area, and design the methodological approaches.

2.2.2. Selection of Resource Persons (RPs)

In this study, the sample size (n = 52 Resource Persons) was determined using non-probability sampling based on purposive selection, aiming to survey respondents with direct and relevant experience in okra cultivation. The sample included an agricultural technician, a representative of the municipal authorities, and fifty specialized farmers (**Table 1**). This methodological approach prioritized

the thematic relevance and analytical depth of the information collected rather than strict statistical representativeness.

For methodological rigor and transparency, Yamane's formula [20] was used to situate the observed sample size within a theoretical probabilistic framework:

$$n = N / (1 + N \times e^2)$$

with n = sample size; N = population size; e = desired margin of error (in decimal, e.g., 0.05 for 5%).

Calculations indicate that, for a plausible finite population, a probabilistic sample targeting a margin of error of 5% - 10% would have required a larger sample size than that used. The sample of 52 respondents thus corresponds, by extrapolation, to an estimated implicit margin of error of 12% - 14%, reflecting moderate accuracy under a strict probabilistic perspective.

Consequently, this study justifies its sample size not based on statistical representativeness, but on the quality, diversity, and saturation of the information obtained. The careful selection of resource persons ensured balanced representation across socio-professional profiles, sociodemographic variables (age, gender, literacy level), and spatial coverage (18 plots across 11 sites). This approach ensures the analytical validity and depth of the collected data, while acknowledging that the implicit margin of error constitutes a methodological limitation of the study.

Table 1. Sociodemographic characteristics of respondents.

Respondents	Gender		Age		Status		Total
	Men	Women	25 - 45	≥46	Literate	Illiterate	
Municipal Authority	01	0	0	01	01	0	01
Agricultural Technician	01	0	01	0	01	0	01
S.F.O.V.C.	02	48	39	11	13	37	50
Total				52			

Source: Investigations from March 16 to May 25, 2025, in the CUZ; **Legend:** S.F.O.V.C. = Specialized Farmers in Okra, Cabbage, and Spinach Cultivation.

2.2.3. Semi-Structured Interviews

Field surveys were conducted between February 16 and May 15, 2025. A participatory approach was employed through the organization of five focus groups across 11 neighborhoods of the CUZ. Each group, composed of 2 to 4 specialized farmers, provided data on farming practices, observed climate impacts, and adaptation strategies. Sessions lasted between 30 and 60 minutes and were led by a spokesperson appointed by the group members for their in-depth knowledge of the subject. The spokesperson presented the main responses, which were supported or corrected by other participants, ensuring the reliability and richness of the information collected.

To complement this data, 11 individual interviews were conducted with farmers in their gardens as well as with institutional actors, including agricultural technicians and municipal authorities. This triangulation of perspectives provided a comprehensive understanding of the local realities regarding the vulnerability of okra crops in the area.

2.2.4. Direct Observation

The third methodological phase involved direct observations conducted at the identified gardening sites. These observations focused on the current state of okra crops in relation to climatic conditions and agricultural practices. Each visit was conducted with the explicit consent of the farmers, who authorized the use of the data collected. These observations provided empirical validation of the information obtained from focus groups and individual interviews.

2.2.5. Determination of the Climate Vulnerability Index for Okra Crops

The climate vulnerability of okra crops in the Urban Commune of N'Zérékoré was assessed using the Climate Vulnerability Index (CVI), calculated as follows:

$$CVI = E \times (S + AC)$$

where:

E = exposure to climate hazards (e.g., erosion, water deficit, irregular rainfall);

S = crop sensitivity (e.g., soil fertility, dependence on rainfall, varietal diversity);

AC = adaptive capacity of market gardeners (e.g., access to irrigation, climate information, and adapted farming practices).

