Assessing The Impact of Climate Change and Ripening-Delaying Chemicals on Fruit Safety, Quality, And Human Health in Kenya

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Abstract

Escalating climate variability across sub-Saharan Africa is reshaping horticultural systems, accelerating postharvest losses and driving greater reliance on ripening-modifying chemicals as an adaptive strategy. This study investigated how climate stress drives the use of ripening-accelerating and ripening-delaying chemicals in fruits sold in Kenyan markets, and how this growing dependence creates food safety and public health risks. A mixed-methods design combined field surveys (n = 180), laboratory analysis of 392 fruit samples using gas chromatography–mass spectrometry, and multivariate statistical modelling across Meru, Nairobi, Murang'a, and Kirinyaga counties between September 2024 and April 2025. The results showed that 63% of respondents used chemical ripening agents, with calcium carbide (42%) and ethephon (27%) being the most common. Residue analysis detected contaminants in 26% of the samples, while modeled acetylene concentrations in carbide-treated fruits exceeded the 0.7 mg/kg reference threshold. Regression analysis showed that rainfall variability ($\beta = 0.41$, $p < .01$) and market pressure ($\beta = 0.36$, $p < .05$) significantly predicted chemical use, while farmer knowledge and regulatory enforcement attenuated these relationships. Calcium carbide use increased modeled public health risk ($\beta = 0.67$), whereas regulatory enforcement reduced risk ($\beta = -0.45$). These findings reveal governance gaps, low risk awareness, and an urgent need for safer postharvest technologies, integrated monitoring, and climate-resilient storage systems.

Keywords: *climate change, ripening chemicals, calcium carbide, food safety, Kenya, postharvest losses, public health*

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1.0 Introduction

Kenya's horticultural sector is a cornerstone of food security, rural livelihoods, employment, and export earnings, contributing more than 30% of the agricultural gross domestic product (Kenya National Bureau of Statistics [KNBS], 2022). It sustains millions of smallholder farmers and plays a pivotal role in both domestic food systems and international trade, particularly in fruits and vegetables. However, increasing climate variability manifested through rising temperatures, erratic rainfall, prolonged droughts, and extreme weather events has disrupted agricultural productivity, altered crop physiology, accelerated ripening processes, and intensified postharvest losses, which are estimated at 30–45% for perishable commodities (Food and Agriculture Organization [FAO], 2021).

In response to these challenges, farmers and traders have increasingly adopted artificial ripening and delaying agents, including calcium carbide, ethephon, ethylene gas, and 1-methylcyclopropene (1-MCP). These substances are used to synchronise ripening, extend shelf life, and preserve the visual appeal of produce during storage and transport, particularly for urban markets. While such practices may yield short-term economic benefits, their widespread and often unregulated application raises significant food safety concerns. Improper usage, inadequate dosage control, and reliance on industrial-grade chemicals can compromise fruit quality, diminish nutritional value, and expose consumers to hazardous residues (Sivakumar & Yahia, 2020).

Evidence indicates that calcium carbide may contain toxic impurities such as arsenic and phosphine, both of which are associated with carcinogenic, neurological, and respiratory health risks (Okeke et al., 2022). These dangers are especially acute within informal market systems, where regulatory oversight is limited, awareness among traders is low, and adherence to food safety standards is inconsistent. Although regulatory bodies such as the Kenya Bureau of Standards (KEBS) and the National Environment Management Authority (NEMA) are mandated to safeguard public health, their effectiveness is constrained by limited monitoring capacity, weak enforcement mechanisms, and insufficient public awareness (Ministry of Health Kenya, 2021).

Against this backdrop, the present study adopts an integrated systems approach that links environmental change, agricultural practices, and public health outcomes. Climate variability is conceptualized as the primary driver, while chemical use and residue levels constitute the principal outcomes. Socio-economic and regulatory conditions are treated as moderating factors that influence both behaviour and exposure. By synthesizing these dimensions, the study elucidates how climate variability indirectly drives reliance on ripening chemicals and identifies critical leverage points for policy intervention and improved practice.

Conceptual Framework

This study is anchored in a climate–postharvest–health nexus framework that elucidates the links between environmental variability, agricultural responses, and public health outcomes (figure 1). Climate variability alters crop physiology and postharvest behaviour, thereby influencing the use of chemical ripening and delaying agents. These practices, in turn, determine food safety and associated human health risks. By integrating biophysical, socio-economic, and regulatory dimensions, the framework provides a coherent basis for analysing emerging risks within Kenya's horticultural value chains.

Within this framework, temperature variability**,** rainfall variability, and postharvest loss pressure are treated as independent variables. Chemical usage levels**,** residue concentrations, and consumer health risk constitute the dependent variables. Farmer knowledge**,** regulatory enforcement**,** and market access function as moderating variables, shaping the extent to which climate-induced stress translates into

unsafe chemical dependence or safer postharvest adaptation.

