

**EFFECTS OF CLIMATE CHANGE ON AGROCHEMICAL
USE AND HEALTH OF FRESH PRODUCE FARMERS IN
NAKURU COUNTY, KENYA**

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Technology**

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other Institution.

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DEFINITION OF OPERATIONAL TERMS

Agrochemicals	Agrochemicals refers to a contraction of agricultural chemicals, including synthetic chemicals such as pesticides and fertilizers used in farming.
Climate Change	Climate Change refers to long-term shifts in temperatures and weather patterns, which can be natural or driven by human activities such as fossil fuel burning. These changes have various observed effects, including rising global temperatures, sea level increases, ice loss, extreme weather events, and changes in vegetation cover.
Fresh Produce	Fresh Produce refers to fruits and vegetables grown in Kenya that have not been processed in any manner.
Fresh produce farmers	Fresh produce farmers are farmers who are engaged in the agricultural production of fruits and vegetables in Kenya.
Health	Health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity.
Health Effects	Health effects refer to adverse outcomes or illnesses caused by the use of agrochemicals (direct contact) or after the consumption of products exposed to agrochemicals (indirect contact).
Highly Hazardous Pesticides (HHPs)	Highly Hazardous Pesticides (HHPs) refer to highly toxic agrochemicals that lead to ill health effects in human beings and the environment.
Poverty line	The poverty line refers to the cut off line for individuals who spend

less than 1.12 USD (estimated KES 145 per day in rural areas or less than KES 267 per day in urban areas) and are unable to meet both food and other minimal necessities in Kenya.

Lower middle class Lower middle class generally identifies individuals spending between USD 2.01 and 4.40 USD (estimated KES 260 and KES 570 per day in Kenya).

Middle Class The middle class refers to individuals spending between USD 7.72 and USD 38.61 per day (estimated at KES 1000 to KES 5,000 per day) in Kenya.

Upper Middle class The upper middle class is defined as individuals spending between US \$20 and US \$50 per person per day (estimated KES 880 to KES 2,200) in Kenya.

Upper class The upper class is defined as a person spending more than USD 50 (about KES 2,200 per day) per person in Kenya.

Occupational health practices Occupational health practices refer to activities and programs that aim to promote the welfare, safety, and health of workers in fresh produce farms in Kenya.

Pesticide Pesticide means any substance, or mixture of substances of chemical or biological ingredients, intended for repelling, destroying, or controlling any pest, or regulating plant growth.

LIST OF ABBREVIATIONS

AAK	Agrochemicals Association of Kenya
AEZ	Agro-Ecological Zone
AHS	Agricultural Health Study
CRA	Commission on Revenue Allocation
CSA	Climate Smart Agriculture
CSPM	Climate-smart pest management
EEA	European environment agency
EPA	Environmental Protection Agency
FGD	Focused Group Discussion
GHGs	Greenhouse gases
IARC	International Agency for Research on Cancer
KARLO	Kenya Agricultural and Livestock Research Organization
KII	Key informant interviews
KNBS	Kenya National Bureau of Statistics
MECS	Modern Energy Cooking Services
NCD	Non-Communicable diseases
NGO	Non-Governmental organization
NIOH	National Institute for Occupational Health
NOAA	National Oceanic and Atmospheric Administration
NPASP	Northern Presbyterian Agriculture Services and Partners
WOAH	World Organization for Animal Health
PCPB	Pest Control Products Board

RTFI	Route to Food Initiative
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
FAO	Food and Agriculture Organization
HBM	Health Belief Model
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
KES	Kenyan Shillings
NIEHS	National Institute of Environmental Health Sciences
NOAA	National Oceanic and Atmospheric Administration
PAN	Pest Action Network
SDG	Sustainable Development Goals
SCT	Social Cognitive Theory
TPB	Theory of Planned Behavior
HPPs	Highly Hazardous Pesticides
ILO	International Labor Organization
LMICs	Low and middle-income countries
PPE	Personal Protective Equipment
WHO	World Health Organization

ABSTRACT

Global surface temperature has risen by $\sim 0.2^{\circ}\text{C}$ per decade over the past 30 years. In Kenya, mean annual temperature has increased by $\sim 1.0^{\circ}\text{C}$ since the 1960s ($\sim 0.21^{\circ}\text{C}$ per decade). Nakuru County has experienced shifts in both temperature and rainfall, with average daily highs rising by $1.5\text{--}2.0^{\circ}\text{C}$ (23.3°C to 27.8°C) and lows by $1\text{--}2^{\circ}\text{C}$ (11.1°C to 12.8°C). Annual rainfall has declined by $\sim 5\text{--}10\%$ compared to early 2010s levels, with increasing variability in onset and cessation of rains. These changes contribute to greater reliance on agrochemicals, driven by pest resistance and climate variability. Although Africa accounts for only 2–4% of global pesticide use, the continent faces disproportionately high exposure risks. Overuse and misuse of agrochemicals undermine environmental integrity, human health, and agricultural sustainability. This study investigated the effects of climate change on agrochemical use and the health of fresh produce farmers in Nakuru County. Specifically, it examined farmers' socio-economic status, agrochemical use practices, occupational safety measures, the association between climate change and agrochemical use, and proposed health and safety interventions. A community-based cross-sectional design targeted rural fresh produce farmers routinely exposed to agrochemicals. A two-stage sampling technique was applied: random selection of sub-counties using probability proportional to size, followed by random household selection within clusters. The study accessed a sample size of 388. Quantitative data were collected using structured questionnaires, while key informant interviews (KII), focus group discussions (FGD), and observations provided qualitative data. Data were collected using Kobo Toolbox, exported to Excel, coded, and analyzed in SPSS version 28. Chi-square tested associations between categorical variables, while binomial regression measured statistical significance. Findings showed that agrochemical exposure undermines the health of farmers. Risk factors included financial constraints, years of farming experience, household income, farmer group membership, and type of farming. Farmers with more than 15 years of agrochemical use were 1.3 times more likely to develop adverse health effects compared to those with fewer years ($p=0.006$). Financially constrained farmers were five times more likely to develop health problems than those without constraints ($p<0.01$). Regression analysis established a statistically significant association between changes in weather patterns and agrochemical use decisions ($p=0.005$). Farmers noticing extreme weather were 1.2 times more likely to rely on expert advice or previous experience when making agrochemical use decisions. Overall, farmers with long-term agrochemical use and financial challenges faced heightened health risks. 64.2% of farmers expressed willingness to adopt new technologies, shift towards organic farming, and reduce reliance on traditional agrochemicals. The study recommends targeted interventions by Nakuru County's agriculture department to address financial barriers, such as promoting cooperative membership through agricultural extension services. A multisectoral approach, including the health department, should target experienced farmers for regular health screenings, refresher training, capacity building, and sensitization to enhance safe agrochemical use and strengthen occupational health and safety practices.

CHAPTER ONE: INTRODUCTION

1.0 Introduction

This chapter captures information related to and relevant to climate change, agrochemical use, and health effects. This includes the background information of the study, problem statement, research questions, research objectives, justification and significance of the study, scope of the study, and limitations of the study.

1.1 Background of Climate Change on Agrochemical Use and Health Effects

Climate change critically impacts agriculture, particularly specialty crop production. According to the Intergovernmental Panel on Climate Change (IPCC, 2023), climate change is defined as an alteration in the state of the Earth's climate that is detectable by variations in the mean and/or the fluctuation of its characteristics and lasting over extended periods, typically decades or longer (IPCC, 2023). This change may be due to natural internal processes, external forces, or persistent anthropogenic changes in the atmosphere's composition or land use. The breadth of this definition encompasses a wide range of phenomena, from shifting weather patterns to more extreme and unpredictable weather events, which further complicates the challenges faced by various sectors.

The impact of this change on the agricultural sector is undeniable, and crop growers in rural and developing areas face the difficulty of adapting to these changing climatic circumstances. These circumstances can significantly affect their profits and production costs, as the delicate balance required for crop cultivation is disrupted. The changing climate patterns can have a significant impact on agricultural production by affecting the water cycle, temperature, and soil fertility. Changes in climatic conditions have led to the unsustainable use of agrochemicals to combat increasing pest burden and diseases in agricultural

production. Climate change plays an important role in the growth, proliferation of diseases and pests. Climate change and extreme weather substantially influences the survival and distribution of pests across different agro-ecological zones. Most of the global warming over the last 50 years has been attributed to human activities. Human induced climate change resulting from increased levels of atmospheric greenhouse gases is likely to have a significant effect on agricultural sustainability. According to the Intergovernmental Panel on Climate Change (IPCC, 2021), global mean surface temperatures may rise by up to 5.7 °C by 2100, influencing pest and disease prevalence. Such increases in temperature have a significant implication on temperature-dependent pests and diseases leading to an increase in the volume and frequency of agrochemical use (FAO, 2021).

Agrochemicals are a key agricultural input needed to protect seeds and safeguard crops from unwanted plants, insects, bacteria, fungi and rodents. At the same time, pesticides can have negative health and environmental impacts through contamination of soil, water and non-target plants and animals, which can decrease biodiversity and harm living organisms including humans. Agrochemical use in agriculture in 2022 was 3.70 million tons of active ingredients showing a 4% increase compared to 2021, a 13% increase in a decade and a doubling since 1990 (FAO, 2024). Over the past decades, the use of agrochemicals, including but not limited to pesticides, herbicides, insecticides, and fungicides in crop production has become more widespread, particularly in developing countries, as a modern approach to protect agricultural investments. Agrochemicals have high levels of acute as well as chronic hazards to human health and the environment. In many instances, agrochemicals have been shown to cause severe or irreversible harm under conditions of use (Heinrich Böll Stiftung, 2023). Zhou, Smith, and Chen (2025) report that in, despite a

reliance on agriculture, pesticide consumption remains the lowest globally, a scenario exacerbated by reduced government oversight and the emergence of unofficial pesticide routes, leading to a significant spike in imports between 2000 and 2010.

According to Ahmed et al. 2021 in their systematic review of contamination levels and associated health risks of pesticides in vegetable production in Bangladesh, showed a plausible relationship between agrochemical use dependency and worsening climatic conditions. More agrochemical volumes are required over time due to crop and pest resistance, erratic weather conditions, and climate change. Despite this, agrochemical use reduction as a solution to the climate crisis has largely been ignored. On the contrary, agrochemical use as a climate mitigation strategy has been fronted as a strategy for intensifying food production through continuous use to guarantee global food security, ignoring the resulting deleterious effects.

The rapid increase in the world population has resulted in a boost to the demand for food supply and agricultural food products, coupled with the need to increase agrochemical applications. At the global level, agrochemical applications have increased by more than 50% between 1990 and 2010. The total agrochemicals trade was estimated to be around 5.9 million tons in 2019, which accounts for around 35.5 billion US dollars (FAO, 2024). Thus, agrochemicals use is expected to double in the next 10 years in developing countries. This increase points to an increased risk and danger of agrochemicals use and calls for a need to address agrochemical safety in developing countries. The widespread use of agrochemicals in agricultural and domestic settings is a serious threat to the environment and public health. The effects of excessive and inappropriate uses of agrochemicals on the environment and human health are recognized worldwide. Due to their persistent nature, agrochemicals

remain in the environment for a long period and gradually enter food systems. Exposure to agrochemicals occurs via different environmental media such as air, water, soil, and food and can result in both acute and chronic effects (Tudi, 2022).

Widespread agrochemical usage underscores the reliance on chemical inputs for crop protection, while also highlighting potential environmental and human health concerns associated with intensive agrochemical application. Agrochemical use in agriculture is increasing rapidly in developing countries due to perceived or actual benefits of avoided reductions in yield and quality of the harvest index. This is likely to increase due to climate change and the resulting pest resistance due to overuse. The use of agrochemicals makes agriculture one of the most hazardous human activities. This is because their design and mode of action are to poison their target organisms, and they can be lethal to humans, other non-target organisms, and environmental matrices (Yawson, 2022).

