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Climate Change Effects on Agrochemical Use Trends and Health of Fresh Produce Farmers in Nakuru County, Kenya: Exploring Emerging Associations

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Abstract

In an ideal agricultural setting, climate-resilient practices are adopted to optimize crop production while minimizing health and environmental risks. However, in regions like Nakuru County, Kenya, where agriculture is predominantly rain-fed and pest management heavily relies on agrochemicals, climate change has disrupted this balance. Shifting weather patterns have intensified pest and disease outbreaks, prompting increased agrochemical use, often without adequate training, regulation, or environmental safeguards. Despite the clear link between climate variability and agricultural practices, limited research has examined how farmers adapt their agrochemical use in response to climate change, particularly in low- and middle-income contexts. This study aimed to determine the association between climate change and agrochemical use trends among Fresh Produce Farmers in Nakuru County, Kenya. A community-based cross-sectional descriptive and analytical design was employed. The target population included Fresh Produce Farmers residing in Nakuru County for at least two years. A two-stage sampling technique, using probability proportional to size (PPS), was applied to select four sub-counties: Njoro, Kuresoi North, Molo, and Bahati. A total of 394 respondents were sampled using Cochran's formula with a 10% non-response adjustment. Quantitative data were collected using structured questionnaires, while qualitative insights were gathered through focus group discussions and key informant interviews. Data were analysed using SPSS v28 for descriptive and inferential statistics, and NVivo for thematic analysis. Findings revealed that 98.7% of respondents were aware of climate change, and 96.4% observed increases in pest and disease pressure attributed to it. There was a significant association between observed climate change and agrochemical use decision-making (OR = 1.2, $p < 0.05$), and a weak negative association with methods of application (OR = 0.87, $p = 0.01$). Most farmers relied on peer advice or agronomists, and few adhered to pre-harvest intervals due to economic pressure and lack of enforcement. The study concludes that Climate variability has emerged as a major driver of agrochemical dependence among Fresh Produce Farmers in Nakuru County. Increased pest and disease pressures due to changing weather patterns have led to more frequent agrochemical use, often guided by informal advice and limited access to extension services. While farmers are aware of climate change, many lack the training and support needed to apply agrochemicals safely and effectively. To promote sustainable farming, the study recommends strengthening agricultural advisory systems, improving farmer training on safe agrochemical use, and promoting climate-smart alternatives such as bio pesticides and organic inputs. Clearer labelling, enforcement of pre-harvest intervals, and use of demonstration farms are also essential to support safer, more resilient agricultural practices.

Keywords: *Climate Change, Agrochemical Use Trends, Fresh Produce Farmers, Nakuru County*

1.1 Introduction

Agriculture remains a cornerstone of Kenya's economy, contributing approximately 51% of the national GDP—26% directly and 25% indirectly—and accounting for 60% of employment and 65% of exports (KNBS, 2024). Despite only 10.2% of Kenyan land being arable, the sector's productivity heavily relies on agrochemicals, including insecticides, fungicides, herbicides, and other synthetic inputs. On average, 12,983 tons of agrochemicals are imported annually, representing a market worth over KES 10.7 billion (~USD 100 million) (Clausing et al., 2021). These substances are essential for improving yield and protecting crops, particularly in regions like Nakuru County, which is a national hub for fresh produce farming.

However, the intensive use of agrochemicals poses serious environmental and public health risks. These chemicals contribute to air, water, and soil pollution, and are associated with numerous adverse health effects in both consumers and farmers (Pathak et al., 2022; Wang et al., 2020). In Kenya, improper handling, inadequate safety infrastructure, and small farm sizes exacerbate direct exposure risks, particularly among smallholder farmers, who operate on 0.2 to 3 hectares of land, yet account for 78% of total agricultural output (Birch, 2018).

While there is growing literature on the health and environmental hazards of agrochemical exposure, limited research exists on how climate change influences agrochemical use patterns, especially in Low- and Middle-Income Countries (LMICs) such as Kenya. This knowledge gap is critical, given that climate variability alters pest and disease dynamics, leading to changing agrochemical usage trends that may compound ecological and occupational health risks. For instance, increased temperatures and erratic rainfall patterns in sub-Saharan Africa have been linked to the amplified frequency and diversity of pest outbreaks, prompting more frequent or intensive pesticide application.