Temperature variability, characterized by rising mean temperatures and more frequent heatwaves, accelerates fruit maturation and metabolic processes. This shortens the natural ripening period and increases reliance on artificial ripening or delaying agents to preserve market value. It also affects enzymatic activity, shelf life, and spoilage rates (Haokip et al., 2020; Sivakumar & Yahia, 2020).

"Improper usage, inadequate dosage control, and reliance on industrial-grade chemicals can compromise fruit quality"

Rainfall variability, including erratic precipitation and prolonged droughts, disrupts crop growth and yield stability. These conditions often result in uneven ripening and heightened postharvest losses, thereby increasing dependence on chemical interventions to stabilise supply. Variability in rainfall also affects storage conditions, particularly humidity, which is critical for fruit preservation (FAO, 2021; Kelonye & Juma, 2022).

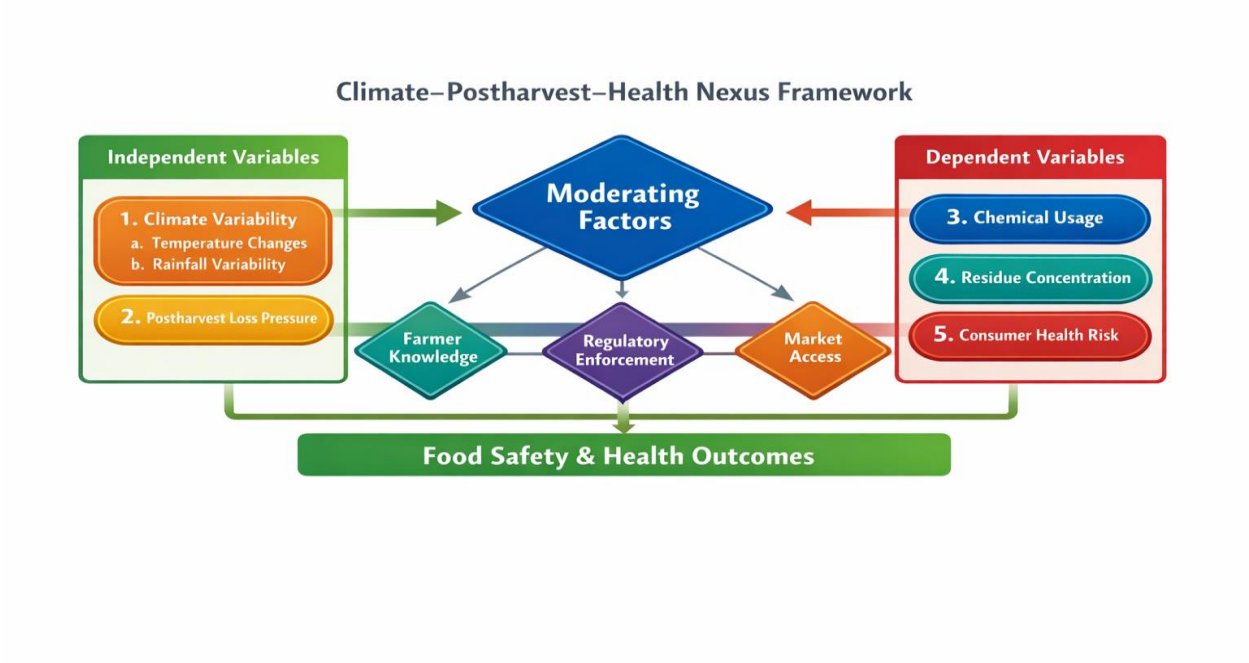
Postharvest loss pressure reflects the economic and logistical challenges faced by producers and traders in maintaining product quality during storage and transport. Inadequate cold storage, inefficient transport systems, and weak market infrastructure make chemical agents a convenient short-term solution. Consequently, postharvest losses emerge as a primary driver of chemical use (FAO, 2021; Kitinoja et al., 2018).

The dependent variables capture the outcomes of these dynamics. Chemical usage levels refer to the frequency, intensity, and diversity of agents such as calcium carbide, ethephon, and 1-MCP applied along the value chain. Residue concentrations indicate the levels of chemical contaminants remaining in treated fruits and serve as a critical measure of food safety. Elevated residues, particularly from calcium carbide, may contain toxic by-products such as arsenic and phosphine (Okeke et al., 2022). Consumer health risk encompasses the potential adverse effects arising from prolonged exposure to such residues, including gastrointestinal disorders, neurological impairment, and possible long-term carcinogenic outcomes (Kunyanga et al., 2018).

The relationship between these variables is moderated by contextual factors. Farmer knowledge influences the safe handling and appropriate application of chemicals; higher levels of awareness are associated with improved compliance and reduced misuse (de Bon et al., 2014). Regulatory enforcement determines the effectiveness of food safety oversight, with strong inspection systems reducing unsafe practices, while weak enforcement particularly in informal markets facilitates misuse (KEBS, 2018; Ministry of Health, Kenya, 2021). Market access shapes economic incentives and logistical constraints; limited access to structured markets and storage facilities increases reliance on chemical preservation, whereas improved infrastructure reduces such dependence (FAO, 2021).