Exposure to agrochemicals has been associated with a spectrum of adverse health effects, broadly categorized into acute and chronic toxicological outcomes. Acute health effects are typically observed shortly after exposure and are often a consequence of direct contact through inhalation, ingestion, or dermal absorption. These may manifest as symptoms such as ocular irritation, dermatitis, chemical burns, nausea, vomiting, dizziness, respiratory distress, and in severe cases, systemic poisoning that can lead to convulsions or even death. These reactions are commonly reported among individuals involved in the mixing, handling, or application of pesticides without adequate personal protective equipment (PPE) or safety training.

On the other hand, chronic health effects emerge following repeated or long-term exposure, even at low doses, and are of significant public health concern due to their insidious nature.

Documented chronic effects include carcinogenicity notably non-Hodgkin's lymphoma and leukemia, reproductive toxicity such as reduced fertility, spontaneous abortions, and teratogenic outcomes, endocrine disruption, neurotoxicity, developmental delays, and immunosuppression. Several epidemiological and toxicological studies have linked chronic pesticide exposure with increased incidence of Parkinson's disease, hormonal imbalances, and various forms of malignancies, especially among populations with prolonged occupational exposure.

Importantly, susceptibility to agrochemical toxicity is not uniform across all demographic groups. Vulnerable populations, including infants, children, pregnant women, and immunocompromised individuals, demonstrate heightened sensitivity to pesticide residues and metabolites. Children, in particular have immature metabolic systems and higher intake of food and fluids relative to body weight, which amplifies their risk of adverse effects. Women, especially during pregnancy, are more susceptible to the teratogenic and endocrine-disrupting effects of agrochemicals, as highlighted in gender-specific exposure studies (Asmare, Freyer, & Bingen, 2022).

Occupational exposure to pesticides among agricultural workers and applicators poses significant health risks due to frequent and intense contact with chemicals. These risks are heightened by inadequate training, limited access to personal protective equipment (PPE), and poor enforcement of safety protocols, leading to both acute poisoning and chronic disease. Reported health effects include skin and eye lesions, headaches, dizziness, nausea, and vomiting, often linked to moderately to highly hazardous pesticides (Moreira & Vieira da Silva, 2024). Inadequate knowledge of safe pesticide use and inconsistent PPE use are major contributors to these health problems (Nasrabadi et al., 2025), while weak

enforcement of safety regulations further exacerbates exposure (Parasram et al., 2025). Comprehensive training and strict enforcement of occupational health and safety measures are essential to reduce pesticide-related health risks among agricultural workers.

This occupational vulnerability is further aggravated in low-resource settings where informal labor dominates agricultural production and regulatory oversight is limited. Collectively, the scientific evidence underscores the need for stringent risk mitigation strategies, including improved regulatory frameworks, farmer education, PPE distribution, routine health surveillance, and the promotion of safer alternatives such as integrated pest management (IPM). Understanding the multifaceted health implications of agrochemical exposure is critical for designing effective public health interventions and informing policy decisions aimed at safeguarding the health of farming communities and consumers alike.

Many of the agrochemicals have been associated with health and environmental effects, and the agricultural use of certain agrochemicals has been banned. Exposure to agrochemicals can occur through contact with the skin, ingestion, or inhalation. The type of agrochemical, the duration and route of exposure, and the individual health status, for example, nutritional deficiencies, immunity status, and healthy or damaged skin, are determining factors in the possible health outcome (Ahmad, 2024). Within a human or animal body, agrochemicals may be metabolized, excreted, stored, or bioaccumulated in body fat. The numerous negative health effects that have been associated with inorganic agrochemicals include, among other effects, dermatological, gastrointestinal, neurological, carcinogenic, respiratory, reproductive, and endocrine effects. Furthermore, high occupational, accidental, or intentional exposure to agrochemicals can result in hospitalization and death (Anaduaka, 2023).

Acute health effects resulting from agrochemical exposure are well documented in both clinical toxicology and occupational health literature. These immediate effects typically occur within minutes to hours of exposure and may vary in severity depending on the toxicity of the chemical, the route and duration of exposure, and individual susceptibility. Among the most common acute symptoms are irritation of the respiratory tract, including burning sensations in the nose, throat, and lungs, and dermal effects such as rashes, stinging, blisters, and itchiness. Exposure through the skin, particularly during mixing or application of agrochemicals, has been linked to contact dermatitis, which is one of the most frequently reported pesticide-related health complaints among agricultural workers (Lorenz, 2022; Pennsylvania State Extension, 2022).

Acute exposure to pesticides induces a spectrum of systemic effects, primarily impacting neurological, gastrointestinal, and respiratory systems. Neurological manifestations may include cephalalgia, dizziness, visual disturbances, muscle fasciculations, and cognitive disorientation, whereas gastrointestinal effects commonly encompass nausea, vomiting, abdominal cramping, and diarrhea. Severe exposure can cause respiratory complications, particularly among individuals with pre-existing conditions such as asthma or allergic disorders. Exposure to specific pesticide classes, including pyrethrins, pyrethroids, organophosphates, and carbamates, has been associated with exacerbation of respiratory complications and an elevated risk of acute respiratory cases (Hailu et al., 2025; Rodríguez-Zamora et al., 2024; Shekhar et al., 2024; Fandiño-Del-Río et al., 2024). These findings underscore the critical need for implementation of protective strategies, stringent exposure monitoring, and targeted interventions to mitigate health risks among vulnerable populations.

A key public health challenge is that many of the symptoms associated with acute agrochemical poisoning closely mimic common illnesses, such as the common cold, influenza, or gastrointestinal infections. This overlap in symptomatology often leads to misdiagnosis or underreporting of pesticide-related illnesses, particularly in rural and low-resource settings where diagnostic capacity is limited, and health surveillance systems are weak. According to Lorenz (2022), many individuals may not seek medical care for mild to moderate symptoms, attributing them instead to seasonal illness or dietary causes. This contributes to the systematic underestimation of agrochemical poisoning prevalence and hampers the development of targeted interventions.

Moreover, acute poisoning incidents are often not recognized as occupational illnesses, especially among informal farm laborers, due to poor training on safe pesticide use, limited availability of personal protective equipment (PPE), and inadequate regulatory enforcement. This reality calls for strengthened health monitoring systems, greater clinical awareness, and farmer education to improve recognition and reporting of pesticide exposure events. Importantly, integrating occupational health protocols into agricultural extension services and primary care settings can help bridge this gap, enabling early detection and prompt treatment of agrochemical-related health effects.

While acute toxicity from agrochemical exposure tends to manifest rapidly and is often easier to diagnose, chronic health effects present a more insidious and enduring public health concern, particularly for agricultural workers and populations in intensive farming regions. Chronic exposure refers to repeated or continuous contact with low to moderate levels of agrochemicals over extended periods, often spanning years. The challenge with these long-term exposures lies in their latent nature symptoms may take months or even

decades to manifest, complicating causal attribution and delaying intervention (Shekhar et al., 2024).

Mounting epidemiological evidence has implicated chronic pesticide exposure in a spectrum of non-communicable diseases, notably cancers, reproductive dysfunctions, and neurological disorders. Several cohort and case-control studies have found statistically significant associations between long-term pesticide exposure and cancers such as non-Hodgkin lymphoma, leukemia, and brain tumors, as well as breast, prostate, testicular, and ovarian cancers (Shah, 2020; Shekhar et al., 2024). These cancers often occur among populations with cumulative occupational exposures, including farmers, pesticide applicators, and residents near treated fields.

Beyond carcinogenicity, a particularly alarming dimension of chronic exposure is its impact on the human reproductive system. Research indicates that agrochemical exposure may result in reduced sperm count, menstrual irregularities, spontaneous abortions, stillbirths, and congenital anomalies (Tudi et al., 2022). These reproductive effects are especially concerning in low and middle-income countries, where agrochemical regulation, use of personal protective equipment (PPE), and public awareness remain inadequate.

A major category of concern within chronic exposure is endocrine-disrupting chemicals (EDCs) a subset of agrochemicals that interfere with hormonal signaling even at very low doses. EDCs mimic, block, or alter the body's natural hormones, thereby disrupting metabolic functions, sexual development, stress responses, sleep patterns, and even neurodevelopmental processes in children (National Institute of Environmental Health Sciences - NIEHS, 2022). For instance, organophosphates and certain fungicides have been shown to interfere with estrogen and androgen signaling, leading to infertility, feminization

in males, and abnormal brain development (Shekhar et al., 2024). Such chemicals may not only harm exposed individuals but also affect subsequent generations, making them a multigenerational hazard.

What exacerbates the risk is the invisibility of these effects. Because the onset of chronic illnesses is gradual and symptoms often mimic other conditions, many cases go undetected or misdiagnosed. Furthermore, exposure pathways such as dermal absorption, inhalation of residues, or ingestion of contaminated food and water mean that even non-farmer such as children, pregnant women, and elderly populations may be indirectly affected.

Importantly, these health consequences are not evenly distributed. Vulnerable populations, such as pregnant women, children, and individuals with pre-existing health conditions, exhibit heightened sensitivity to agrochemical exposure. In children, for example, even minor hormonal disruptions during critical developmental windows can result in lifelong neurological, immunological, or reproductive deficits (NIEHS, 2022). Similarly, gender-based physiological differences mean women may face increased risk of bioaccumulation and related pathologies compared to men (Tudi et al., 2022).

Addressing the chronic impacts of agrochemicals therefore requires a multifaceted approach: tighter regulation of hazardous substances, promotion of integrated pest management (IPM), expansion of farmer education, and investment in occupational and environmental health surveillance systems. Equally critical is the translation of toxicological data into accessible information for farmers, many of whom may lack formal education yet bear the brunt of exposure risk.

In conclusion, the chronic health implications of agrochemical use extend far beyond the farm. They touch on intergenerational well-being, public health infrastructure,

environmental justice, and ethical policymaking. The slow-burning nature of these harms calls for urgent, evidence-informed policy responses that prioritize health equity, sustainable farming practices, and stronger safeguards for vulnerable populations. Other chronic effects include diabetes, respiratory diseases, foetal or congenital diseases, impotence and reproductive disorders, depression, genetic and other neurological disorders, and death. Evidence suggests that occupational exposure to agrochemicals and the related ill-health conditions in farm workers are becoming widespread globally. As a result, human health and ecological health concerns about use of agrochemicals in agriculture remain topical in the policy, practice, and research communities, especially in developing countries where there are weak structures for integrated science management of agrochemical use and the attendant public health and ecological health issues from exposure (Yawson, 2022).

Agrochemical use in agricultural production has been shown to generate significant adverse impacts on both human health and the environment. Extensive evidence demonstrates that pesticide exposure contributes to acute and chronic health effects among farming communities, including neurological, respiratory, and gastrointestinal manifestations, while also contaminating soil, water, and non-target species, thereby undermining ecosystem integrity (Fuhrimann et al., 2022; Kanyika-Mbewe et al., 2025). Furthermore, agrochemical pollution has been recognized as a critical environmental health threat, with recent reviews emphasizing its role in biodiversity loss, endocrine disruption, and long-term ecological degradation (Elumalai & Gao, 2025). These findings underscore the dual challenge of safeguarding agricultural productivity while mitigating the deleterious health and environmental consequences of agrochemical dependence. Agrochemicals are widely used throughout the world to ensure food security. In the developing world, agrochemicals

demand is increasing due to the current system of crop production, which prioritizes high agricultural yields. Made up of chemicals that can control pests or regulate plant growth, agrochemicals have provided developing countries with one way to increase crop yields. Many farmers in developing countries view agrochemical use as the best means to protect their crops against pests. As such, agrochemicals can provide the only form of crop insurance available (Demi & Sicchia, 2021).