Kenya has already experienced the effects of this shift. Between 2015 and 2018, the country saw a 144% increase in imported insecticides, fungicides, and herbicides (UNEP, 2022; PCPB, 2022). In Nakuru County, where both small-scale and commercial farming dominate the landscape, agrochemicals are heavily used on crops such as kales, tomatoes, potatoes, and other vegetables. The intensification of agrochemical application in this region correlates with both increasing pest resistance and heightened climate stress, further complicating the sustainability of current agricultural practices (Constantine et al., 2023; Marete et al., 2021a).

The intersection of climate change and agrochemical use poses urgent public health, food safety, and environmental risks in Kenya (Dena, 2021; UNEP, 2022). Frequent rejection of Kenyan produce due to excessive residues and unsafe practices among poorly equipped farmers raise major concerns (Nippanon et al., 2019). This study examines how climate variability influences agrochemical use trends among Nakuru's Fresh Produce Farmers to guide sustainable interventions.

1.2 Problem Statement

Ideally, agricultural systems should promote both food security and environmental sustainability, utilizing inputs such as agrochemicals in a manner that is safe, regulated, and responsive to climatic conditions. In this ideal context, farmers are well-informed, supported by robust extension services, and adapt to changing weather patterns with resilience and safety-conscious practices. Agrochemical use would be efficient, minimal, and governed by guidelines that protect both human health and the environment.

However, the reality in many parts of the Global South, including Kenya, significantly deviates from this standard. In Nakuru County, a region known for intensive fresh produce farming, there has been a sharp rise in agrochemical use, spurred in part by erratic weather, pest resistance, and the need to maintain yields under climate stress. Climate change has altered pest ecology and crop vulnerability, prompting more frequent, intensive, and sometimes inappropriate agrochemical application. Despite this, many smallholder farmers lack access to protective equipment, knowledge, and training, resulting in unsafe handling practices.

These unsafe practices have serious consequences. Farmers face elevated risks of chronic exposure to toxic agrochemicals, which has been linked to respiratory illness, DNA damage, endocrine disruption, and rising rates of non-communicable diseases such as cancer—with Nakuru County ranking second nationally in cancer burden (Okumu Lynet, 2023). At the same time, the overuse and misuse of agrochemicals contribute to environmental degradation, soil pollution, and long-term fertility decline, further worsening the agricultural ecosystem under climate pressure.

While multiple studies have explored agrochemical health effects and climate change independently, very few have investigated how climate change influences agrochemical use trends and practices—particularly at the smallholder level. The interaction between climatic variability, shifting pest pressures, and farmer responses through agrochemical use remains poorly understood, especially in Sub-Saharan Africa.

This research, therefore, addresses a critical knowledge gap by examining how climate change is shaping agrochemical use patterns and practices among Fresh Produce Farmers in Nakuru County, and what health implications may arise from this shift. By generating localized, evidence-based insights, the study aims to inform safer and more climate-resilient agricultural practices in Kenya and beyond.

1.3 Objective

To determine the association between climate change and agrochemical use trends among Fresh Produce farmers in Nakuru County, Kenya.

1.4 Research Question

What is the association between climate change and agrochemical use trends among Fresh Produce Farmers in Nakuru County, Kenya?

2.0 Literature Review

2.1 Climate Change and Pest Pressure: A Complex Feedback Loop

Climate change is exerting a profound influence on agricultural systems globally through shifts in temperature, precipitation patterns, and the frequency of extreme weather events. These climatic alterations not only affect crop physiology but also reshape the ecology, distribution, and virulence of crop pests and pathogens (Heeb et al., 2019; EEA, 2023). Rising temperatures have been linked to increased overwintering success and faster reproductive cycles of insect pests, while altered rainfall patterns create conditions favorable to plant pathogens. For instance, higher humidity and rainfall are known to enhance the incidence of fungal diseases, while drought-stressed crops become more susceptible to insect damage (Skendžić et al., 2021).

Evidence suggests that climate-induced pest outbreaks are becoming more frequent and severe, leading to rising agrochemical use in both intensity and frequency. In the United States, pesticide

application rates for Lepidoptera insect pests in sweet corn increase significantly from cooler to warmer regions, with Florida farmers applying up to 32 treatments per season compared to only 5 in New York (Glasgow, 2019). Similarly, desert locust invasions in Africa, fueled by erratic rainfall, have devastated crops across multiple countries, underscoring the critical links between climate anomalies and pest outbreaks (Skendžić et al., 2021).