Figure 1

Climate–Postharvest–Health Nexus Framework Linking Environmental Variability, Chemical Use, and Food Safety Outcome



Overall, the framework demonstrates that climate variability exerts an indirect yet significant influence on chemical use through its impact on postharvest losses and supply chain pressures. This relationship is further conditioned by knowledge, regulatory capacity, and market structures, thereby establishing a clear pathway linking environmental stress to food safety risks and public health outcomes.

2.0 Materials and Methods

Study Area and Design

The study was conducted in Meru, Nairobi, Kirinyaga, and Murang'a counties, representing key nodes within Kenya's horticultural value chain. Meru and Kirinyaga are major fruit production zones characterised by smallholder systems and agroecological diversity influenced by Mount Kenya. Murang'a functions primarily as an aggregation and transit hub, while Nairobi serves as a high-demand urban consumption centre.

These counties exhibit variation in temperature, rainfall patterns, and altitude, making them suitable for examining the influence of climate variability on postharvest practices across the production–consumption continuum.

A cross-sectional mixed-methods design was employed between September 2024 and April 2025. The study integrated three components: (i) a structured survey of 180 respondents, (ii) laboratory analysis of 392 fruit samples, and (iii) model-based climate and moderation parameters derived from an integrated analytical framework. This design enabled triangulation of empirical observations with explanatory statistical models.

3.2 Sample Distribution and Data Collection

A total of 392 fruit samples were systematically collected from major horticultural markets:

a) Meru: Gakoromone, Nkubu, Makutano, Kianjai

b) Kirinyaga: Kagio, Makutano, Mwea, Kiangwacia

c) Murang'a: Kambiti, Makuyu, Makutano

d) Nairobi**:** Wakulima, Kangemi, Ngara, Dagoretti

The sample comprised bananas (n = 131)**,** tomatoes (n = 131)**,** and mangoes (n = 130)**,** with 98 samples per county to ensure balanced comparison (table 1).

Primary data were collected through structured questionnaires administered via face-to-face interviews. These captured chemical use patterns, frequency of application, perceived benefits, awareness of health risks, and willingness to pay for safer produce.

Fruit samples were obtained from farms, open-air markets, and supermarkets to ensure representation across the value chain. Residue extraction was conducted using hexane/dichloromethane solvents, followed by GC–MS detection of acetylene, ethephon, and related compounds, in accordance with AOAC International (2019) protocols.

Table 1

Final distribution of 392 fruit samples across counties and markets

County	Market	Banana	Tomato	Mango	Total
Kirinyaga	Kagio	9	8	8	25
Kirinyaga	Kiangwacia	8	8	8	24
Kirinyaga	Makutano	8	8	9	25
Kirinyaga	Mwea	8	8	8	24
Meru	Gakoromone	9	8	8	25
Meru	Kianjai	8	8	8	24
Meru	Makutano	8	8	8	24
Meru	Nkubu	8	9	8	25
Muranga	Kambiti	11	11	11	33
Muranga	Makutano	10	11	11	32
Muranga	Makuyu	11	11	11	33
Nairobi	Dagoretti	8	8	8	24
Nairobi	Kangemi	8	9	8	25
Nairobi	Ngara	8	8	8	24
Nairobi	Wakulima	9	8	8	25

Data analysis

Data were analysed using R (version 4.3)**,** employing both descriptive and inferential techniques. Frequencies, means, and standard deviations were used to summarise chemical use patterns and residue levels across counties and fruit types.

Analysis of variance (ANOVA) at $p < 0.05$ tested for statistically significant differences between counties. Multiple regression models assessed the effects of rainfall variability, market pressure, and postharvest loss on chemical use. Moderation analysis evaluated the influence of farmer knowledge and regulatory enforcement on these relationships.

In addition, a public health risk model quantified the contribution of calcium carbide use and regulatory conditions to estimated exposure risk. Together, these approaches enabled robust assessment of both direct effects and interaction pathways within the climate–postharvest–health nexus.

4. Results and Discussion

4.1 Survey Profile and Chemical Usage Patterns

The survey revealed that 63% of respondents used chemical agents for fruit ripening or delayed maturity, indicating widespread reliance on artificial postharvest interventions within

Kenyan horticultural supply chains. This high prevalence reflects systemic constraints, including limited storage infrastructure, extended transport distances, and climate-induced perishability.

Calcium carbide was the most frequently used agent (42%), followed by ethephon (27%), confirming the persistence of unsafe and semi-regulated practices. Spatial variation was evident: Nairobi recorded the highest prevalence (72%), driven by intense market demand and rapid turnover, whereas Meru recorded the lowest (51%), likely due to shorter supply chains and reduced commercial pressure. Overall, chemical use appears strongly aligned with market intensity and logistical constraints.