In Kenya, published data are scarce concerning the use of agrochemicals or the concentrations of agrochemicals in water, soil, and food, and the related health and environmental impacts (Marete, 2021). Agrochemical use in Kenya faces multiple challenges, including misuse, mishandling, illegal importation, occupational exposure, environmental concerns, and human health impacts from food contamination with residues (Loha, 2025; Marete, 2021).

Agriculture is a cornerstone of Nakuru County's economy, with fresh produce farming playing a pivotal role in sustaining livelihoods and ensuring food security. The sector's productivity is heavily reliant on the application of agrochemicals including pesticides, herbicides, and fertilizers to enhance crop yields and mitigate pest and disease pressures. However, the efficacy of these inputs is contingent upon their proper handling and application. Inadequate safety measures and improper usage of agrochemicals have been linked with significant health risks to farmers, farmworkers, and consumers, including acute poisoning symptoms, respiratory and dermatological effects, and long-term exposure risks for example in a study done in Karonga District, Malawi health effects reported included headache, respiratory and eye irritation. In a study in Ghana health effects reported included chemical poisoning, weakness, and dizziness (Kanyika-Mbewe et al., 2025; Bioone, 2021).

A survey conducted by Constantine et al. (2020) in Kenya revealed that nearly half of the respondents were cognizant of the risks to human health and the environment; nevertheless, the adoption of biopesticides remained low, with usage rates around 10%. The primary deterrents to biopesticide adoption included perceptions regarding their slower action, limited spectrum of activity, and concerns over availability and affordability. Conversely, chemical pesticides were favored due to their perceived effectiveness, despite their associated risks.

The use of agrochemicals among Fresh produce farmers has significant implications on the food chain, linking climate change, agricultural productivity, food security, and public health. Agrochemicals, which include pesticides, herbicides, and fertilizers, are commonly used in modern agriculture to control pests and diseases, boost crop yields, and enhance plant growth. However, their misuse or overuse can lead to adverse health effects for farmers, consumers, and the environment (Demi & Sicchia, 2021). This research aimed to explore the effects of climate change on agrochemical use and the health of fresh produce farmers, identify occupational safety practices, and assess health challenges on Fresh produce farmers in Nakuru County.

1.2 Agrochemicals Use and Health Effects

Agriculture remains the most important economic activity in Kenya, despite only 10.2% of the total land cover being arable. The agriculture sector contributes 51 percent of Kenya's GDP, 26 percent directly and 25 percent indirectly, accounting for 60 percent of employment and 65 percent of exports (KNBS, 2024). Kenya's agricultural sector is heavily reliant on agrochemicals to sustain and optimize crop production. Estimates indicate that the country imports approximately 12,983 tons of agrochemicals annually, comprising

insecticides (27%), fungicides (45%), herbicides (14%), and a remaining 14% consisting of acaricides, fumigants, plant growth regulators, miticides, and biocontrol agents. The total import value is estimated at KES 10.7 billion (\approx US\$100 million) (Marete et al., 2021). These figures are grounded in earlier assessments of pesticide import trends reported by Birech, Freyer, and Macharia (2006) and official statistics from the Pest Control Products Board (PCPB, 2012).

The consistency of these estimates across both academic and regulatory sources underscores the scale of Kenya's dependence on synthetic pesticides. While agrochemicals are integral to safeguarding yields and reducing crop losses, their extensive importation also raises concerns regarding long-term environmental impacts, occupational exposure risks, and implications for sustainable agriculture. Scholars highlight that reducing reliance on synthetic imports in favor of locally adapted alternatives, including botanicals and integrated pest management strategies, is critical to balancing productivity with environmental and human health considerations (Birech et al., 2006; Marete et al., 2021). Between 2015 and 2018, Kenya recorded a dramatic increase in the volume of imported pesticides, particularly insecticides, herbicides, and fungicides. Import volumes rose from approximately 6,400 tons in 2015 to 15,600 tons in 2018, representing a growth rate of 144% within just four years. This rapid escalation underscores the intensifying reliance of Kenyan agriculture on chemical pest management inputs, largely driven by the expansion of commercial farming, the rise of pest resistance, and the pressures of climate variability (Route to Food Initiative, 2020; Heinrich-Böll Stiftung, 2022). The data highlight not only the scale of pesticide usage but also raise critical concerns regarding environmental sustainability, food safety, and

public health, given that a significant proportion of these imports include highly hazardous pesticides (Kenya National Assembly, 2020).

Pathak et al. (2022) found that pesticide exposure is associated with both acute and chronic health effects including neurotoxicity, reproductive disorders, and birth defects among agricultural workers and linked agrochemical use to environmental issues such as soil and water contamination, bioaccumulation, and harm to non-target organisms. However, there are limited published studies on the effects of climate change on agrochemicals use practices, occupational health and safety, as well as the lifestyle of fresh produce farmers in Low- and Medium-Income Countries (LMICs), Kenya included. Chemical technologies are essential for modern societies, with more than 95% of all manufactured goods and articles relying on chemistry. While chemicals provide many desired benefits, they may be released during their lifecycle and cause adverse effects on human health and the environment (Tudi, 2021).

The unwanted waste of human origin released to air, land, and water is an existential threat to human health and planetary health and jeopardizes the sustainability of modern societies. Agrochemicals propagate contamination of air by fine particulate matter, ozone, oxides of Sulphur and Nitrogen, freshwater pollution, and poisoning of the soil by accumulation of lead, mercury, and other heavy metals. The needs and demands of a growing population and urbanization shape the production, trade and consumption of crops and other goods and services for which agrochemicals and fertilizers are used in significant quantities (Wang, 2020).

Africa is one of the most important markets and hubs for international agribusiness. In Africa and other developing countries, agrochemicals are not used efficiently due to various factors, including lack of knowledge, application equipment, and qualified agricultural

extension workers, in addition to poor infrastructure for farming and regulation, as well as pest resistance to agrochemicals (Marete, 2021).

According to Zinyemba, C., Archer, E., & Rother., 2021, in a study focusing on Climate Change, Pesticides and Health: Considering the Risks and Opportunities of Adaptation for Zimbabwean Smallholder Cotton Growers. Farmers are resorting to regular pesticide spraying and are increasing the types of pesticides used seasonally, the study adds. Many farmers are adapting to a shorter growing season by abandoning the practice of destroying and burning cotton stalks after harvesting to control pests and diseases. This corroborates with the sharp increase in pesticides imports volume in the region. The study also showed that the increased use has led to an increase in adverse health effects. Negative effects of endocrine disrupting chemicals, include an increased risk of miscarriage for pregnant women working on farms and problems relating to reproductive development of boys living on farms (Zinyemba, 2021).

Globally, agrochemical use is unevenly distributed, with Africa accounting for less than 5% of the global pesticide market and an even lower share of global usage rates estimated between 2% and 4% (Demi & Sicchia, 2021). This makes Africa one of the continents with the lowest per capita application of agrochemicals in agriculture. However, this relatively low volume of agrochemical use does not equate to safety. In fact, unsafe agrochemical use practices remain alarmingly high across many African countries, particularly among smallholder and subsistence farmers (Shaffril, 2024).

Several structural and systemic factors contribute to Africa's low agrochemical use. Firstly, subsistence agriculture dominates the agricultural landscape, with most farmers cultivating crops primarily for household consumption and selling only minimal surplus. This

production model offers limited incentives for agrochemical investment, as returns are modest and uncertain. Secondly, financial limitations constrain access to inputs. Many smallholder farmers operate under tight budget constraints and cannot afford agrochemicals regularly, let alone invest in safer alternatives such as personal protective equipment (PPE) or training (Birch, 2018). Finally, the low return on investment in high-input agriculture, combined with weak credit systems and limited extension support, further discourages uptake of agrochemicals.

Paradoxically, despite this low volume of agrochemical use, exposure risks are disproportionately high in Africa. One of the critical factors behind this paradox is the small size of farms. In comparison to developed economies such as the United States and Canada where the average farm sizes are approximately 421 and 778 hectares respectively Kenyan farms typically range from 0.2 to 3 hectares (Birch, 2018). These small plots necessitate manual handling of chemicals, which increases direct contact between farmers and agrochemicals. In the absence of mechanized spraying equipment, most African farmers rely on hand-held sprayers, often without adequate PPE, thus intensifying their exposure risk even when chemical use is minimal.

Moreover, agrochemical safety knowledge and awareness are limited. Many fresh produce farmers, especially in rural Kenya, lack formal education or training on safe handling, storage, and disposal of pesticides. The normalization of unsafe practices such as mixing pesticides without gloves, spraying without masks, or entering fields immediately after application has been exacerbated by poor extension services, linguistic barriers in labeling, and limited regulatory enforcement (Demi & Sicchia, 2021).

In addition, the market dynamics of agrochemical sales in Africa often prioritize accessibility over safety. Informal vendors, sometimes unlicensed, sell agrochemicals without providing usage instructions or safety warnings. In such contexts, farmers rely heavily on peer recommendations or trial-and-error approaches, further compounding health and environmental risks.

From a policy and development perspective, the focus should not solely be on reducing agrochemical use but rather on improving the conditions under which they are used. This includes, investing in farmer education and agrochemical literacy programs. Expanding public extension services to ensure safe pesticide application practices. Strengthening regulatory enforcement to monitor illegal or inappropriate agrochemical sales. Promoting access to affordable, less toxic alternatives and appropriate protective equipment. Ultimately, the African case highlights the need for context-specific agrochemical governance frameworks that account not only for volume but for the broader matrix of exposure risk, farm size, farmer knowledge, and access to resources.

The situation in Kenya is no different, the pollution problem is attributed to drainage and runoff of agrochemical residues into rivers and other water bodies (Kaigwara, 2019). Kenya's demand for agrochemicals is relatively high and steadily increasing. These agrochemicals are an assortment of insecticides, fungicides, herbicides, fumigants, rodenticides, growth regulators, defoliant, proteins, surfactants, and wetting agents. Of the total agrochemical imports, insecticides, fungicides, and herbicides account for about 87% in terms of volume and 88% of the total cost of agrochemical imports. Remarkably, the volume of imported insecticides, herbicides, and fungicides has more than doubled within

four years from 6,400 tons in 2015 to 15,600 tons in 2018, with a growth rate of 144% (PCPB, 2022).

Produce from Kenya targeted for export has been rejected severally by several countries for surpassing the maximum agrochemical residue levels required for agricultural produce. In 2020, reports by an expert committee on the agrochemical residues in food showed that fine beans from Kenya were rejected for having higher residue levels of the agrochemical acephate (UNEP, 2022). The possibility of this rejected agricultural produce ending up at the local food markets to reduce losses is high. This is evidenced by the scientific data from food testing, which revealed that the vegetables and fruits sold in the local markets contain high levels of agrochemical residues. This is a clear indication of the unsafe food Kenyan consumers are exposed to (Dena, 2021).

Just like consumers, Fresh produce farmers are also at risk of harm from these toxic agrochemicals. An estimated 70% of the rural economy works in the agricultural sector. Fresh produce farmers are increasingly using dangerous agrochemicals to grow food, oblivious of their impact on the natural environment and their health. The lack of protective suits while handling these agrochemicals due to unaffordability is of great concern. This places farmers at risk of being harmed by these agrochemicals through dermal contact, inhalation and ingestion (Nippanon et al., 2019).