Climate Change and Pesticide Efficacy

Beyond increasing pest pressure, climate change alters pesticide efficacy, often in unpredictable ways. For example, elevated temperatures can reduce the toxicity of some commonly used insecticides such as pyrethroids and spinosyns, diminishing their effectiveness against target species like Ostrinia nubilalis (Glasgow, 2019). Simultaneously, biological control methods are disrupted by thermal mismatches between pests and their natural enemies. Reduced parasitoid effectiveness under high temperatures and extreme weather events such as heatwaves or storms further impair ecological pest regulation (Moradhaseli et al., 2019; Barnett et al., 2021).

These dynamics create a positive feedback loop: greater pest populations and reduced control efficacy lead farmers to apply agrochemicals more frequently and in larger quantities, intensifying both environmental and health risks.

2.2 Water Stress, CO_2 Enrichment, and Pest-Plant Interactions

Climate-driven water stress has a dual impact: it weakens crop defenses and alters pest feeding behavior. Crops under drought are more vulnerable to herbivory, while elevated atmospheric CO_2—though sometimes enhancing biomass—can lower the nutritional value of plants, prompting pests like Trichoplusia ni to increase consumption (Omotoso & Omotayo, 2024). These indirect effects further drive up the volume of pesticide applications required to maintain crop quality and yield.

2.2.1 Agrochemical Trends and Environmental Contamination

The increased reliance on agrochemicals to combat climate-induced pest challenges has significant environmental consequences. Persistent application contributes to soil degradation, aquatic toxicity, and bioaccumulation in ecosystems and the food chain. In Nakuru County, for instance, fish from Lake Nakuru have been found to contain endosulfan and heptachlor epoxide at levels above international safety thresholds, despite these chemicals being banned in Kenya (Nantongo et al., 2023). This reflects both continued illegal usage and the long environmental half-life of some agrochemicals.

In addition, many fresh produce farmers in Kenya lack adequate training and access to protective gear, resulting in unsafe handling of increasingly potent chemical mixtures. As climate change drives up pest threats, these farmers are caught in a vicious cycle of agrochemical dependence, exacerbated by knowledge gaps and regulatory enforcement challenges (Marete et al., 2021a).

2.3 Food Security and Public Health Implications

Globally, up to 40% of food production is lost to pests, and this figure is projected to rise under climate change scenarios. The resulting increase in agrochemical use may offset short-term yield losses but poses long-term risks to environmental and public health. Notably, the health burden includes neurological damage, endocrine disruption, and increased cancer risks linked to chronic exposure among farm workers and consumers alike (Montrose, 2021; FAO, 2020).

In Kenya, Nakuru County ranks among the top regions for cancer prevalence, raising concerns about the cumulative effects of agrochemical exposure on public health (Okumu Lynet, 2023). Yet, agrochemical use is still often presented as a necessary strategy for food security under changing climatic conditions, despite growing evidence of its deleterious side effects (Bouri et al., 2023).

2.3.1 Synthesis and Research Gap

While substantial literature exists on the effects of climate change on crop yields and pest dynamics, limited studies examine the interaction between climate change and agrochemical use patterns, especially in low- and middle-income countries (LMICs). The few studies that do exist often fail to account for the local context, including smallholder constraints, regulatory limitations, and adaptation capacity.

In Nakuru County, this gap is particularly critical: fresh produce farming is both a key economic activity and a potential hotspot of agrochemical overuse due to changing climate pressures. Understanding how climate variability influences pesticide use patterns at the local level is essential to inform climate-smart, health-conscious agricultural practices.

3.0 Research Methodology

This study adopted a community-based cross-sectional analytical and descriptive design to assess the influence of climate variability on agrochemical use among Fresh Produce Farmers in Nakuru County, Kenya. The research was conducted across four agriculturally intensive sub-counties—Njoro, Kuresoi North, Molo, and Bahati—selected through a two-stage cluster sampling approach modeled on WHO's 30-cluster method and refined using Probability Proportional to Size. A total sample of 394 respondents was determined using Cochran's formula, adjusted for a 10 percent non-response rate. Data collection tools included structured questionnaires, key informant interviews (KIIs), focus group discussions (FGDs), and observational checklists. Quantitative data were analyzed using SPSS v28, applying descriptive statistics, chi-square tests, and binomial logistic regression at a 5 percent significance level, while qualitative data were thematically coded and triangulated using NVivo. Instrument validity was ensured through pre-testing and expert review, while reliability was enhanced by rigorous training and field supervision. Ethical clearance was granted by MIRERC, with further approvals from NACOSTI and Nakuru County authorities, and informed consent obtained from all participants to ensure voluntary participation and data confidentiality.