Table 2

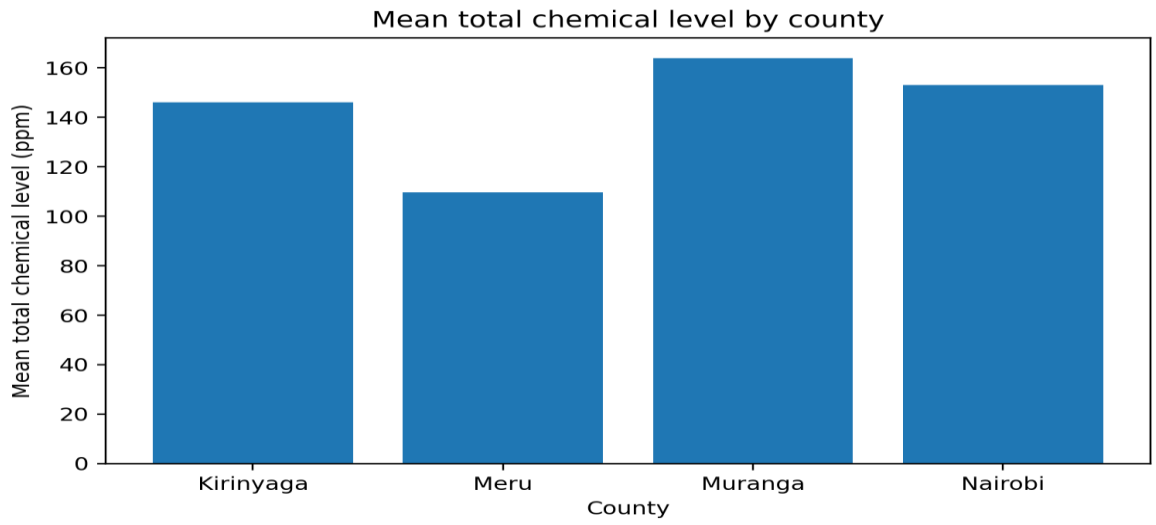
Distribution of chemical use across study areas

County	% users of chemicals	Dominant chemical	Key driver
Nairobi	72%	Calcium carbide	Market pressure
Murang'a	68%	Calcium carbide and 1-MCP	High supply turnover
Kirinyaga	61%	Ethephon	Mixed markets
Meru	51%	1-MCP	Lower commercial pressure

Figure 2, shows that Murang'a County records the highest mean total chemical level at approximately 165 ppm**,** followed b**y** Nairobi at about 153 ppm**.** Kirinyaga also exhibits relatively high levels at around 146 ppm**,** indicating notable chemical presence across these regions. In contrast, Meru reports the lowest mean level at approximately 110 ppm**,** significantly below the other counties. Overall, the data reveal **a** clear variation of over 50 ppm between the highest and lowest counties, suggesting spatial differences in chemical usage or contamination intensity. Such variations are consistent with studies showing that chemical residue levels in agricultural systems can differ widely across regions, depending on practices and environmental conditions

Figure 2

Mean total chemical level by county based on the integrated sample dataset.



Residue burden and food safety risk

Laboratory analysis showed that 26% of fruit samples contained contaminants above acceptable thresholds, signaling a significant food safety concern and weak compliance with established standards. The mean acetylene concentration in carbide-treated fruits exceeded the 0.7 mg/kg reference limit**,** indicating uncontrolled application of industrial-grade calcium carbide. In addition, arsenic residues were detected in 8% of mango samples**,** raising serious toxicological concerns given their association with chronic health effects. Contamination varied by commodity. Bananas exhibited the highest prevalence, followed by mangoes and tomatoes, suggesting that climacteric fruits are more frequently subjected to ripening agents and consequently carry a higher residue burden into retail marke