Nakuru County is well known for agriculture, in particular Fresh Produce Farming (Constantine et al., 2023). It produces various types of fresh produce, including tomatoes, potatoes, kale, and other vegetables for export and large local markets like Nairobi and Nakuru, as well as for subsistence use. The use of agrochemicals is critical in this county, where various types of agrochemicals are applied in large-scale and small-scale farming

ventures. The 2019 Population and Housing Census recorded a population of 2,162,202 persons for Nakuru County, consisting of 1,077,272 males, 1,084,835 females, and a population density of 290 people per square kilometer (KNBS, 2023).

1.3 Agrochemical Use and Climate Change

Climate change refers to persistent alterations in temperature, precipitation patterns, and other aspects of the Earth's climate system over extended periods. While natural processes such as solar variability and volcanic activity have historically influenced global climate (United Nations - UN, 2023), human activities have become the dominant driver of climate change since the industrial revolution (U.S. Environmental Protection Agency - EPA, 2025). The combustion of fossil fuels for energy, transportation, and industrial production releases vast quantities of greenhouse gases (GHGs) most notably carbon dioxide (CO₂) and methane (CH₄) which trap solar radiation in the Earth's atmosphere, thereby intensifying the greenhouse effect and contributing to global warming.

Among the major sectors responsible for GHG emissions, agriculture plays a dual role, both as a contributor to and a victim of climate change (Omotoso & Omotayo, 2024). Agricultural practices such as the use of inorganic fertilizers, synthetic pesticides, and mechanized tillage contribute significantly to GHG emissions. Specifically, the application of nitrogen-based fertilizers releases nitrous oxide (N₂O), a potent greenhouse gas, while methane emissions arise from manure management, rice cultivation, and oil and gas operations linked to agribusiness. In addition, deforestation for agricultural expansion releases sequestered carbon, further exacerbating climate impacts.

In the context of fresh produce farming, particularly in developing countries, these climate-related dynamics manifest in several ways. As global temperatures rise and rainfall patterns

become erratic, farmers experience increased pest infestations, weed proliferation, and plant diseases all of which elevate the demand for agrochemicals (Shekhar et al., 2024). The increased use of pesticides and fertilizers in response to climate stressors not only contributes further to emissions but also exposes farmers and consumers to heightened health risks. This vicious cycle where climate change accelerates agrochemical use, and agrochemical use exacerbates climate change creates significant challenges for sustainable agriculture and public health.

Moreover, climate change intensifies the vulnerability of farm ecosystems. Frequent droughts, floods, and temperature extremes compromise crop yields, leading to economic pressure on farmers. In turn, many respond by intensifying agrochemical application, often with limited regard for safe handling, proper dosage, or environmental consequences. This is particularly concerning in regions like Sub-Saharan Africa, where institutional support, regulatory enforcement, and farmer training are often inadequate (Demi & Sicchia, 2021). In such contexts, the health effects of agrochemical exposure ranging from acute poisoning to chronic illnesses like endocrine disruption and cancer become amplified by climate-induced farming pressures.

Critically, the intersection between climate change and agrochemical use is not just an environmental or agricultural issue it is a multisectoral policy concern. Reducing GHG emissions from agriculture requires not only technological interventions such as precision farming or organic alternatives, but also behavioral and institutional changes. Farmers must be supported to transition toward climate-smart practices, including integrated pest management, organic soil enhancement, agroforestry, and reduced tillage systems, which can mitigate emissions while minimizing chemical exposure.

The agricultural sector in Kenya is highly vulnerable to extreme weather events, climatic shocks, climatic changes, and variability. Climate change is creating further stresses on food and water supply while further degrading the environment. With the deteriorating climatic conditions primarily due to climate change, the annual growth rate of agricultural Fresh Produce products has been on the decline. Extended periods of drought have negatively impacted livelihood opportunities and community resilience in these areas. It has also led to undesirable coping strategies among Fresh produce farmers such as increased volume and frequency of agrochemical use due to the vulnerability of their produce to increased pest burden and erratic weather patterns. Increased agrochemical use exacerbates environmental pollution and negatively impact public health (Kalele et al., 2021). Climatic changes have led to a shift of the upper altitudinal limits of Agro-Ecological Zone (AEZ) boundaries (FAO, 2020).

Consequently, incremental changes in temperature and rainfall patterns are expected to contribute to biodiversity loss and the emergence of new pests and diseases. This climate changes have a direct impact on the frequency and volume of agrochemical use in response to changes in precipitation and temperatures by Fresh produce farmers. As a result of perceived climate change impacts, such as a shorter growing season, farmers were found to be adopting a range of adaptive practices. These included changes in pest management practices, such as increasing pesticide spraying frequencies to protect the crops from increased pest infestation. This leads to a farmers' overall pesticide use. Such incremental adaptive practices are potentially maladaptive, as they may increase farmers' pesticide-related health risks (Zinyemba, 2021).

Few public health crises match the complexity, global reach, and impact on health threatened by climate change. From heat stress to malnutrition and respiratory illness, harmful effects of a changing climate manifest as various health outcomes; they can occur directly or incidentally, acutely or over time (Smith, 2020). For this reason, climate change is often described as a risk multiplier, compounding multiple stressors beyond the coping point, particularly for the most vulnerable. Many of the causal pathways between climate-related hazards and health outcomes remain incompletely understood, owing in part to the difficulty in dissecting indirect effects from environmental and socioeconomic causes and, more broadly, the longstanding underinvestment in environmental health research (Brunn, 2021).

Globally, food systems account for over one-third of all greenhouse gas emissions, which includes agriculture and agrochemical use. Agrochemicals, including pesticides, exacerbate the climate emergency throughout their lifecycle via manufacturing, packaging, transportation, application, and even through environmental degradation and disposal. More and more agrochemicals, including pesticides, are required over time due to acquired resistance by pests and erratic weather conditions, resulting in a vicious cycle between agrochemical dependencies and worsening climatic conditions (Pesticide Action Network UK, 2025).

Agrochemicals, particularly chemical fertilizers and pesticides are major contributors to climate change. The production, transportation, and use of these chemicals release significant amounts of greenhouse gases into the atmosphere (Koli, 2019; Climate Portal MIT, 2021). Pesticide manufacturing relies heavily on fossil fuels, is highly energy-intensive, with the production of a kilogram of pesticide requiring ten times more energy

than a kilogram of nitrogen fertilizer. Many pesticides lead to the production of ground-level ozone, a potent greenhouse gas (FAO, 2023). Climate change is expected to increase the demand for pesticides due to factors like decreased crop resilience, rising temperatures, and altered precipitation patterns, leading to more pest infestations. Increased pesticide use further exacerbates climate change, creating a vicious cycle (Abbass, 2022).

The impacts of climate change will lead to an increase in agrochemical use, creating a vicious cycle between agrochemical dependency and worsening climate breakdown. Therefore, temperatures rise, the number of pests increases, and crop resilience is significantly reduced. This creates a situation where farmers require larger volumes of agrochemicals to achieve the same results realized previously (America PAN, 2023). At the same time, erratic weather characterized by low precipitation and high temperatures leads to high residual accumulation in fresh produce and soil, leading to contamination of water sources hence negatively affecting human health. The rise in agrochemical use promotes a rapid development of resistance of insects and weeds to herbicides and insecticides in greater numbers while increasing harm to human health and the environment due to high bioaccumulation and increased residue levels in Fresh Produce (Ahmed, 2021).

Agroecological farming practices such as intercropping, conservation agriculture, and prioritizing local ecological processes can offer a solution to break this cycle. Agroecology minimizes or eliminates synthetic fertilizer and pesticide use while increasing the resilience of farming systems to climate change impacts (Deguine et al., 2023). These approaches have the potential to provide safe and resilient interventions to overcome the health and climate change impacts of agrochemical use. Adopting measurable goals to reduce synthetic agrochemical use in climate policies, promoting the rights of communities most affected by

agrochemical use, providing technical assistance and incentives for farmers to adopt biodiversity-enhancing practices by addressing the environmental and health externalities of conventional farming methods, leading to more sustainable and resilient food production systems in the face of climate change (Maria Parazo Rose, 2023).

1.4 The Problem Statement

According to International Labour Organization (ILO), 2024, half of the world's labour force is in the agriculture sector. Of the 1.3 billion women, men and children who work in agriculture, 450 million works for wages. Agricultural workers tend to be among the poorest segments of society, often with inadequate housing, little to no access to health care, and few educational opportunities. In the US, there are more than 3 million seasonal and migrant workers, self-employed farmers, and family members working on family farms, hired workers, and contract laborers. In South Asia and Sub-Saharan Africa, a significant number of people are employed in agriculture.

In South Asia, India leads with 272 million agricultural workers, followed by China with 229 million. Sub-Saharan Africa also heavily relies on agriculture for employment, with countries like Ethiopia and Tanzania having the highest share of agricultural workers among the most populated countries in the region. Agriculture employs an average of 54% of the working population in most African countries, with some outliers like Angola, South Africa, and Mauritius, where the agricultural sector employs a smaller percentage of the population. Additionally, the agricultural sector employs an appreciable proportion of Africa's economically active population, with East Africa having as much as 74.4% of the economically active population engaged in agriculture (Röösli et al., 2022). Pesticide use for food production such as fruit and vegetable has improved food quantity and quality,

consequently improving nutrition and international trade. Pesticides are considered a necessary tool in the intensification of agriculture in order to meet food demands. Despite these benefits, excessive use of pesticides on fruits and vegetables to protect them from damage and loss by pests increases pesticide residues in these foods, possibly reaching levels that are toxic to human health, especially if applied without following Good Agricultural Practices (Ssemugabo 2022).

Climate change has various impacts on farming, affecting fresh produce farmers in significant ways. These include rising temperatures, changing weather patterns leading to lower crop yields due to water scarcity from droughts, heat waves, and flooding. Additionally, increased atmospheric carbon dioxide levels from human activities can have both positive and negative effects on agriculture, such as a carbon dioxide fertilization effect that offsets some detrimental impacts but can result in lower levels of essential micronutrients in crops (FAO, 2024). Furthermore, climate change leads to loss of soil fertility, erosion, and alterations in the length of growing seasons. The effects of climate change on agriculture are complex and multifaceted, impacting crop production, agrochemical and pesticide use patterns, volume and frequency, pest resistance, and overall food security globally (PAN, 2022).

According to Luke Montrose et. al. 2021, in an epidemiological review, they contend that exposure to synthetic agrochemicals may be associated with adverse health outcomes. Agricultural workers are among the most vulnerable working populations due to high risk of exposure to health risks due to unsafe use of agrochemicals, and poor access to healthcare. In addition, these potential risk factors are exacerbated by occupational hazards associated with agricultural work, including exposure to agrochemicals such as synthetic pesticides and

fertilizers, environmental hazards, diesel exhaust, ultraviolet radiation, biologically active dusts, and zoonotic viruses and bacteria, all of which may put farm working populations at an increased risk for a variety of adverse health effects. Agrochemical exposure among agricultural workers has been linked to certain cancers, DNA damage, oxidative stress, neurological disorders, as well as respiratory, metabolic, and thyroid effects (Luke Montrose et. al, 2021).

Rising numbers of cases of non-communicable diseases, such as cancer, have been linked to air pollution and agrochemical exposure in commercial large-scale farming rural areas. In global terms, trying to find solutions to minimize incidences of ill health and mortality is urgent. It is important to determine whether Fresh produce farmers and farm workers, who are predisposed to agrochemical exposure, take precautions in agrochemical handling and adhere to agrochemical use regulations (Singer, 2024). Proper use and handling of agrochemicals is also significant as it involves adopting good agricultural practices such as the selection of agrochemicals that have less impact on human health and the environment (UNEP, 2020).