4.0 Findings

4.1 Factors Influencing Agrochemical Use

The primary determinant influencing agrochemical use among Fresh Produce Farmers was pest infestation, reported by 98.5% of respondents. Climate change was the second most cited factor (85.3%), while government regulations had the least influence (0.5%).

Table 1. Factors Influencing Use of Agrochemicals (N = 388)

Factor	Yes n (%)	No n (%)
Pest infestation	382 (98.5)	6 (1.5)
Climate change	331 (85.3)	57 (14.7)
Disease management	278 (71.6)	110 (28.4)
Weed control	202 (52.1)	186 (47.9)
Cost effect	15 (3.9)	373 (96.1)
Government regulation	2 (0.5)	386 (99.5)

Qualitative findings revealed that most farmers rely heavily on informal sources—such as fellow farmers, agrovet sellers, or personal experience—when deciding which chemicals to use. Formal agricultural training was rare, and many participants expressed distrust or limited access to professional extension services. Economic pressures and immediate pest threats often outweighed adherence to regulated or evidence-based use.

"You just consult other farmers… If their crops did well, you buy what they used." – Farmer, Njoro

4.2 Types of Agrochemicals Used

A substantial majority (96.4%) reported using pesticides, while herbicides were the least used (41.5%). A small fraction (0.8%) mentioned using organic alternatives such as rabbit urine or plant-based solutions.

Table 2. Types of Agrochemicals Used

Type	Yes n (%)	No n (%)
Pesticides	374 (96.4)	14 (3.6)
Fungicides	245 (63.1)	143 (36.9)
Insecticides	231 (59.5)	157 (40.5)
Herbicides	161 (41.5)	227 (58.5)
Other (Organic)	3 (0.8)	385 (99.2)

FGD participants cited a wide range of agrochemical products, including synthetic brands such as Thunder, Alfakill, Zidomil, and Zetanil, and natural solutions like rabbit urine. Economic considerations strongly influenced brand and type selection.

"You can get one chemical for 200 shillings and another for 700—same crop, just your pocket decides." – Farmer, Kuresoi

4.3. Frequency of Agrochemical Application

More than half of the respondents (60.8%) applied agrochemicals weekly, especially during the rainy season when pest pressure was high. Seasonal patterns influenced frequency, with reduced spraying during dry periods and intensified use during cold or wet conditions.

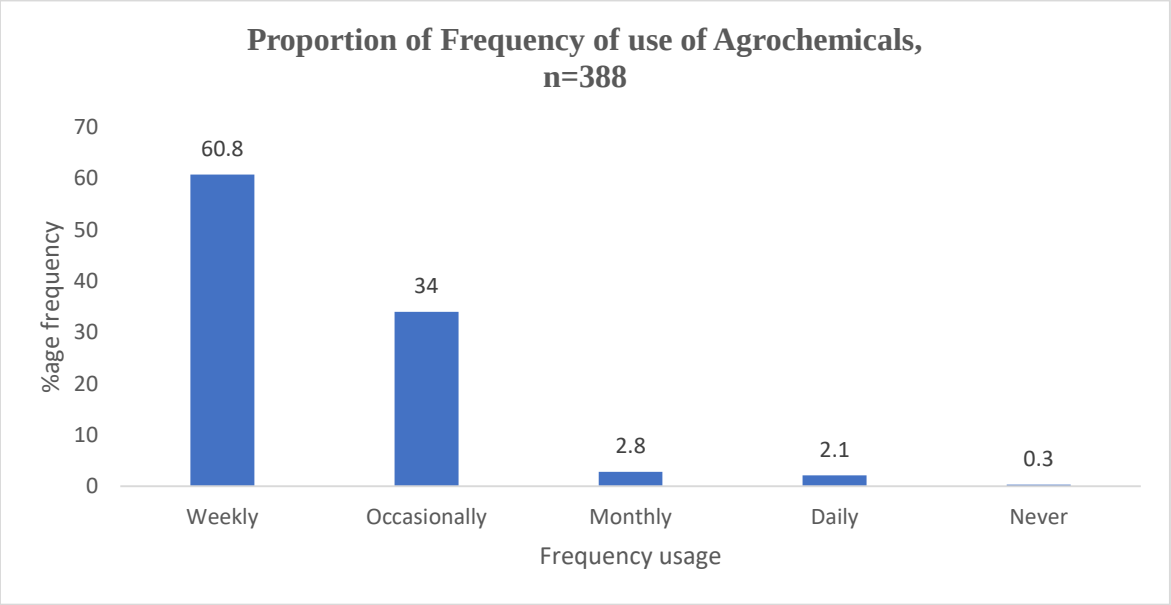

Figure 1. Frequency of Agrochemical Use (n = 388)