Each component was normalized between 0 and 1 using the min–max transformation, which ensured the harmonization of initially heterogeneous variables and facilitated their integration within a common analytical framework. The components *E*, *S*, and *AC* were then aggregated into composite indices through a weighted mean. The assignment of weights was based jointly on the methodological recommendations proposed by [21]-[23], as well as on the judgment of local experts, in order to adjust the relative importance of each indicator to the specific agro-climatic realities of the Urban Commune of N'Zérékoré. In line with these references and field observations, exposure) identified as the major constraint in rainfall-dependent farming systems (received the highest weight within the index structure. This approach ensured a transparent, reproducible, and scientifically robust quantification of the climate vulnerability of okra crops, while remaining adaptable to other production systems in the locality.

2.2.6. Data Processing

All data collected during the surveys were first organized and checked for completeness and consistency. Quantitative data were then coded and entered into Microsoft Excel (version 2013) for basic statistical analyses, including calculation of means and standard deviations, which were essential for descriptive analysis and the production of illustrative graphs. For spatial representation of the results, QGIS (version 3.16.3) was employed due to its advanced capabilities in thematic

mapping, allowing precise visualization of the geographic distribution of okra cultivation sites within the study area.

However, the study employed a non-probabilistic, purposive sampling approach. While this limits the statistical generalization of the findings to the entire population of okra producers in the Urban Commune of N'Zérékoré, it allowed the selection of respondents with direct and relevant experience, ensuring the depth and reliability of the collected information. Moreover, the triangulation of survey data, interviews, and direct observations enhances the robustness of the analysis.

3. Results

3.1. Agricultural Practices for Okra Cultivation in the CUZ

The survey of 52 market gardeners across 18 fields in 11 sites of the CUZ revealed that okra cultivation relies primarily on traditional practices, combining manual clearing with herbicides, hand sowing and fertilization, and basic irrigation (**Table 2**).

Table 2. Summary of agricultural practices for okra cultivation.

Agricultural Practice	Types Observed in the Fields	Proportion Observed
Sowing	Broadcast or Random Sowing	73.8%
	Cluster Sowing	26.2%
Fertilization	Mineral Fertilizers (Urea and NPK)	87.7%
	Farm Manure	13.3%
Cultivation Methods	Rainfed	98.2%
	Irrigated	2.8%
Plant Protection	Crop Rotation	71.6%
	Chemical Pesticides	29.4%
Clearing	Herbicides	100%
Watering	Manual Watering	100%

Analysis of cultural practices across the 18 okra plots shows that broadcast or random sowing is the dominant method, applied in 73.8% of the fields, mainly located in non-flooded lowlands, while 26.2% of the plots are sown in holes (pockets). Fertilization relies predominantly on the use of mineral fertilizers, such as urea and NPK, applied in 87.7% of the plots, whereas farmyard manure is used only marginally (13.3%). Okra cultivation is mostly rainfed (98.2%), with irrigation limited to 35.8% of the fields, exposing production to fluctuations in rainfall patterns within the CUZ. Regarding crop protection, farmers primarily use traditional practices such as crop rotation (71.6% of plots), while the use of chemical pesticides remains low (29.4%), due to high costs and limited knowledge among market gardeners.

3.2. Okra Varieties Cultivated and Agricultural Calendar according to Climatic Conditions in the CUZ

Analysis of okra (*Abelmoschus esculentus*) cultivation calendars in the Urban Commune of N'Zérékoré revealed that production relies primarily on local varieties adapted to the climatic conditions and traditional practices of the area. Among these, the varieties “*Kaaly Gbély*, *Fodéya*, and *Kaaly Fikhé*”, known by local vernacular names, are selected by market gardeners (particularly women at the local market) based on their disease resistance, earliness, productivity, and tolerance to temperature fluctuations and the specific rainfall patterns of the CUZ (Table 3).

Table 3. Local okra varieties, agricultural calendar, and climatic conditions in the CUZ.