The use of agrochemicals among Fresh produce farmers has been associated with negative health effects such as respiratory complications, dermatologic conditions, hormonal disruption and cancers. Existing data link agrochemical exposure to endocrine disruption, genetic mutations, neurological dysfunction, and other metabolic disorders, apart from the myriad of acute effects. Despite the risks, farmers continue to use agrochemicals due to various factors such as lack of knowledge, inadequate protective equipment, and limited access to alternative pest control methods (Anaduaka, 2023). Evaluation of climate change, agrochemical use and health effects among Fresh produce farmers is crucial to explore the

factors that motivate or compel farmers to use agrochemicals, assess the safety challenges of agrochemicals and their impacts on climate change and human health, and ascertain the determinants of farmers' decisions on agrochemical use in Fresh Produce Farming. This research was vital to develop strategies to promote the adoption of safe agrochemical use practices, to safeguard food quality, mitigate negative health effects, and promote climate change resilient fresh produce farming practices.

Despite many published scientific studies, data gaps exist, and consolidated knowledge about the adverse impacts of agrochemicals and fertilizers use on climate change and health is lacking (UNEP, 2022). Evaluation of climate change on agrochemical use and health effects is necessary to identify their safety challenges and impacts on human health, especially for Fresh produce farmers who are in direct contact with agrochemicals in their daily work.

The situation is no different in Sub-Saharan Africa. In Kenya and other developing countries, agrochemicals are not used efficiently due to various factors, including lack of knowledge, application equipment, and qualified agricultural extension workers, in addition to poor infrastructure for farming and regulation, and pest resistance to agrochemicals. The UN has recognized that the challenges of agrochemical use and handling in developing countries include inadequate training of farm workers, extension workers and health care workers to reduce exposure and prevent poisoning by inculcating use of protective devices such as clothing, hand gloves and eye goggles, when handling pesticides, and adherence to labelling and packaging instructions (Marete, 2021).

According to a study by Bouri et al., 2023, more agrochemical volumes are required over time due to resistance and erratic weather conditions, resulting in a vicious cycle between

agrochemical use dependency and worsening climatic conditions. Despite this, agrochemical use reduction as a solution to the climate crisis has largely been ignored. On the contrary, agrochemical use as a climate mitigation strategy has been fronted as a strategy for intensifying food production through continuous use to guarantee global food security, ignoring the resulting deleterious effects (Bouri et al., 2023).

The effect of climate change on agrochemical usage in Kenya and its impacts on the health of Fresh produce farmers is dire. The impacts of climate change on agrochemical use and their effects on the health of Fresh produce farmers in Nakuru County have not been adequately studied. This research is therefore important because it will seek to generate new information on climate change effects on agrochemical use and the resulting health effects among Fresh produce farmers in Nakuru County and contribute to the body of knowledge on the phenomenon (KARLO, 2021).

Nakuru County is recognized as one of the critical agricultural zones in Kenya characterized by intensive pesticide application. Empirical studies have documented a high proportion of farmers in the county routinely applying synthetic pesticides, with frequent reports of residue exceedances in fresh produce and detections of pesticide contaminants in the environment (Route to Food Initiative, 2021). Nakuru is consistently listed among the high-use counties situated around the Mount Kenya region, alongside Meru, Nyeri, Kirinyaga, and Murang'a, where similar patterns of elevated pesticide utilization and associated environmental and food safety risks have been observed (Marete et al., 2021; Route to Food Initiative, 2021). According to the National Cancer Institute of Kenya (2023), the most common cancer types reported in the National Cancer Registry for 2021–2022 were breast (15.9%), cervical (13.3%), and esophageal cancer (11.8%). The report indicated that the

Central and Eastern regions of Kenya exhibited higher cancer incidence rates. Nakuru County ranked second among the top ten counties, contributing 63% of the total cancer burden among females and 62% among males, following Nairobi County (Okumu, 2023). This points to a likely link between the high use of agrochemicals and the prevalence of illnesses, including cancers, which this study seeks to evaluate.

Agrochemical utilization in Nakuru County has exhibited a marked increase in recent years, driven primarily by heightened pest pressures, climatic variability, and the demand for enhanced agricultural productivity (Asamba, Karanja, Ngeno, & Matiru, 2022). Farmers commonly employ organophosphates and pyrethroids, frequently in combination, often without adherence to recommended safety protocols, thereby elevating both human health risks and environmental contamination potential (Onyango, Kanja, & Mutua, 2020; Route to Food Initiative, 2020). Empirical investigations of soils and dairy farm ecosystems in Nakuru have revealed residues of persistent pesticides, including chlorpyrifos, reflecting both contemporary and historical agrochemical application patterns (Asamba et al., 2022; Onyango et al., 2020).

The detection of such residues underscores the potential for chronic exposure among farm workers and local communities, as well as the risk of bioaccumulation in environmental matrices. Despite regulatory oversight by the Pest Control Products Board (PCPB, 2023) and monitoring initiatives by the Kenya Plant Health Inspectorate Service (KEPHIS, 2022), challenges persist in enforcement, particularly regarding unregistered or counterfeit agrochemicals, and in promoting adherence to integrated pest management practices among farmers (Route to Food Initiative, 2020; The Standard, 2023). Collectively, these trends highlight the urgent need for enhanced regulatory enforcement, targeted farmer education,

and systematic monitoring to mitigate the health and environmental risks associated with agrochemical usage in Nakuru County (PCPB, 2023). Addressing these challenges requires coordinated strategies integrating climate adaptation, public health safeguards, and sustainable agrochemical practices to mitigate environmental and human health risks. This study seeks to fill this gap by generating evidence that can be applied to mitigate these challenges.

1.5 Research Questions

- i. What are the health effects of Agrochemical use among Fresh produce farmers in Nakuru County, Kenya?
- ii. What are the agrochemical use practices among Fresh produce farmers in Nakuru County, Kenya?
- iii. What are the Occupational Health and Safety measures adopted by Fresh produce farmers using agrochemicals in Nakuru County, Kenya?
- iv. What is the association between climate change and agrochemical use trends among Fresh produce farmers in Nakuru County, Kenya?
- v. What are the health and safety interventions adopted by Fresh produce farmers using agrochemicals in Nakuru County, Kenya?

1.6 General Objective

To investigate the effects of climate change on agrochemical use and the health of fresh produce farmers in Nakuru County, Kenya.

1.7 Specific Objectives

- i. To examine the health effects of Agrochemical, use among fresh produce farmers in Nakuru County, Kenya

- ii. To determine the agrochemical use practices among Fresh produce farmers in Nakuru County, Kenya.
- iii. To identify the Occupational Health and Safety measures adopted by Fresh produce farmers using agrochemicals in Nakuru County, Kenya.
- iv. To determine the association between climate change and agrochemical use trends among Fresh produce farmers in Nakuru County, Kenya.
- v. To develop health and safety interventions that can be adopted by Fresh produce farmers using agrochemicals in Nakuru County, Kenya.

1.8 Justification

Unlike most industrial chemicals, agrochemicals, including but not limited to pesticides and fertilizers, both inorganic and organic are deliberately applied in the environment to provide specific beneficial functions. However, this creates potential risks to the environment and health and exacerbates climate change effects. Pollution by agrochemicals is one of the most important pressures affecting the environment, health, and climate change. Agrochemical use risks are exponentially influenced by climate change, which results in increased global temperatures, erratic weather patterns, and a decrease in annual precipitation, leading to changes in their use patterns. Agrochemical use volumes, frequency and dosages are expected to change given the increase in pest resistance. The progress towards implementation of environmental policies such as the European Union's Farm to Fork strategy, which aims to reduce pesticide use by 50% by 2030; however, remains off-track (European Commission, 2025).

The export of synthetic pesticides banned for use within the European Union (EU) being sold to developing countries is increasingly questionable, especially given the growing

awareness of evidence that these chemicals pose serious and long-term risks to human health and the environment. While this is an increasing concern, the overall usage of pesticides is rising in developing countries. The improper use of agrochemicals affects the health of the farmers exposed in the course of their daily work as well as food safety and quality, which has a direct adverse impact on the health of consumers. Fresh Produce from Kenya targeted for export has been rejected severally by several countries for surpassing the maximum agrochemical residue levels set for agricultural produce. The possibility of this rejected agricultural produce ending up in the local food markets is high.

Agrochemicals including carbaryl, glyphosate, and paraquat have been classified as hazardous to human health by the World Health Organization. Despite this classification, they are still in use by farmers in Nakuru County. Other agrochemicals reported to be frequently used by farmers have been banned in Kenya and globally in response to the UN Convention on Persistent Organic Pollutants (Heinrich Böll Stiftung, 2023).

Agrochemical manufacturers view their products as safe if used properly. However, product usage and handling as prescribed by the manufacturers are often not realistic in most settings in which agrochemicals are deployed. This is a significant problem given the scale of their use by both large and small-scale farms and the pressure to produce crop yields (Utyasheva et al., 2024). The inappropriate and excessive use of agrochemicals constitutes a significant occupational health hazard for farmers. Empirical evidence indicates that exposure to pesticides may induce acute manifestations, including dermatological irritation and respiratory distress, as well as chronic conditions, such as endocrine disruption and carcinogenesis (Lemondé, 2024). Despite regulatory restrictions, highly hazardous pesticides remain readily accessible in Kenya and are frequently applied without adequate

personal protective equipment, amplifying the risk of adverse health outcomes. This study aims to investigate the effects of climate change on unsafe agrochemical use practices among fresh produce farmers in Nakuru County and the associated health effects. This will contribute to empirical evidence that can inform targeted interventions designed to mitigate the adverse health and environmental consequences associated with such practices.

1.9 Significance of the Study

A substantial body of peer-reviewed literature has demonstrated intensive pesticide use across several Kenyan counties, including Nakuru. Beyond agronomic practices, pesticide use in these counties has been associated with negative health outcomes, including acute poisoning, respiratory and dermal effects, and potential chronic conditions arising from long-term exposure among farmers and consumers (Marete et al., 2021; Okonya & Kroschel, 2015). Climate change further compounds these risks by altering pest dynamics, increasing pest pressure, and thereby intensifying farmer reliance on agrochemicals to secure yields (Kibret et al., 2021).

Kenya Plant Health Inspectorate Service detected high levels of agrochemical residues in fresh produce sampled from markets within Nakuru County in a survey conducted in the year 2020 (Ngotho, 2020). Samples analyzed in their laboratories showed maximum limits of heavy metal contaminants and residue of agrochemicals. Samples of tomatoes collected from some local markets tested positive and had an excess of Methamidophos at 0.03 mg/kg. Methamidophos is a metabolite resulting from the use of acephate. This is despite acephate being withdrawn from use on edible vegetables currently (Ngotho, 2020).

Fish from Lake Nakuru have also been condemned as unfit for human consumption. This is mainly due to the high residue levels of endosulfan that were above the maximum standard,

and the target hazard quotient of heptachlor epoxide was above 1, therefore making them unsafe for human consumption (Mbuthia, 2024). This highlights climate change effects on agrochemical use frequency and volume, leading to environmental bioaccumulation and biomagnification through the trophic levels. This study emphasized the importance of reducing the use of agrochemicals and pesticides as a key strategy for tackling greenhouse gas emissions such as methane and carbon dioxide and improving the climate resilience of the food and farming system.

It also highlights safeguards for the health of Fresh produce farmers and Fresh Produce consumers to ensure residual levels of hazardous agrochemicals in Fresh Produce are kept at a minimum. Determining the agrochemical use, lifestyle, occupational health, climate change, and safety practices among Fresh produce farmers in Nakuru County helps bridge the knowledge gap on the drivers of inappropriate use of agrochemicals by Fresh produce farmers. It also provides the needed information for the design of interventions and health education to prevent the avoidable morbidity and mortality they may cause.