Notably, one of the respondents noted that…*"During cold seasons, we spray weekly... in the sun, maybe every two weeks."* – Farmer, Bahati

4.4. Methods of Application

All respondents (100%) used spraying as the primary method of application. Foliar application was used by 27.1%, while fertigation and drenching were rare.

Table 3. Methods of Agrochemical Application

Method	Yes n (%)	No n (%)
Spraying	388 (100)	0 (0)
Foliar Application	105 (27.1)	283 (72.9)
Fertigation	4 (1.0)	384 (99.0)
Drenching	3 (0.8)	385 (99.2)

Further, farmers reported using manual knapsack sprayers for small-scale operations and tractor-mounted sprayers for larger farms. One of the respondents observed that *"We carry the pump on our backs… it's dangerous, but it's what we have."* – Farmer, Njoro

4.5. Decision Drivers for Application Methods

The majority (85.1%) determined their application methods based on past experience rather than professional advice. Some consulted agrovets, while others relied on visual crop assessments.

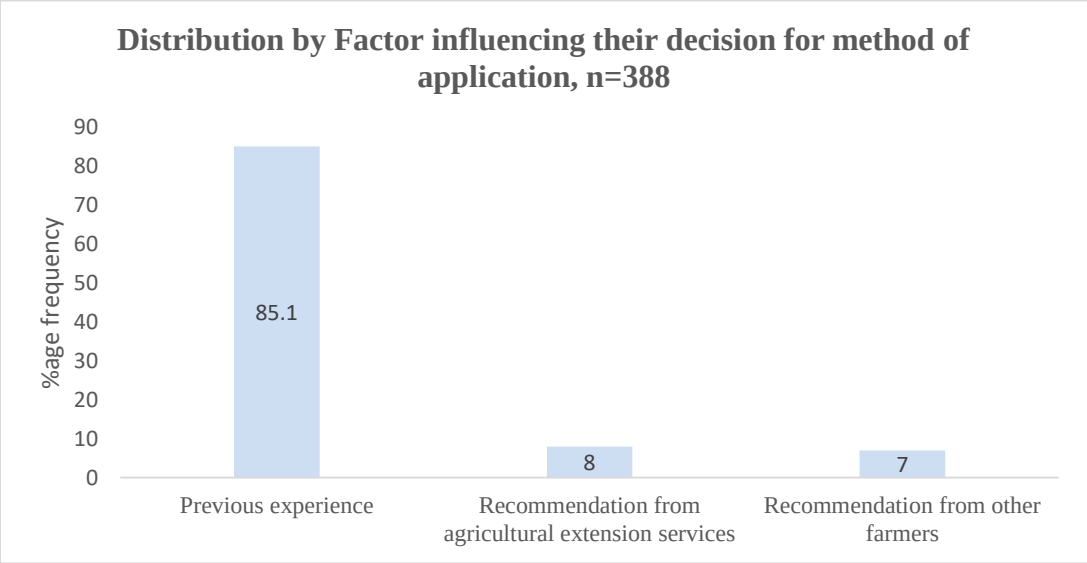

Figure 2. Basis for Method of Application Decision

4.6 Pre-Harvest Interval (PHI) Practices

Adherence to pre-harvest intervals (PHI) was largely inconsistent. Farmers cited economic pressure, market volatility, lack of enforcement, and inaccessibility of training as major barriers. Despite awareness of the health risks, immediate income needs often outweighed compliance.

"If the buyer comes today and you sprayed yesterday, you sell. They don't ask." – Farmer, Bahati

"Even if you use farmyard manure, they won't buy your produce. They want the big, clean-looking crops." – Farmer, Njoro

4.7. Future Plans for Agrochemical Reduction

A majority (67%) had no plans to eliminate agrochemical use, while only 8.8% indicated clear intentions to transition away from synthetic inputs. However, 24.2% expressed conditional interest, citing the need for training, organic market development, and access to safer alternatives.