Variety of Gombo	Proportion by Market Gardeners	Sowing Period	Harvest Period	Climate Adaptation	Comments
<i>Kaaly Gbély</i>	35%	Early March/Early October	May to June/December to January	Tolerates moderate drought, resistance to local diseases	Long variety, high productivity in wet seasons
<i>Fodéya</i>	32%	Early March/Early October	May to June/December to January	Resistant to temperature variations and irregular rainfall	Short variety, suited to drier areas
<i>Kaaly Fikhé</i>	22.6%	Early March/Early October	May to June/December to January	Tolerant to local water stress conditions	Intermediate variety, farmer-selected
<i>Hybrides locales</i>	21.2%	Early March/Early October	May to June/December to January	Fast growth, variable tolerance	Minority variety, used to secure supply

According to the 52 market gardeners surveyed, sowing mainly takes place in two periods: early March and early October, allowing for optimal germination and plant development. For them, harvesting takes place when each variety reaches maturity: May-June for March sowings and December-January for October sowings. Short local varieties are preferred in the context of prolonged drought, while longer, more productive varieties require regular rainfall and are generally grown at the beginning of the rainy season (March). Local hybrids, although in the minority (21.2%), are used to accelerate production and secure local supply. This distribution of varieties and growing periods illustrates an adaptive agricultural strategy aimed at maximizing yields while reducing the risks associated with climatic hazards and rainfall fluctuations.

3.3. Effects of Climate Change on Okra Production in the CUZ

The study revealed that changes in climatic patterns, declining soil fertility, outbreaks of pests and diseases, reduced water availability, impacts on pollination, disruptions of agricultural cycles, and economic losses are the main effects of cli-

mate change on okra production. Among the 52 market gardeners surveyed, nearly half reported reduced water availability as the primary factor affecting okra cultivation in the CUZ (**Figure 2**).

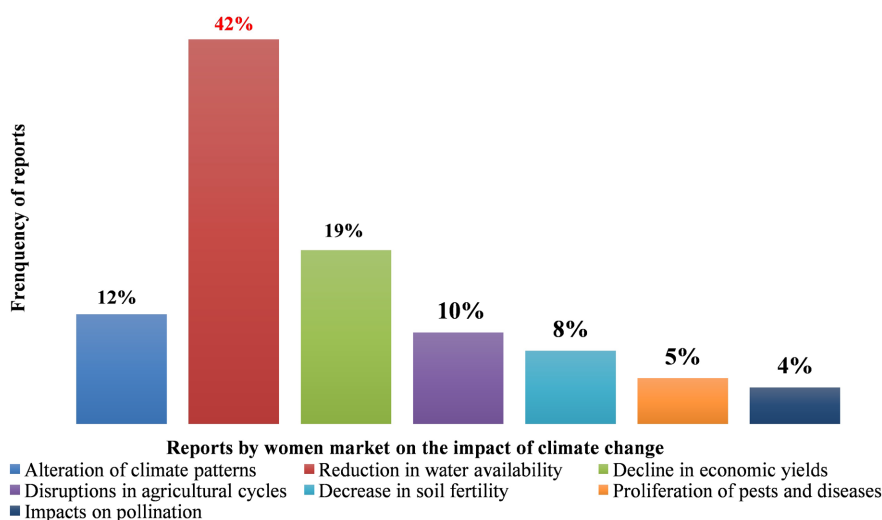


Figure 2. Frequency of reports by women market gardeners on the impact of climate change on okra production.

Analysis of **Figure 2** indicates that reduced water availability is the primary constraint perceived by market gardeners in the CUZ, reported by 42% of respondents, making it a central concern for their activities. This is followed by declines in economic yields (19%) and climate-related changes (12%), reflecting a strong sensitivity to financial and environmental impacts. Disruptions in agricultural cycles (10%) and reduced soil fertility (8%) further highlight the vulnerability of production systems. Pests and diseases (5%) and impact on pollination (4%) appear to be of lesser concern, likely due to their less immediate perception. These results demonstrate a clear hierarchy of concerns related to climate change.

3.4. Environmental Factors Contributing to the Vulnerability of Okra Crops

Five main environmental factors (drought, limited access to irrigation water, excessive rainfall, storms or strong winds, soil degradation, and pest attacks) seriously affect okra cultivation in the CUZ. According to the perceptions of the 52 resource persons surveyed, more than half identified limited access to irrigation water as the primary factor constraining the development of their crops (**Figure 3**).