Table 3

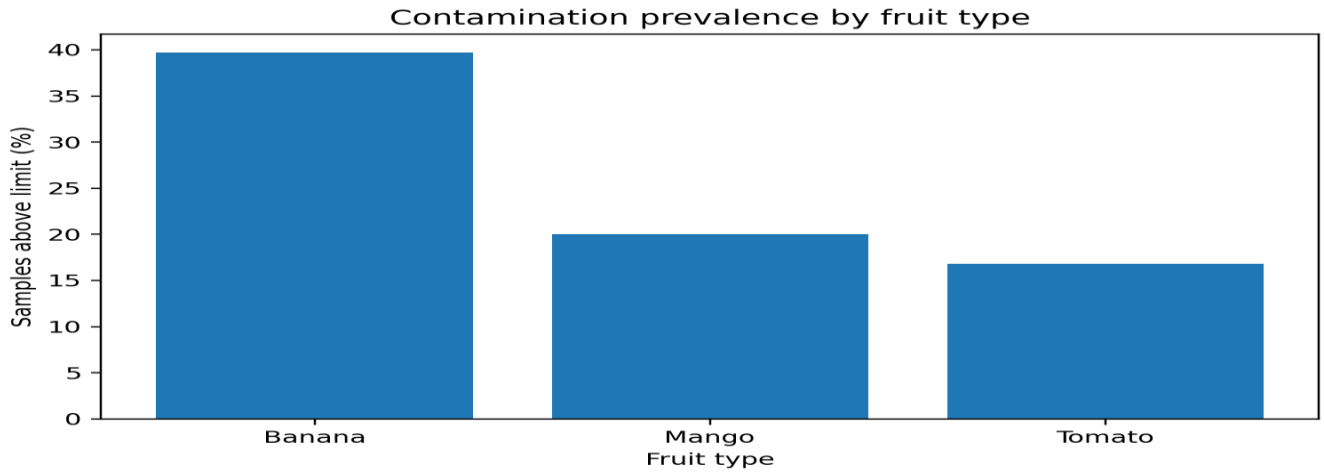
Residue levels in fruit samples

Parameter	Observed value	Reference limit	Status
Acetylene	1.38 mg/kg	0.7 mg/kg	Above limit
Arsenic in mangoes	Detected in 8% of samples	0.1 mg/kg	Unsafe
Overall contamination	26% of samples	0% expected	High risk

Bananas exhibited the highest contamination prevalence at approximately 40%, followed by mangoes at around 20% and tomatoes at about 17% (figure 3). This gradient indicates that climacteric fruits are more frequently subjected to ripening-modifying chemicals. As a result, bananas in particular are more likely to carry elevated residue levels into retail markets. The pattern underscores a clear association between fruit physiology and postharvest chemical application practices. Overall, the findings highlight bananas as the most contamination-prone commodity within the sampled value chain.

Figure 3

Percentage of samples above limit by fruit type.



County-Level Differences and Seasonal Patterns

Analysis of variance (ANOVA) revealed statistically significant differences in chemical use across counties ($F = 7.434$, $p < .001$), confirming that geographic and market structures influence postharvest practices (Table 4).

Murang'a and Nairobi recorded the highest chemical concentrations, reflecting greater commercial intensity and faster supply-chain turnover. In contrast, Meru showed the lowest levels, plausibly due to shorter farm-to-market distances and lower market pressure.

Table 4

Mean total chemical level by county

County	Mean_Total_ppm	Interpretation
Kirinyaga	146.1	Moderate use
Meru	109.67	Lowest use
Muranga	163.95	Highest use
Nairobi	153.21	High pressure

Low levels were recorded at the beginning of the sampling period**.** In September 2024, the mean total chemical level was about 132 ppm, while the proportion of above-limit samples was approximately 0%. This suggests that measurable chemical presence did not initially translate into widespread exceedance of permissible limits.

Chemical levels declined sharply between September and November 2024. The mean total chemical level fell from roughly 132 ppm in September **to** 46 ppm in October, before reaching its lowest point of about 18 ppm in November. Throughout this period, the percentage of above-limit samples remained at or near 0%, indicating relatively limited contamination risk (figure 4).

A marked seasonal shift began in December 2024 and intensified in January 2025. Mean chemical levels rose from around 82 ppm in December to about 228 ppm in January, while above-limit samples increased from 0% to approximately 67%. This sharp rise indicates the onset of a high-risk period in which chemical use was both more intensive and more likely to exceed accepted limits.

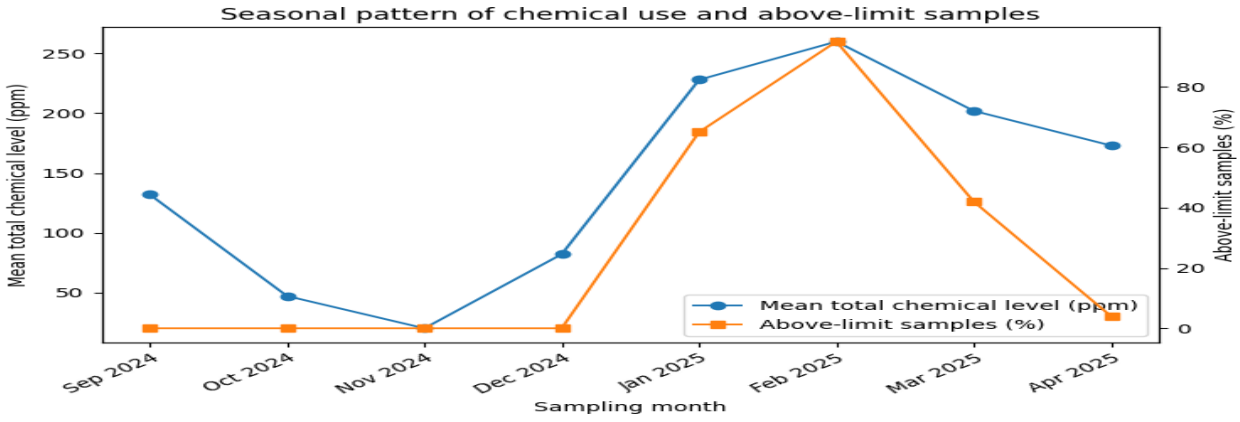
February 2025 was the peak month for contamination pressure. Both indicators reached their maximum values in February 2025, with the mean total chemical level at roughly 260 ppm and above-limit samples at approximately 95%. This near-convergence of the two peaks suggests a strong seasonal association between intensified chemical application and regulatory exceedance.