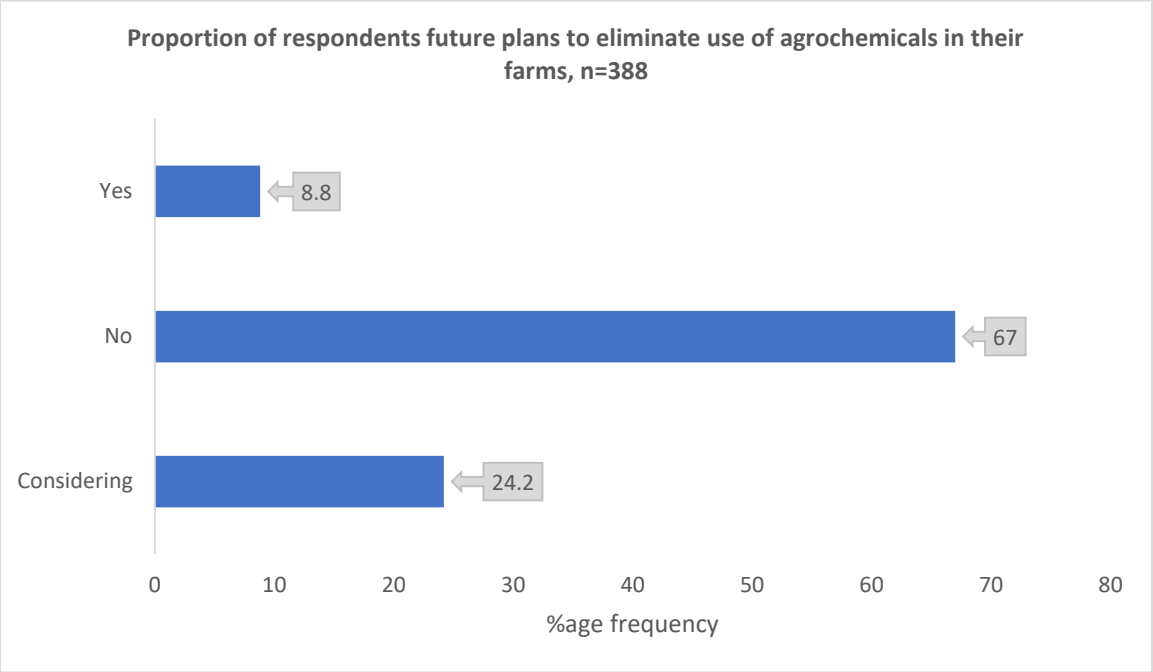

Figure 3. Future Plans to Eliminate Agrochemical Use

Innovative farmers were exploring natural pest control methods, including homemade plant-based solutions and traditional practices, but these were often seen as labor-intensive and economically unviable without external support.

"Some of us boil leaves and use the water—it works for pests too." – Farmer, Mau Narok

5.0 Discussion

This study explored the association between climate change awareness and agrochemical use trends among Fresh Produce Farmers in Nakuru County, Kenya. The findings reveal a complex interplay between farmers' perceptions of climate change, observed environmental changes, and subsequent decisions regarding agrochemical application.

5.1 Climate Change Awareness and Perceived Agricultural Risk

Nearly all respondents (98.7%) reported being aware of climate change and acknowledged its threat to fresh produce farming. This high level of awareness aligns with earlier research emphasizing the role of indigenous knowledge and experiential learning in shaping farmers' understanding of climatic variability (Islam et al., 2021). However, only 33.8% reported observing changes in local weather patterns, a finding consistent with studies in Nigeria and Kenya where farmers could perceive climate anomalies but not always label them as "climate change" (Oluwatimilehin & Ayanlade, 2021; Chepkoech et al., 2018). This highlights a crucial semantic and cognitive gap between scientific framing and local interpretation of climate dynamics.

5.2 Pest Pressure and Agrochemical Demand

A substantial proportion of respondents (96.4%) reported increased pest, weed, and disease pressure—factors that strongly influence agrochemical use. This finding supports earlier evidence that climate change intensifies biological stressors, prompting heavier chemical interventions

(Tudi et al., 2021). These stressors are closely linked to erratic rainfall, warming temperatures, and altered crop cycles, which collectively increase the frequency and severity of pest outbreaks.