As previously shown (**Figure 3**), limited access to irrigation water was reported by 58% of respondents, highlighting the strong dependence of okra cultivation on water resources. Excessive rainfall, cited by 21%, is the second most concerning factor, often causing flooding, root rot, or soil degradation. Soil depletion, mentioned by 13%, is associated with intensified farming practices and erosion. In contrast, storms and pest attacks, reported by only 4% of respondents each, appear

to be of lesser concern. This hierarchy reflects a clear perception of the environmental threats affecting okra cultivation in the locality.

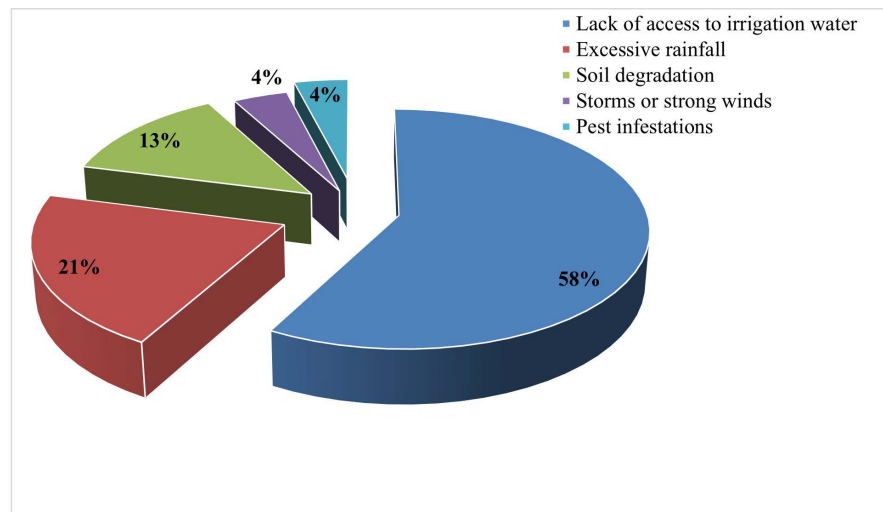


Figure 3. Frequency of opinions expressed by okra farmers on environmental factors.

3.5. Socioeconomic Factors Contributing to the Vulnerability of Okra Crops

Four main socioeconomic factors contribute to the vulnerability of okra cultivation in the CUZ. According to the perceptions of the 52 market gardeners surveyed, more than half of the participants reported that high costs of agricultural inputs and low crop incomes are the most significant economic barriers affecting the marketing of okra products (**Figure 4**).

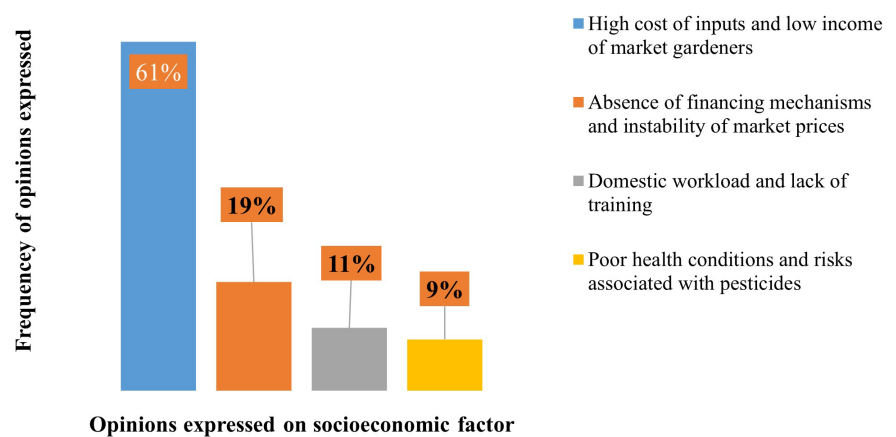


Figure 4. Frequency of opinions expressed by female market gardeners on the three crops studied, by socioeconomic factor.