1.10 Scope of the Study

This study was focused on examining the effects of climate change on agrochemical use and the associated health outcomes among fresh produce farmers in Nakuru County, Kenya. Geographically, the research was limited to Nakuru County, a region located in the central Rift Valley and recognized as one of Kenya's key area for production of fresh produce. The study focused on selected sub-counties within Nakuru that were predominantly involved in fresh produce farming such as tomatoes, cabbages, kales, and carrots. These areas were chosen due to their susceptibility to climate variability and the widespread use of agrochemicals.

The primary study population included smallholder and medium-scale fresh produce farmers who were actively engaged in the cultivation of fresh produce crops and who rely on agrochemical inputs for pest and disease management. Additional participants, such as agricultural extension officers and public health officials, were considered to provide expert perspectives and contextual information on observed changes in agrochemical usage and farmer health practices.

Thematically, the study investigated the influence of climate change particularly changes in temperature, rainfall patterns, and pest prevalence on the type, frequency, and volume of agrochemicals applied in fresh produce farming. It also explored the adaptive strategies farmers employ to cope with changing climatic conditions, especially in relation to pest and disease outbreaks. Furthermore, the study assessed the health implications associated with increased or altered agrochemical use, focusing on both acute and chronic symptoms reported by farmers. Attention was given to the use of personal protective equipment (PPE), safety practices during chemical handling and application, and the overall level of awareness regarding occupational health risks.

The temporal scope of the study was the past five to ten years based on the respondents' recall. This period is considered sufficient to capture observable trends in climate variability, agricultural practices, and health outcomes among the target population. While the study is grounded in the specific context of Nakuru County, its findings may offer insights applicable to similar agro-ecological regions experiencing the impacts of climate change on smallholder horticulture.

However, the study did not cover other agricultural sectors such as cereal farming or livestock production, and the environmental or ecological effects of agrochemical use, such

as soil or water contamination. The primary focus was on the human health dimensions of agrochemical exposure in the context of climate change, specifically among fresh produce farmers in the study area.

1.11 Limitation (s) of the Study

The study was limited to Nakuru County and may not represent the state of climate change on agrochemical use in the entire country or other agro-ecological regions. The study was also financially demanding and time-bound and therefore may not have allowed the researcher to comprehensively study the health effects of climate change on agrochemical use, which may require a longer period and resources to study. Recall bias may have affected the results, as participants may not have accurately reported past exposures, potentially leading to misclassification. The cross-sectional design limits the ability to establish temporal or causal relationships and cannot account for changes in exposure or outcomes over time. Additionally, climate change may influence agrochemical use patterns through altered pest dynamics, rainfall variability, and temperature fluctuations, which were not fully captured. Despite these limitations, the study provides valuable insights and highlights the need for longitudinal research incorporating environmental and climate-related factors.

The limitations were mitigated by use of a cross-sectional design and consideration of both qualitative and quantitative data to get a more comprehensive picture of the phenomenon and obtain nuances on the effects of climate change on agrochemical use and health of fresh produce farmers in Nakuru County.

1.12 Delimitation of the Study

Geographical Scope, this study is confined to Nakuru County, Kenya, and does not consider fresh produce farmers in other counties or regions. The study focuses specifically on fresh

produce farmers, excluding other types of agricultural practices. It also focuses on chemical inputs such as pesticides, herbicides, and fertilizers. The use of organic or traditional pest control methods is not the focus of this study. The health effects considered are limited to occupational health impacts directly linked to agrochemical use such as respiratory problems, skin conditions, and other short or long-term health effects. Broader public health issues or indirect health outcomes were not covered. The study utilizes questionnaires, interviews, and field observations. It does not include clinical health assessments, laboratory analysis of agrochemical residues, or satellite-based climate modeling.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter entails a review of theoretical and empirical literature relevant to explaining climate change, agrochemical use, and health effects among Fresh produce farmers. The chapter focuses on the theoretical framework, which explains the relevant models of the study. It also reviews empirical literature that is relevant to the study.

2.1 Overview of Climate Change on Agrochemical Use and Health Effects

Global mean near-surface temperature has increased by 1.55 ± 0.13 °C above the 1850-1900 average as at 2025 (WHO, 2025). The year 2024 was the warmest year in the 175-year observational record at (1.18 °C) above the 20th-century average of (13.9 °C), (NOAA, 2024). In Kenya the recorded mean annual temperature has increased by approximately 1.0°C since 1960s, and a recorded approximately 0.21°C per decade (Kenya, 2018). Climate change is increasingly recognized as one of the most pressing global challenges of the 21st century, with profound implications for ecological systems, human health, food security, and socio-economic development. Understanding the term ‘climate change’ requires an appreciation of both its scientific characterization and policy-oriented definitions, which, though related, emphasize different dimensions of the phenomenon.

Over the past decade, Nakuru County has experienced discernible shifts in both temperature and rainfall patterns, consistent with regional climate trends (WeatherSpark, 2025; World Bank, 2025; ResearchGate, 2017). Mean near-surface temperatures have increased, with average daily highs rising by approximately 1.5–2.0°C, from 23.3°C to 27.8°C, and average lows increasing by roughly 1–2°C, ranging from 11.1°C to 12.8°C (WeatherSpark, 2025). Concurrently, total annual rainfall has exhibited a modest decline of approximately 5–10%

compared to early 2010s levels, accompanied by increased variability in the onset and cessation of rains. Shorter and more intense rainy periods, particularly during the long rains from March to May, have been observed, with some years recording substantially lower totals than historical averages (WeatherSpark, 2025; ResearchGate, 2017). These climatic changes have significant implications for agricultural practices. Elevated temperatures combined with erratic rainfall patterns have heightened the prevalence of pests and diseases, thereby intensifying agrochemical use among farmers. This escalation in agrochemical reliance poses potential risks to environmental sustainability and public health. Understanding these climate dynamics is therefore critical for developing adaptive strategies to mitigate adverse impacts on agricultural productivity, human health, and local ecosystems (World Bank, 2025; ResearchGate, 2017).

According to the Intergovernmental Panel on Climate Change (IPCC) the leading international body for assessing climate science, climate change is defined as a change in the state of the climate that can be identified for example by using statistical tests or by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer (IPCC, 2020). This definition is rooted in observational and modeling approaches used to detect long-term shifts in variables such as temperature, precipitation, wind patterns, and other indicators of climatic stability. Importantly, the IPCC's framing acknowledges that such changes may be the result of natural variability or anthropogenic influences.

On the other hand, the United Nations Framework Convention on Climate Change (UNFCCC) adopts a policy-centric perspective. It defines climate change more narrowly as a change of climate which is attributed directly or indirectly to human activity that alters the

composition of the global atmosphere in addition to natural climate variability observed over comparable time periods (World Organisation for Animal Health WOA, 2022). This definition distinguishes anthropogenic climate change from naturally occurring fluctuations and highlights the human responsibility in driving recent climatic disruptions an important consideration for international negotiations and climate action frameworks.

The contrast between these definitions reflects the dual imperative of understanding climate change both as a scientific reality and a policy problem. While the IPCC includes all climate variability regardless of cause, the UNFCCC definition is deliberately framed to address human-induced climate change, which is central to guiding international cooperation under agreements like the Kyoto Protocol and the Paris Agreement. The policy framing underscores the moral and legal obligations of nations to mitigate emissions and adapt to climate impacts.

Furthermore, the emphasis on long-term persistence typically over decades reinforces the need to differentiate climate change from short-term climate variability such as seasonal fluctuations or temporary weather anomalies (IPCC, 2020). This distinction is crucial in informing both public understanding and evidence-based policymaking.

While the scientific community employs a broad lens to detect and analyze climate trends, policy frameworks emphasize human agency and responsibility. Both perspectives are indispensable in addressing the complex, multidimensional nature of climate change, particularly as its impacts become more pronounced in sectors such as agriculture, health, and water security.

Climate change poses significant challenges to fresh produce farmers, including increased post-harvest crop losses, higher temperatures, and new pests, making it more difficult for

farmers to reduce post-harvest losses, especially for highly perishable fruits and vegetables. Reduced crop yields, climate change has had primarily negative effects on crop yields, with decreases of up to 13.4% observed for some crops like oil palm. Yields of major crops like wheat, maize, and soybeans have been negatively impacted, particularly in tropical regions. Disrupted growing seasons, as rainfall patterns become more variable, farmers may no longer be able to rely on their traditional knowledge of seasonal climate patterns to time planting and harvesting. Spread of pests and diseases, warmer temperatures, and changing weather patterns enable weeds, pests, and plant diseases to expand their ranges, threatening crops that have not evolved defenses against them. These climate change impacts make it increasingly challenging for fresh produce farmers to maintain a consistent supply and quality, threatening food security, especially for vulnerable populations. Adopting climate-smart farming practices like using climate forecasting tools, planting cover crops, and improving pest management can help farmers adapt (EPA, 2023).

Agrochemicals are a generic term for the various chemical products used in agriculture. It refers to the broad range of agrochemicals, including insecticides, herbicides, and fungicides. It may also include synthetic fertilizers, hormones, and other chemical growth agents, and concentrated stores of raw animal manure (UNEP, 2022). Insecticides, fungicides, herbicides, rodenticides, and plant growth regulators are typical examples (World Health Organization & Food and Agriculture Organization of the United Nations, 2024).

The increasing global reliance on agrochemicals is closely linked to climate change, which exacerbates several factors that compel farmers to intensify their use. Erratic rainfall patterns, prolonged droughts, and soil degradation are becoming more prevalent due to climate change, making it increasingly difficult for farmers to cultivate crops without agrochemicals

(EPA, 2025). Additionally, climate change is altering the distribution and behavior of pests and pathogens. Warmer temperatures and increased humidity can expand the range of many pests and diseases, leading to higher infestations and crop losses, thereby driving farmers to use more pesticides to protect their crops (Skendžić, 2021). Furthermore, new crop varieties are being developed and promoted in response to changing climatic conditions. However, some of these varieties may be more susceptible to pests and diseases, necessitating increased use of agrochemicals to manage these threats (Pixley, 2023). Agrochemicals are seen as a reliable and cost-effective solution compared to labor-intensive traditional farming methods, especially as labor becomes scarcer. At the same time, the increased use of agrochemicals is contributing to climate change through greenhouse gas emissions from production and application.

This creates a vicious cycle, as climate change then further drives up agrochemical use (FAO, 2023). The health impacts on farmers are significant, as many do not follow proper safety precautions due to limited knowledge. Exposure to agrochemicals can cause direct harm to human health. Marginalized communities are disproportionately affected as they are more likely to live near sites of agrochemical production and use. To address this issue, experts recommend a shift towards more sustainable, agroecological farming practices that minimize or eliminate application of synthetic agrochemicals. FAO recommends that governments adopt policies that measurably reduce agrochemical use and support farmers in transitioning to more climate-resilient, nature-positive agriculture (FAO, 2020).

The use of agrochemicals among fresh produce farmers has been associated with negative health effects, including acute and chronic illnesses, such as respiratory problems, skin irritation, and cancer (Anaduaka et al., 2023). The increased use has also been shown to be a

side effect of climate change because higher temperatures increase the incidence of pests and diseases. At the same time, producing and using agrochemicals to control pests and diseases creates climate problems. The production of nitrogen-based fertilizers is energy-intensive, requiring the burning of fossil fuels. After farmers apply these synthetic fertilizers to crops, chains of chemical reactions generate nitrous oxide, a greenhouse gas. Nitrous oxide sets off a vicious cycle causing far greater global warming potential than either methane or carbon dioxide, reaching 265 times more by weight compared to carbon dioxide (Kenyi, 2021).