5.3 Method of Agrochemical Application and Climate Sensitivity

The study found a statistically significant but weak negative association between observed climate change and the diversity of agrochemical application methods. This suggests that as farmers experience more pronounced weather fluctuations, they may narrow their use of application techniques—possibly as a form of risk minimization or due to resource limitations. The finding is in line with Ahumada et al. (2023) and Reddy et al. (2022), who observed that smallholder farmers tend to optimize for cost-efficiency and simplicity during climatic stress, often reverting to familiar practices over diverse technologies.

The odds ratio (OR = 0.87; $p = 0.01$) further indicates that those recognizing changes in weather were marginally less likely to employ multiple application methods. This may reflect either reduced access to agricultural extension support or a lack of knowledge on the suitability of different methods under changing conditions (Iyiola et al., 2023). Moreover, inappropriate timing and methods of application have been previously linked to poor awareness and training among farmers, contributing to indiscriminate agrochemical use (Khatun et al., 2023).

5.4 Decision-Making and Expert Consultation

Importantly, the study identified a positive and significant association between perceived climate variability and consultative decision-making in agrochemical use. Respondents who observed extreme weather events were 1.2 times more likely to base their agrochemical decisions on expert advice. This finding corroborates the role of advisory systems in promoting rational and environmentally sound chemical use (Tabe-Ojong et al., 2023; Wuepper et al., 2021).

The data suggest that increased exposure to climate stressors may prompt farmers to seek external validation or technical recommendations, particularly when managing novel or intensified pest challenges. These results emphasize the critical role of both public and private extension services in facilitating adaptive capacity and promoting agroecological sustainability.

The key findings included high awareness of climate change exists, but localized recognition of weather anomalies remains limited. Pest and disease pressures linked to climate variability are a major driver of agrochemical use. Narrower application methods associated with increased weather volatility, possibly due to economic or informational constraints. Positive advisory uptake correlates with climate awareness, underscoring the value of extension support in promoting responsible agrochemical use.

6.0 Conclusion

This study established a clear association between climate change awareness and agrochemical usage trends among Fresh Produce Farmers in Nakuru County, Kenya. The findings highlight that while nearly all farmers are aware of climate change and perceive it as a threat to agriculture, their responses to this challenge are mixed and often constrained by economic, informational, and institutional factors.

Increased pest, weed, and disease pressure linked to climatic variability has intensified farmers' reliance on agrochemicals, particularly pesticides. Although farmers are responsive to environmental changes, their ability to apply diverse and effective agrochemical methods is often limited by access to reliable knowledge, advisory support, and resources. Notably, farmers who

recognized extreme weather patterns were more inclined to seek expert advice, underscoring the role of extension systems in influencing safe and sustainable agrochemical practices.

The study concludes that without targeted interventions—such as strengthened advisory services, climate-responsive training, and access to alternative pest control methods—the current agrochemical use trajectory could exacerbate both health and environmental risks under worsening climate conditions.

7.0 Recommendations

1. Strengthen Agricultural Extension Services

Invest in expanding both public and private advisory systems to support climate-smart agrochemical decision-making. Promote localized and frequent training sessions tailored to smallholder farmers, with a focus on safe chemical handling, proper dosage, and application timing.

2. Integrate Climate Information into Farmer Education

Provide real-time, localized weather and pest forecast systems through mobile platforms and farmer networks. Raise awareness on the link between climate patterns and pest dynamics, and train farmers to adapt their chemical use accordingly.

3. Promote Alternative and Sustainable Inputs

Encourage the adoption of low-toxicity or organic alternatives, such as biopesticides and traditional plant-based solutions. Support demonstration farms to showcase the effectiveness of integrated pest management (IPM) and other ecological approaches.

4. Enforce Safe Use Regulations and PHI Compliance

Implement monitoring and follow-up mechanisms to ensure adherence to pre-harvest intervals (PHIs) and banned substances. Label agrochemicals in locally spoken languages and with user-friendly visuals to improve comprehension among low-literacy farmers.

5. Facilitate Access to Credit and Subsidies

Provide subsidized access to protective equipment, sprayers, and approved agrochemicals. Create climate-resilient input packages that integrate seed, organic treatments, and technical support for smallholders.

By addressing the nexus of climate change, agrochemical reliance, and farmer behaviour, these recommendations aim to support a transition toward safer, more sustainable, and climate-resilient agricultural systems in Nakuru County and similar contexts.

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