Figure 4 shows that 61% of market gardeners identify high input costs and low crop incomes as the main constraints to their activities, reflecting a high level of economic vulnerability. The lack of financing mechanisms and price instability, reported by 19% of respondents, further exacerbates this precariousness by limit-

ing planning and investment capacity. Social constraints, such as the domestic workload and lack of training (11%), although significant, are perceived as less urgent than financial challenges. Poor health and pesticide-related risks (9%) were mentioned less frequently, indicating limited awareness of these issues. These results underscore the importance of strengthened economic support through subsidies, tailored financing, and awareness-raising initiatives. An integrated approach is therefore essential to sustainably enhance the capacities of market gardeners in this locality.

3.6. Endogenous Adaptation Strategies of Okra Market Gardeners in the CUZ

In response to the climatic constraints identified in the previous sections, the 52 surveyed market gardeners implement various adaptation strategies to maintain the viability of okra cultivation in the Urban Commune of N'Zerekore. According to their perceptions, adjusting the sowing calendar appears to be the most frequently adopted strategy among producers (**Figure 5**).

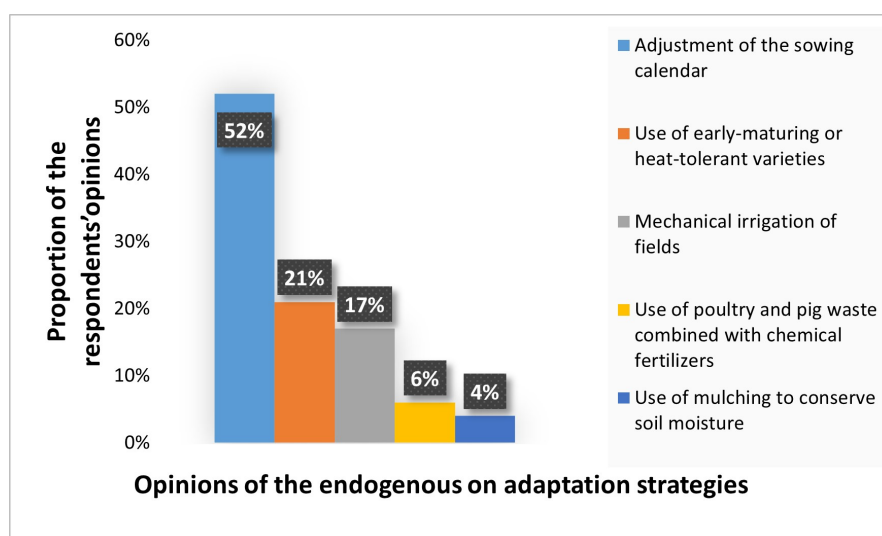


Figure 5. Proportion of respondents' opinions on endogenous adaptation strategies.

Analysis of **Figure 5** shows that adjusting the sowing calendar is the primary adaptation strategy employed by market gardeners (52%), reflecting a direct response to irregular rainfall patterns. The adoption of early-maturing or heat-tolerant varieties (21%) aims to mitigate the effects of rising temperatures and the shortening of the rainy season. Mechanical irrigation (17%) represents efforts to manage water resources, while the combined use of animal manure and chemical fertilizers (6%) illustrates an integrated fertilization approach based on local knowledge. Finally, mulching (4%), although less commonly practiced, remains an effective technique for conserving soil moisture and combating erosion. Overall, these practices are largely empirical and reactive, highlighting an adaptive capacity that is still limited by a lack of technical support and access to modern production resources.

3.7. Climate Vulnerability Index of Okra Crops in the CUZ

The assessment of the Climate Vulnerability Index (CVI) for okra crops in the Urban Commune of N'Zérékoré reveals marked spatial heterogeneity among the studied sites. Of the 11 sites analyzed, 4 exhibit high vulnerability ($CVI > 0.70$), 5 show medium vulnerability ($0.40 < CVI \leq 0.70$), and 2 display low vulnerability ($CVI \leq 0.40$) (Table 4).

Table 4. The Climate Vulnerability Index (CVI) of the sites studied.