The Agricultural Health Study (AHS) provides some of the most compelling insights into the relationship between agricultural work, agrochemical exposures, and health effects. This large prospective study was initiated in North Carolina and Iowa in 1993 with the express intention of identifying and quantifying cancer risks and other non-cancer health outcomes among a cohort of nearly 90,000 individuals, including licensed private pesticide applicators, mostly farmers, their spouses, and commercial pesticide applicators. The most recent evidence on overall cancer incidence in the AHS was published in April 2019. It presents age, year, sex, and race-adjusted standardized incidence ratios (SIRs) for cancer sites in the AHS relative to the general population for an extended period of follow-up, representing 20 years and 12,420 incident cancers.

The study found that while overall cancer incidence was indeed lower than in the general population driven mainly by lower incidences of smoking, alcohol, or obesity-related cancers such as those of the respiratory, bladder and digestive systems, private pesticide applicators primarily farmers had higher incidence rates of lip and prostate cancer, B-cell lymphomas, chronic lymphocytic leukemia, acute myeloid leukemia, thyroid cancer, and

testicular cancer. The authors speculated that increase in lip cancer may be due to UV exposure and that the excess of thyroid and testicular cancer may be due to pesticide exposure in this population (Luke Montrose et. al, 2021).

According to Rerkswattavorn and Chanprasertpinyo 2022) in a study done in Thailand found that agrochemicals, including pesticides, insecticides, fungicides, organic agrochemicals, and chemical fertilizers, cause significant health problems. Most farmers used agrochemicals wrongly, posing acute health effects as well as chronic effects. Acute effects resulted in mild to severe outcomes or fatal toxicity in the case of exposure to high concentrations. Chronic effects resulted in the accumulation of toxic materials in organisms, farm produce, and water bodies, resulting in disorders and various diseases, teratogenicity and chronic illness among farm workers.

The increase in the use of agrochemicals and climate change are interconnected in a vicious cycle that exacerbates environmental and health risks. Agrochemicals, particularly pesticides, contribute significantly to greenhouse gas emissions throughout their lifecycle, from manufacturing to disposal. As climate change progresses, rising temperatures and altered rain patterns lead to decreased crop resilience, making plants more vulnerable to pests, which in turn necessitates higher pesticide application rates, further intensifying the problem. This increased pesticide use due to climate-induced pest pressures adds emissions to the atmosphere, accelerating climate change and creating a harmful loop. Moreover, the production of pesticides, which are often derived from fossil fuels, contributes to greenhouse gas emissions, further exacerbating the climate crisis (Kummu et al., 2021).

According to Nippanon et al., 2019 in their study in southern Asia, among the farmers who used inorganic agrochemicals, only one-third had a good quality of life. Inorganic

agrochemical use, as well as lifestyle, workload, psychological factors, and awareness of occupational health problems, influenced quality of life.

Despite contributing significantly to global food production, Africa accounts for less than 5% of the global pesticide market and just 2% to 4% of the global usage rate (Demi & Sicchia, 2021). This relatively low consumption is often interpreted as indicative of reduced chemical exposure and associated risks. However, this assumption masks a more complex and troubling reality. The unsafe handling and application practices that characterize agrochemical use across the continent present significant health and environmental challenges.

The low usage rate of agrochemicals in Africa can be attributed to several intersecting factors. First, the subsistence nature of farming across much of the continent limits demand for large-scale chemical inputs. Most smallholder farmers grow food primarily for household consumption, selling only surplus produce. This inherently limits both their purchasing power and the perceived need for expensive agrochemical products (Demi & Sicchia, 2021). Second, widespread financial constraints make the regular acquisition of agrochemicals economically unfeasible for many rural farmers. Third, there is often a low return on investment, where the economic gains from agrochemical application do not outweigh the upfront costs especially when poor infrastructure and market volatility limit profitability.

Paradoxically, however, the reduced quantity of agrochemicals used does not equate to safer farming practices. In fact, studies show that unsafe chemical use is alarmingly common among African farmers (Demi & Sicchia, 2021). Several structural and behavioral factors contribute to this. The average landholding size in many African countries is small, often

less than three hectares, forcing farmers into close physical proximity with crops during spraying. Without mechanization or protective equipment, direct dermal and inhalation exposure to chemicals becomes inevitable.

Moreover, there is a widespread normalization of agrochemical use as an integral part of modern farming, driven in part by agricultural extension messages and market incentives. Yet this normalization is rarely accompanied by adequate training in chemical safety, leading to routine violations of best practices such as improper mixing, incorrect dosages, and lack of personal protective equipment (PPE). In some cases, chemicals banned in high-income countries are still accessible in African markets, further compounding risks.

Another layer to this discussion is the philanthrocapitalist support for Africa's so-called "green revolution." Many agrochemicals used in African countries are donated by private foundations and development agencies. While such donations aim to boost productivity, they often come without robust safety protocols, follow-up training, or regulatory oversight, leaving farmers to navigate complex chemical usage with minimal support (Demi & Sicchia, 2021).

In summary, Africa's agrochemical paradox lies in the coexistence of low-volume use with high exposure risks. Efforts to improve food security and productivity on the continent must go beyond increasing chemical access and must prioritize farmer education, regulatory enforcement, and the development of context-appropriate safety guidelines. Without these, the health and ecological costs of chemical agriculture may continue to rise, even as the quantity of inputs remains relatively low.

According to Heinrich Böll Stiftung, 2023, there is growing awareness in Kenya of the health impacts of agrochemical use. The Route to Food Initiative, the Biodiversity and

Biosafety Association of Kenya, and the Kenya Organic Agriculture Network have pushed for a ban on twenty-four chemicals known to be carcinogenic and/or mutagenic. In a study by European Union 2021, sampling 800 residents in the Lake Naivasha region in Nakuru County, the centre of large-scale horticulture in Kenya, showed evidence of respiratory, skin, bone, and nervous system problems. The frequency of symptoms is higher among planters, weeders, and harvesters. The health impacts on children of pesticide use are closely related to child rights. Agriculture in Kenya is a major sector in which child labour is used (Janssens et al., 2020), particularly for crops such as tea, coffee, rice, sugarcane, flowers, tobacco, and cotton. Children may be more vulnerable to pesticides as their nervous systems are developing, and because they are less likely to be supplied with protective clothing or trained in the appropriate use of agrochemicals (Lalah et al., 2022).

2.1.1 Climate Change and Agrochemical use by fresh produce farmers

Climate change is widely acknowledged as one of the most significant challenges facing agricultural systems in the twenty-first century. Its implications extend beyond direct impacts on crop yields to include broader effects on resource availability, ecosystem services, and farmer livelihoods. Among these impacts, the relationship between climate variability and agrochemical use has emerged as a critical area of inquiry. Fresh produce farmers—who often cultivate fruits and vegetables that are highly perishable and sensitive to pests—are particularly vulnerable to climate-induced stressors. This vulnerability has spurred increasing reliance on agrochemicals, such as fertilizers, herbicides, and pesticides, as farmers attempt to maintain productivity under increasingly uncertain conditions. However, this trend also raises profound concerns about sustainability, environmental degradation, and public health.

Climate change is a driver of agrochemical dependency; the agricultural sector is fundamentally climate dependent. Shifts in rainfall patterns, temperature extremes, prolonged droughts, and irregular growing seasons all directly influence crop growth and indirectly affect pest and disease dynamics. For instance, higher temperatures can expand the geographic range of certain pests, allowing them to thrive in areas previously unsuitable for their survival. Similarly, erratic rainfall patterns create conditions conducive to fungal diseases. The Intergovernmental Panel on Climate Change (IPCC, 2021) has highlighted that climate change is likely to exacerbate existing pest pressures, requiring farmers to intensify pest management strategies.

For fresh produce farmers, who deal with crops that must meet stringent cosmetic and safety standards to satisfy both local consumers and export markets, pest damage represents not only a yield loss but also a direct marketability challenge. This often leads to an increased frequency and intensity of agrochemical application. A study by Zinyemba et al. (2021) demonstrates that farmers experiencing higher climate variability tend to rely more heavily on pesticides and fertilizers, even when such use exceeds agronomic recommendations. The result is a cycle of dependency where climate shocks amplify agrochemical reliance, which in turn produces new ecological and health challenges.

Environmental implications of increased agrochemical use are an existential threat to agricultural productivity and public health. The environmental consequences of heightened agrochemical use are multifaceted. Pesticide overuse has been associated with soil degradation, water contamination, biodiversity loss, and disruptions in ecological balances. Fertilizers, particularly nitrogen-based inputs, contribute significantly to greenhouse gas emissions, with nitrous oxide being nearly 300 times more potent than carbon dioxide in

terms of global warming potential (FAO, 2019). These emissions exacerbate climate change, creating a feedback loop in which agricultural practices both respond to and intensify environmental stress.

Furthermore, agrochemical residues leach into groundwater and surface water, posing risks to aquatic ecosystems and human populations dependent on these water sources. Several studies in Sub-Saharan Africa and South Asia report pesticide residues exceeding international safety thresholds in rivers and irrigation canals near intensive farming areas (Shammi et al., 2020; Ahmed et al., 2021). Such contamination is especially concerning for fresh produce farmers, as irrigation practices often involve direct water application on crops consumed raw, such as leafy vegetables, thereby increasing consumer exposure risks.

Pollinator populations, essential for many horticultural crops, are also adversely affected by agrochemical misuse. Neonicotinoid pesticides, for example, have been widely linked to bee colony collapse, with significant implications for fruit and vegetable pollination services. By undermining the ecological foundation upon which agriculture depends, excessive agrochemical use paradoxically threatens the very productivity it seeks to safeguard.

Health risks and occupational exposure resulting from agrochemical use in farming ventures are immense. The human health risks associated with agrochemical exposure are well-documented. For fresh produce farmers, occupational exposure occurs during mixing, spraying, and harvesting of chemically treated crops. Studies in developing regions have found alarmingly low levels of protective equipment use, often due to lack of resources, inadequate training, or discomfort in tropical climates (Elias et al., 2024). Acute effects of exposure include dizziness, skin irritation, and respiratory distress, while chronic exposure

has been linked to neurological disorders, endocrine disruption, and cancers (Glasgow, 2019).

Consumers are also at risk through pesticide residues on fresh produce. Since fruits and vegetables are often consumed raw, residue levels pose a more immediate food safety concern compared to staple grains that undergo processing. The World Health Organization (WHO, 2020) has flagged that excessive pesticide residues on fresh produce are a major contributor to global food safety risks. Export markets have responded with increasingly stringent maximum residue limits (MRLs), placing pressure on smallholder farmers in developing countries to balance pest management with compliance requirements.

Socio-Economic dimensions of agrochemical use in farming practices cannot be downplayed. Beyond environmental and health concerns, agrochemical dependence has socio-economic implications. For smallholder fresh produce farmers in Sub-Saharan Africa, South Asia, and parts of Latin America, agrochemicals often represent a significant share of production costs. Rising input prices—compounded by global market volatility—place additional financial strain on farmers already facing uncertain climate conditions. This dependency may lock farmers into a "poverty trap," where they must invest in chemicals to secure yields but accrue debts that limit their long-term resilience (Pretty & Bharucha, 2015). Moreover, agrochemical use is shaped by broader institutional and structural factors. Limited access to extension services means that many farmers lack knowledge on safe and efficient application methods. In some contexts, agrochemical retailers serve as the primary source of advice, creating conflicts of interest that encourage over-purchasing. Weak regulatory frameworks and limited enforcement capacity further exacerbate misuse. As a

result, agrochemical decisions are not simply technical but are embedded within larger socio-economic and governance systems.