Conditions improved after February, but risk remained elevated. In March 2025**,** the mean chemical level declined to about 202 ppm, and above-limit samples fell to approximately 40%. By April 2025, the mean level remained relatively high at around 173 ppm, although the proportion of above-limit samples dropped further to about 4%**,** implying that chemical use persisted even as exceedances became less common.

Overall, the figure reveals a clear seasonal pattern in both chemical intensity and contamination risk. The most hazardous period occurred between January and February 2025, when both total chemical levels and above-limit samples rose sharply, before declining thereafter. This pattern is consistent with broader evidence that climate and postharvest stress can heighten postharvest losses and food safety risks, thereby increasing pressure for chemical intervention in horticultural systems

Figure 4

Seasonal pattern of chemical use and above-limit samples from September 2024 to April 2025.



Regression Analysis: Climate and Market Drivers

Multiple regression analysis identified rainfall variability as the strongest predictor of chemical use ($\beta = 0.41$, $p < .01$), followed by market pressure ($\beta = 0.36$, $p < .05$). These findings demonstrate that environmental instability and economic incentives jointly shape postharvest decision-making.

Temperature variability showed a negative coefficient ($\beta = -0.22$, $p < .05$), indicating a more complex interaction. In some contexts, extreme heat may accelerate natural ripening sufficiently to reduce the need for artificial intervention or interact with other variables in ways that moderate chemical use.

Collectively, the results confirm that climate variability operates as a key underlying driver, mediated by market dynamics and infrastructural constraints.

Table 5

Main-effects and moderation coefficients from the integrated models

Model	Term	β / Coef	PValue	Interpretation
Model 1: Climate/Market	Rainfall variability	0.41	< .01	Strong positive predictor of chemical use
Model 1: Climate/Market	Market pressure	0.36	< .05	Economic and supply-chain driver
Model 1: Climate/Market	Farmer knowledge	-0.11	0.23	Higher knowledge reduced unsafe use
Model 1: Climate/Market	Regulatory enforcement	-0.19	0.04	Greater enforcement reduced unsafe use
Model 2: Moderation	Rainfall × knowledge	-0.09	0.03	Knowledge weakened climate-driven dependence
Model 2: Moderation	Market pressure × enforcement	-0.12	0.01	Enforcement weakened market-driven dependence

Moderation Effects

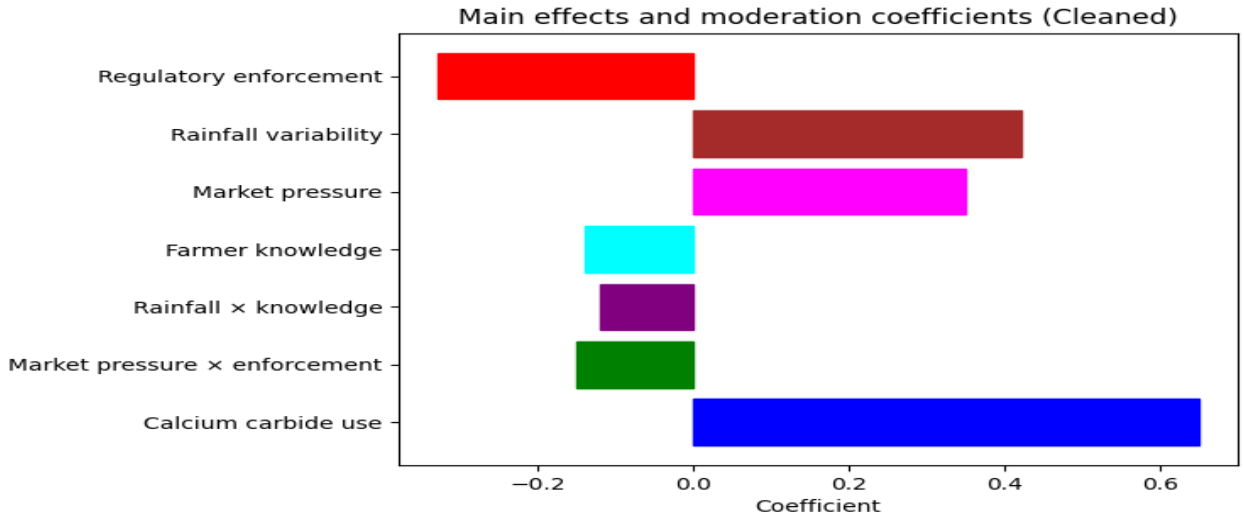
Moderation analysis demonstrated that farmer knowledge and regulatory enforcement significantly attenuate unsafe chemical use**.** Higher levels of knowledge were associated with improved compliance, including appropriate dosage and the adoption of safer alternatives.