Site	Exposure (E)	Sensitivity (S)	Adaptability (AC)	IVC	Vulnerability Level
Site 1	0.80	0.75	0.05	0.75	High
Site 2	0.78	0.72	0.06	0.72	High
Site 3	0.82	0.74	0.04	0.78	High
Site 4	0.79	0.71	0.05	0.71	High
Site 5	0.65	0.60	0.05	0.65	Medium
Site 6	0.60	0.55	0.05	0.60	Medium
Site 7	0.58	0.50	0.05	0.55	Medium
Site 8	0.55	0.45	0.05	0.50	Medium
Site 9	0.50	0.40	0.05	0.45	Medium
Site 10	0.35	0.30	0.05	0.35	Low
Site 11	0.32	0.28	0.05	0.30	Low

4. Discussion

The study of okra cultivation practices in the CUZ reveals a predominance of traditional techniques, with broadcast sowing being the main method (73.8%) and fertilization relying primarily on mineral fertilizers (87.7%), while the use of manure remains marginal. This heavy dependence on chemical inputs, also observed by Mertz *et al.* [16] in West Africa, results from the limited availability of organic resources and production pressures. Okra, which is predominantly rain-fed (98.2%), remains highly vulnerable to climatic hazards, corroborating the findings of Challinor *et al.* [14] on the fragility of rainfall-dependent agricultural systems. Limited use of irrigation (35.8%) and chemical pesticides (29.4%) reflects economic and technical constraints that hinder sustainable intensification. The predominance of local varieties such as Kaaly Gbély, Fodéya, and Kaaly Fikhè illustrates adaptation to local agroecological conditions, as these varieties are recognized for their tolerance to water stress, as highlighted by Bitá and Gerats [6]. Additionally, the diversification of varieties and the staggering of sowing dates (March and October) represent locally developed strategies to manage climate risks and secure production.

Moreover, the results of this study align with the broad scientific consensus regarding the adverse effects of climate change on agricultural systems in West Af-

rica. Reduced water availability, perceived as the main constraint to vegetable production in the CUZ, corroborates the analyses of Rosenzweig *et al.* [4], who identify irregular access to water as a major challenge for food security. In addition, disturbances in rainfall patterns and the increasing frequency of droughts, frequently reported by IPCC [9] [11], directly affect vegetative growth, flowering, and yields. Soil degradation, combined with heightened environmental stress observed in this study, is also consistent with the findings of Morton [5] and Bitu and Gerats [6], who describe declining soil fertility and increasing crop sensitivity to extreme conditions. These observations underscore the need to promote resilient and ecologically sustainable agricultural techniques, particularly in water management, soil conservation, and the adoption of more tolerant crop varieties [12].

On the socioeconomic level, constraints such as high input costs, low agricultural incomes, and the absence of adequate financing mechanisms significantly weaken okra farmers in the CUZ. These findings are consistent with Diallo [17], who emphasizes the importance of institutional support to enhance the resilience of smallholder farmers. Furthermore, price instability and the lack of irrigation infrastructure, also identified in this study, represent structural challenges previously highlighted by Roudier *et al.* [13] and the FAO [7].

In addition, market gardeners in the Urban Commune of N'Zerekore are implementing various adaptation strategies to cope with climatic constraints, particularly irregular rainfall and rising temperatures. Adjusting the sowing calendar, using early-maturing or heat-tolerant varieties, employing mechanical irrigation, and combining organic and chemical fertilizers reflect targeted and integrated responses, corroborating the findings of Challinor *et al.* [14] and Asante [19]. Mulching, although practiced marginally, contributes to soil moisture conservation and erosion control. The assessment of the Climate Vulnerability Index (CVI) reveals marked spatial heterogeneity, indicating that crop resilience depends on environmental, technical, and socioeconomic factors, as highlighted by Derbile *et al.* [21], Mwinkom *et al.* [22], and Adu *et al.* [23]. These observations call for context-specific approaches combining local knowledge and scientific innovations, alongside targeted policies (such as input subsidies, improved credit access, technical training, and irrigation support) to address key vulnerabilities and strengthen producers' adaptive capacity and livelihoods.

5. Conclusions

The study on the vulnerability of okra crops to climate change in the CUZ indicates that farming practices are primarily based on traditional knowledge, supplemented by limited innovations, reflecting gradual adaptation to climatic and socioeconomic pressures. However, the heavy reliance on rainfall and chemical fertilizers, coupled with inadequate irrigation and plant protection management, represents a major source of vulnerability. Identified impacts include water scarcity, soil fertility degradation, pest and disease outbreaks, and disruptions of agricultural cycles. Women farmers in particular emphasized water scarcity as the pri-

mary constraint, while flooding significantly reduces yields. These findings underscore the high sensitivity of okra cultivation to climatic hazards, especially irregular rainfall, droughts, and excessive precipitation. Moreover, socioeconomic constraints such as high input costs and low incomes further exacerbate producers' vulnerability.

The adaptation strategies observed in the Urban Commune of N'Zérékoré demonstrate the resilience of market gardeners in coping with climate-related challenges. However, to further strengthen this resilience, it is essential to promote the dissemination of okra varieties tolerant to abiotic stresses, improve access to irrigation water, enhance the technical capacities of producers, and facilitate knowledge exchange among agricultural stakeholders. An integrated approach that combines traditional knowledge with scientific innovations is crucial for ensuring the long-term sustainability of okra cultivation in this region. Furthermore, it is necessary to implement comprehensive agricultural policies that integrate agroecological practices, climate-adapted irrigation techniques, and economic support mechanisms. Future research should focus on locally viable technical solutions and institutional strengthening to sustainably enhance the adaptive capacity of local women farmers.

To enhance the resilience of okra production in the Urban Commune of N'Zérékoré, low-cost, locally adapted irrigation technologies, such as drip irrigation or rainwater harvesting, should be promoted. In addition, the targeted dissemination of climate-resilient local okra varieties, coupled with producer training, could help secure yields and strengthen adaptive capacity.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Lobell, D.B., Schlenker, W. and Costa-Roberts, J. (2011) Climate Trends and Global Crop Production since 1980. *Science*, **333**, 616-620. <https://doi.org/10.1126/science.1204531>
- [2] Nelson, G.C., Rosegrant, M.W., Koo, J., Robertson, R., Sulser, T., Zhu, T., Ringler, C., Msangi, S., Palazzo, A., Batka, M., Magalhaes, M., Valmonte-Santos, R., Ewing, M. and Lee, D. (2009) Climate Change: Impact on Agriculture and Costs of Adaptation. Food Policy Report, IFPRI.
- [3] UNEP (2022) Adapting to Climate Change: A Toolkit for Sustainable Agriculture. Programme des Nations Unies pour l'environnement.
- [4] Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A.C., Müller, C., Arneth, A., *et al.* (2013)