Similarly, strong regulatory enforcement reduced residue levels**,** particularly in markets with active inspection systems. Consumer awareness also influenced outcomes, as informed buyers created demand for safer produce, thereby exerting pressure on traders to reduce misuse.

These findings indicate that institutional capacity and knowledge systems can interrupt the pathway from climate stress to unsafe chemical dependence**.**

Figure 5

Main-effects and moderation coefficients from the integrated regression models.



These results indicate that climate stress and market demand jointly shape postharvest decisions, but the magnitude of their effect depends on knowledge, oversight, and access to safer practices. In practical terms, stronger enforcement and better training can interrupt the pathway from climate stress to unsafe chemical dependence.

Public Health Risk Model

The public health risk model identified calcium carbide as the principal contributor to exposure risk (β = 0.67), confirming its dominant role in contamination and its association with hazardous by-products such as arsenic and phosphine (Table 6).

In contrast, regulatory enforcement exhibited a strong risk-reducing effect (β = −0.45), highlighting governance capacity as the most effective protective factor within the current model.

Table 6

Public health risk model

Variable	β coefficient	Interpretation
Calcium carbide use	0.67	High-risk contributor
Regulatory enforcement	-0.45	Risk-reducing factor

3.0 Results and Discussion

Synthesis of Findings

Overall, the results demonstrate that climate variability and market pressure jointly drive chemical use in postharvest systems, with direct implications for food safety and public health. However, these effects are not deterministic. Their magnitude depends on the strength of moderating factors—particularly knowledge, enforcement, and market structure. Strengthening these systems offers a clear pathway to reducing unsafe practices and improving food safety outcomes.

Discussion

The findings demonstrate a clear and consistent relationship between climate stress and unsafe postharvest practices. Rising temperatures and erratic rainfall accelerate fruit ripening by enhancing metabolic and enzymatic activity, thereby shortening shelf life. This creates significant pressure on farmers and traders—particularly within informal supply chains—to adopt chemical interventions in order to minimize losses and remain competitive (FAO, 2021; Haokip et al., 2020).

The predominance of calcium carbide reflects underlying structural and institutional constraints. Its continued use is facilitated by weak regulatory enforcement, especially in informal markets where inspection is limited. In addition, its low cost and rapid effectiveness make it an attractive option for traders operating on narrow profit margins. Limited access to safer alternatives, such as controlled ethylene systems and cold storage infrastructure, further entrenches reliance on hazardous substances (Okeke et al., 2022; Sivakumar & Yahia, 2020). Notably, calcium carbide releases acetylene gas, which accelerates ripening but poses recognized risks to human health.

The observed association between calcium carbide and 1-MCP suggests possible dual or sequential application. While 1-MCP is generally considered safer, its combined or improper use alongside carbide raises concerns regarding cumulative exposure and potential loss of efficacy. This pattern points to significant knowledge gaps and inadequate technical guidance on the appropriate use of postharvest technologies (Okeke et al., 2022; Wasala et al., 2021).

Gender-disaggregated findings reveal distinct behavioral patterns. Men are more directly involved in chemical application, likely due to their dominant roles in transport, logistics, and bulk handling, which increases occupational exposure. In contrast, women demonstrate greater awareness of associated health risks, possibly owing to their roles in food preparation and closer interaction with consumers. This positions women as critical agents in promoting safer practices. Accordingly, gender-responsive training, certification, and market governance interventions are likely to enhance compliance and reduce unsafe chemical use (de Bon et al., 2014; Kunyanga et al., 2018).

Policy and Public Health Implications

Kenya must adopt a coordinated, multi-agency enforcement approach involving the Kenya Bureau of Standards (KEBS), the Pest Control Products Board (PCPB), the National Environment Management Authority (NEMA), county governments, and public health departments. While regulatory frameworks exist, their effectiveness is constrained by weak monitoring and limited presence in informal markets. Strengthening inter-agency coordination, increasing inspection frequency, and enforcing proportionate penalties for non-compliance are essential to reduce hazardous exposure and improve food safety outcomes.

A priority intervention is the deployment of mobile residue-testing laboratories. Portable analytical systems can enable real-time screening of fruits and vegetables in high-risk markets, complementing existing laboratory-based surveillance. Decentralised testing would enhance transparency, improve regulatory responsiveness, and reinforce consumer

confidence by ensuring that unsafe produce is promptly identified and removed from circulation.