- Assessing Agricultural Risks of Climate Change in the 21st Century in a Global Gridded Crop Model Intercomparison. *Proceedings of the National Academy of Sciences of the United States of America*, **111**, 3268-3273. <https://doi.org/10.1073/pnas.1222463110>
- [5] Morton, J.F. (2007) The Impact of Climate Change on Smallholder and Subsistence Agriculture. *Proceedings of the National Academy of Sciences of the United States of America*, **104**, 19680-19685. <https://doi.org/10.1073/pnas.0701855104>
- [6] Bitá, C.E. and Gerats, T. (2013) Plant Tolerance to High Temperature in a Changing Environment: Scientific Fundamentals and Production of Heat Stress-Tolerant Crops. *Frontiers in Plant Science*, **4**, Article 273. <https://doi.org/10.3389/fpls.2013.00273>
- [7] FAO (2021) Le climat et l'agriculture: Défis et solutions. Organisation des Nations Unies pour l'Alimentation et l'Agriculture.
- [8] FAO (2020) The State of Food and Agriculture 2020: Overcoming Water Challenges in Agriculture. Organisation des Nations Unies pour l'alimentation et l'agriculture.
- [9] IPCC (2021) Sixième rapport d'évaluation sur les changements climatiques: Résumé pour les décideurs. Groupe d'experts intergouvernemental sur l'évolution du climat.
- [10] Altieri, M.A., Nicholls, C.I., Henao, A. and Lana, M.A. (2015) Agroecology and the Design of Climate Change-Resilient Farming Systems. *Agronomy for Sustainable Development*, **35**, 869-890. <https://doi.org/10.1007/s13593-015-0285-2>
- [11] Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J. and Urquhart, P. (2014) Africa. In: Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R. and White, L.L., Eds., *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B. Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, 1199-1265.
- [12] Sultan, B. and Gaetani, M. (2016) Agriculture in West Africa in the Context of Climate Change: Focus on Cereal and Irrigated Crop Farming. *Climate Change and Agriculture. Impacts, Adaptation, and Mitigation*, **35**, 1-13.
- [13] Roudier, P., Sultan, B., Quirion, P. and Berg, A. (2011) The Impact of Future Climate Change on West African Crop Yields: What Does the Recent Literature Say? *Global Environmental Change*, **21**, 1073-1083. <https://doi.org/10.1016/j.gloenvcha.2011.04.007>
- [14] Challinor, A.J., Watson, J., Lobell, D.B., Howden, S.M., Smith, D.R. and Chhetri, N. (2014) A Meta-Analysis of Crop Yield under Climate Change and Adaptation. *Nature Climate Change*, **4**, 287-291. <https://doi.org/10.1038/nclimate2153>
- [15] Knox, J., Hess, T., Daccache, A. and Wheeler, T. (2012) Climate Change Impacts on Crop Productivity in Africa and South Asia. *Environmental Research Letters*, **7**, Article ID: 034032. <https://doi.org/10.1088/1748-9326/7/3/034032>
- [16] Mertz, O., Mbow, C., Reenberg, A. and Diouf, A. (2008) Farmers' Perceptions of Climate Change and Agricultural Adaptation Strategies in Rural Sahel. *Environmental Management*, **43**, 804-816. <https://doi.org/10.1007/s00267-008-9197-0>
- [17] Diallo, A. (2020) Impacts des changements climatiques sur l'agriculture en Afrique de l'Ouest. Éditions Universitaires de Guinée.
- [18] Camara, M., Kourouma, S. and Keita, M. (2018) Urbanisation et insécurité alimentaire en Guinée forestière: Cas de la commune urbaine de N'Zérékoré. *Revue Guinéenne de Géographie*, **10**, 45-58.

- [19] Asante, J., Opoku, V.A., Hygienus, G., Andersen, M.N., Asare, P.A. and Adu, M.O. (2024) Photosynthetic Efficiency and Water Retention in Okra (*Abelmoschus esculentus*) Contribute to Tolerance to Single and Combined Effects of Drought and Heat Stress. *Scientific Reports*, **14**, Article No. 28090. <https://doi.org/10.1038/s41598-024-79178-5>
- [20] Yamane, T. (1967). *Statistics: An Introductory Analysis*. 2nd Edition. Harper & Row.
- [21] Derbile, E.K., Bonye, S.Z. and Yiridomoh, G.Y. (2022) Mapping Vulnerability of Smallholder Agriculture in Africa: Vulnerability Assessment of Food Crop Farming and Climate Change Adaptation in Ghana. *Environmental Challenges*, **8**, Article ID: 100537. <https://doi.org/10.1016/j.envc.2022.100537>
- [22] Mwinkom, F.X.K., Damnyag, L., Abugre, S. and Alhassan, S.I. (2021) Factors Influencing Climate Change Adaptation Strategies in North-Western Ghana: Evidence of Farmers in the Black Volta Basin in Upper West Region. *SN Applied Sciences*, **3**, Article No. 548. <https://doi.org/10.1007/s42452-021-04503-w>
- [23] Adu, D.T., Kuwornu, J.K.M., Anim-Somuah, H. and Sasaki, N. (2018) Application of Livelihood Vulnerability Index in Assessing Smallholder Maize Farming Households' Vulnerability to Climate Change in Brong-Ahafo Region of Ghana. *Kasetsart Journal of Social Sciences*, **39**, 22-32. <https://doi.org/10.1016/j.kjss.2017.06.009>