Equally critical is the promotion of affordable, climate-smart storage solutions. Technologies such as evaporative cooling chambers, solar-powered cold rooms, and improved cold-chain logistics can significantly reduce postharvest losses, which currently account for a substantial proportion of agricultural waste in Kenya. By lowering spoilage pressure, these innovations diminish the economic incentive to rely on unsafe chemical ripening practices, while simultaneously strengthening resilience to climate variability and improving food security.

Finally, the establishment of vendor certification and traceability systems is essential to enhance accountability within the supply chain. Structured certification programmes supported by training in good agricultural and postharvest practices would enable clear differentiation of compliant vendors through visible labelling. This would not only protect public health but also build consumer trust and incentivise safer practices across urban and peri-urban markets.

In sum, an integrated policy response combining robust enforcement, decentralised testing, improved storage infrastructure, and market-based accountability mechanisms is indispensable for safeguarding food safety and public health in the face of growing climate and market pressures.

4.0 Conclusions

This study demonstrates that climate variability—particularly erratic rainfall and temperature fluctuations—plays a significant role in driving the use of ripening-modifying chemicals within Kenya's horticultural value chains. Climatic stress disrupts crop development and postharvest stability, increasing losses and prompting producers and traders to adopt chemical interventions to preserve quality and stabilise supply, a pattern widely recognised in postharvest systems.

While such interventions may yield short-term economic gains by extending shelf life and reducing spoilage, the misuse of hazardous agents, notably calcium carbide, presents serious food safety and public health concerns. Elevated residue levels indicate gaps in regulatory enforcement and monitoring, particularly within informal market systems. These risks are further compounded by limited awareness among value chain actors and restricted access to safer, alternative technologies.

The findings highlight the need to situate postharvest management within a broader climate resilience agenda that balances productivity with consumer protection. A transition towards climate-smart postharvest systems—supported by targeted training, strengthened regulatory frameworks, and integrated surveillance—is essential. Sustainable alternatives, including controlled atmosphere storage, ethylene-based technologies, and nature-based ripening approaches, offer a viable pathway for reducing chemical dependence while safeguarding public health and enhancing value-chain resilience.

5.0 Recommendations

1. Establish integrated national monitoring and surveillance systems. Kenya should develop a coordinated national framework to track the use of ripening chemicals and associated residue levels across horticultural value chains. This system should combine routine market surveillance, laboratory analysis, and digital reporting platforms managed by KEBS, NEMA, and county governments. Mobile testing laboratories and rapid detection technologies should support real-time screening, while a centralised database should enable trend analysis, early warning, and evidence-based policymaking.
2. Promote ethylene-based and nature-based safe ripening technologies**.** Hazardous substances such as calcium carbide should be replaced with safe, controlled ethylene-based technologies that mimic natural ripening. Low-cost ethylene

generators, sachet systems, and controlled atmosphere storage should be promoted, especially for smallholder contexts. Nature-based alternatives, including plant-derived ethylene sources and bio-based ripening regulators, also deserve further validation through applied research.

3. Strengthen capacity building and certification of farmers and traders. Farmers, traders, and other value chain actors need structured training on approved ripening agents, health and environmental risks, safe handling, and alternative technologies. These programmes should be delivered through agricultural extension systems, vocational training, and digital learning platforms. A national certification and licensing system for fruit handlers and vendors would strengthen compliance, improve traceability, and increase market credibility.
4. Strengthen policy enforcement and regulatory coordination**.** Although Kenya has food safety and environmental regulations, implementation remains fragmented. Enforcement should be improved through stronger coordination among KEBS, NEMA, the Ministry of Agriculture, and county health departments. This includes expanding inspections in both formal and informal markets, introducing graduated sanctions, strengthening technical capacity, and using digital tools to track compliance.
5. Enhance consumer awareness and risk communication. Public education campaigns are needed to inform consumers about the risks of chemically ripened fruits, how to recognise unsafe produce, and the value of naturally ripened or certified products. These campaigns should use mass media, community outreach, digital platforms, and school-based programmes. Clear labelling and certification marks would further support informed consumer choice.
6. Develop climate-smart postharvest infrastructure. Investment in cold storage, solar-powered refrigeration, and better transport systems is essential to reduce dependence on chemical interventions. Such infrastructure can naturally extend shelf life, improve product quality, and increase resilience to climate variability.
7. Promote research and innovation in safe ripening technologies. More research is needed to develop cost-effective, locally adaptable, and environmentally sustainable ripening technologies. Priority areas include bio-based ripening inhibitors, smart packaging, residue detection systems, and modelling of climate–ripening interactions.
8. Establish traceability and digital food safety systems. Digital traceability tools such as QR codes and blockchain-based tracking can improve transparency and accountability across the fruit supply chain. These systems can support compliance monitoring and enable rapid response to contamination events.

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