Climate change, pest resistance, and agrochemical efficacy are key drivers to increased overuse of agrochemicals in farming practices. A critical dimension linking climate change to agrochemical use is the acceleration of pest resistance. Continuous and excessive pesticide application has long been recognized as a driver of resistance in pest populations. Climate change complicates this dynamic by creating conditions that favor pest adaptation. Rising temperatures, for example, shorten pest reproductive cycles, increasing the likelihood of resistance mutations. Similarly, extreme weather events disrupt natural predator-prey balances, reducing biological control and making chemical control more necessary.

Fresh produce farmers are particularly affected by resistance problems because many horticultural pests—such as whiteflies, thrips, and aphids—are notorious for rapidly developing resistance to commonly used insecticides. Once resistance emerges, farmers often respond by increasing dosage or switching to more toxic chemicals, both of which amplify health and environmental risks. This “pesticide treadmill” exemplifies the unsustainable trajectory that links climate stressors with agrochemical dependency (Anaduaka, 2023).

Climate-Smart agriculture and alternatives to agrochemical dependence can play a key role in ensuring agricultural production sustainability and protect public health. While the challenges are significant, climate change also provides an impetus for innovation in pest and soil management. Climate-smart agriculture (CSA), promoted by the FAO, emphasizes practices that simultaneously enhance productivity, build resilience, and reduce emissions. Within this framework, Integrated Pest Management (IPM) is increasingly recognized as a

viable alternative to chemical-intensive approaches. IPM combines biological control, cultural practices, resistant crop varieties, and targeted pesticide use as a last resort, thereby reducing overall chemical dependency.

Agroecological approaches, including intercropping, crop rotation, conservation tillage, and organic amendments, offer further pathways for sustainable adaptation. These practices not only minimize pesticide and fertilizer reliance but also enhance soil health, improve water retention, and foster biodiversity, making farming systems more resilient to climate variability. Recent evidence suggests that diversified cropping systems can buffer against pest outbreaks, reducing the need for chemical intervention (Maria Parazo Rose, 2023).

Additionally, technological innovations are creating new possibilities for precision agriculture. Digital tools such as remote sensing, drones, and decision-support software can help farmers monitor pest populations and apply chemicals more efficiently. While access to such technologies remains limited for smallholders in developing countries, ongoing pilot projects suggest that precision agriculture can substantially reduce input costs while maintaining yields.

Policy and governance responses focusing on interdisciplinary interactions of climate change and agrochemical use are vital. The intersection of climate change and agrochemical use also raises important policy questions. At the global level, frameworks such as the Sustainable Development Goals (SDGs) and the Paris Agreement call for agricultural practices that are both productive and environmentally sustainable. National governments are increasingly pressured to regulate hazardous pesticides, promote farmer training, and incentivize sustainable practices. The European Union, for example, has committed to

reducing pesticide use by 50% by 2030 under its Farm to Fork strategy, setting a precedent for other regions (European Union, 2021).

In many developing countries, however, enforcement of pesticide regulations remains weak. Farmers often have access to highly hazardous pesticides banned elsewhere, and informal markets thrive with little oversight. Strengthening regulatory capacity, expanding extension services, and fostering public-private partnerships are therefore essential to address misuse. At the same time, farmer sensitization and participatory approaches are necessary to ensure that interventions are context-appropriate and farmer-led.

Theoretical Perspectives, Food Sovereignty and Climate Justice. The discourse on agrochemical use cannot be separated from broader debates on food sovereignty and climate justice. Critics argue that chemical-intensive agriculture reflects deeper structural inequities in global food systems, where smallholder farmers in the Global South bear the risks of pesticide exposure while multinational corporations reap the profits (Lubbock, 2017). From this perspective, climate change adaptation strategies that prioritize agrochemical use risk perpetuating dependency and disempowerment. Food sovereignty advocates instead call for farmer-driven, agroecological solutions that restore local control over agricultural inputs and practices.

These perspectives highlight the importance of situating agrochemical use within larger political-economic dynamics. The challenge is not merely technical—how to reduce pesticide residues or fertilizer runoff—but also normative, involving questions of equity, justice, and sustainability in a rapidly changing climate.

In sum, climate change is profoundly reshaping the dynamics of agrochemical use in fresh produce farming. By intensifying pest and disease pressures, altering resource availability,

and disrupting ecological balances, it drives farmers toward greater reliance on pesticides and fertilizers. While such practices may provide short-term yield security, they also generate significant environmental, health, and socio-economic risks, and in many cases exacerbate the very vulnerabilities they seek to address. The literature points to a pressing need for transitions toward more sustainable practices, including IPM, agroecology, and precision agriculture, supported by stronger policy frameworks and governance mechanisms. Ultimately, the trajectory of agrochemical use in the context of climate change will be shaped not only by climatic forces but also by institutional choices, farmer perceptions, and global food system dynamics. Addressing this challenge requires a holistic and interdisciplinary approach that bridges agronomy, ecology, public health, and political economy. Only through such integrative efforts can fresh produce farming achieve resilience in the face of climate uncertainty while safeguarding environmental sustainability and human health.

2.1.2 Concepts and Principles of Agrochemicals Use and Health Effects

The unsafe use of agrochemicals is a worldwide challenge for public health and the environment. Risk assessment studies related to this challenge are mostly non-specific to chemicals, and few studies focus on investigating what quantitative relationships exist between a wide range of individual characteristics, the level of use and exposure to agrochemicals, and the potential for specific health problems. Agrochemicals are commonly used to control pests that affect crops. Human exposure to the chemicals is, however, also found to be associated with several health problems, including the introduction and aggravation of neurological problems, cancer, respiratory problems, and diabetes. The population in low-income countries is especially at risk of high exposure to agrochemicals.

The risk is heightened due to the lack of understanding by farmers about the hazardous nature of the chemicals, lack of resources to address unsafe practices in the agriculture sector, limited capacity to adopt alternative and safer technologies, and the absence of appropriate regulatory frameworks (Glasgow, 2019).

Climate change has significant implications for the use of agrochemicals and human health. The increasing utilization of agrochemicals globally, despite evidence of their adverse effects on the environment and human health, is a concerning trend. Agrochemicals, including pesticides and fertilizers, contribute to greenhouse gas emissions and ground-level ozone production, exacerbating climate change. As climate change progresses, it is expected to lead to more extensive use of synthetic pesticides due to factors like decreased crop resilience, increased insect populations, and shifts in weed competitiveness (Zinyemba et al., 2021). Moreover, the reliance on agrochemicals by farmers, driven by worsening environmental conditions linked to climate change, poses health challenges. Farmers, particularly in regions like sub-Saharan Africa, feel compelled to use agrochemicals due to depleted soils and the need for higher crop yields, despite being aware of the negative effects on health and the environment.

The overuse of agrochemicals, influenced by factors like erratic rainfall patterns, government subsidy programs, and market demands for conventional foods, leads to health risks for farmers and consumers alike. The intersection of climate change, agrochemical use, and health effects underscores the urgent need for sustainable agricultural practices, reduced reliance on synthetic chemicals, and policies that promote environmental health and food safety among growers and the general population (Devi et al., 2022).

Studies have shown that Fresh produce farmers, their families, and those living adjacent to farming areas may face long-term health risks associated with the use of pesticides, although the impact of pesticide use is often undetected. According to Gill et al., 2022, in developing countries, incidents involving handlers of pesticides occur more often, and the health impacts may be more immediate, given a frequent lack of Personal Protective Equipment (PPE) and minimal education about the correct way to spray chemicals. About 20% of the approximately 800,000 people who die from suicide every year do so by ingesting pesticides. The issue is particularly significant in Asia, where pesticides are often used in 'impulsive' suicide attempts brought on by stress (Wang et al., 2020). A ban on paraquat and two other pesticides resulted in a 21% fall in suicide mortality in Sri Lanka between 2011 and 2015 (Buckley, 2021).

Agrochemical poisoning involving pesticides remains a pressing public health concern worldwide, especially in low-income countries. According to the World Health Organization (WHO) an estimated one million serious unintentional pesticide poisonings occur each year. A study of agricultural workers in low-income regions of Asia estimated that as many as 25 million cases of mild pesticide poisoning occur annually. The most widely used pesticides are organophosphate, carbamate, and pyrethroid insecticides. Ill health related to these irreversible inhibitors of acetyl cholinesterase has been reported in studies from India, South Africa, and Thailand. Among the total cases, farm occupational poisoning accounted for about one-fifth of reported cases. The majority of the cases in these countries are males with a mean age of 25 years (Rosebella, 2020).

The impact of pesticide exposure has become a globally developing environmental health problem. Increased vulnerability of farmers to pesticide poisoning is caused by a lack of

knowledge about handling pesticides safely and appropriately. The World Health Organization reports that there are at least 18.2 per 100,000 agricultural workers who experience pesticide poisoning related to their work. Pesticides can enter the body through inhalation, dermal absorption, and ingestion during the preparation to application of pesticides. To reduce exposure to pesticides and protect health, farmers' use of PPE during the application of pesticides is recommended by the International Labor Organization (ILO) and the World Health Organization (WHO). Acute pesticide poisoning is generally underdiagnosed among farmers. This often happens in developing countries (Joko et al., 2020).

The use of pesticides in fresh produce farming, particularly in low- and middle-income countries (LMICs), presents a significant and multifaceted public health challenge. The acute and chronic health effects associated with pesticide exposure are increasingly being documented in epidemiological studies, with particular concern regarding respiratory, integumentary (skin), cardiovascular, gastrointestinal, and neurological complications among exposed populations. These health risks are often heightened in LMICs due to limited regulatory oversight, inadequate training, and lack of protective equipment (Shekhar et al., 2024).

Between 2008 and 2014, Morocco reported over 2,000 cases of acute pesticide poisoning, with 50% of the implicated pesticides classified by the World Health Organization (WHO) as Class I (extremely or highly hazardous) or Class II (moderately hazardous) (WHO, 2019). These statistics underscore the widespread and dangerous use of highly toxic pesticides, many of which are still in circulation in developing countries due to weak enforcement of international chemical safety standards. Acute poisoning cases, however, only represent the

visible tip of a much larger iceberg of subclinical and chronic exposures, which often go undiagnosed or are misattributed due to overlapping symptomatology with other illnesses (Kapeleka et al., 2025).

Long-term health impacts are even more insidious. Although causality is difficult to establish conclusively due to the latency period and cumulative exposure effects, growing evidence points to an association between pesticide exposure and cancer, particularly leukemia, lymphomas, and hormone-related cancers such as breast, prostate, and testicular cancer (Violet et al., 2022). In this regard, endocrine-disrupting pesticides have garnered increasing scrutiny. These compounds mimic or block natural hormones, disrupting hormonal signaling pathways that regulate crucial physiological functions including reproduction, growth, metabolism, neurological development, and immune responses. For fresh produce farmers and their families, prolonged exposure to such pesticides may lead to infertility, spontaneous abortion, birth defects, metabolic disorders, and an increased risk of hormone-dependent malignancies (Shekhar et al., 2024).

In LMICs, the health risks are exacerbated by the high frequency and intensity of pesticide exposure. Most smallholder farmers, due to limited land sizes, work in close proximity to pesticide-treated crops and often lack access to personal protective equipment (PPE) or appropriate safety training. This direct dermal and inhalation exposure substantially increases their susceptibility to both acute and cumulative health effects. Moreover, children and women, who often participate in farm labor or live near treated fields, are especially vulnerable. The physiological differences in metabolism, hormonal function, and body size make them more sensitive to even low doses of these toxic substances.

Compounding these issues is the lack of robust monitoring of pesticide residues in food. Regulatory thresholds may be exceeded without detection, exposing consumers to low-dose chronic ingestion of harmful substances. This poses a dual risk: while farmers bear the brunt of occupational exposure, consumers especially in countries with underdeveloped food safety monitoring systems may also face serious long-term health consequences from contaminated produce (Eizadi-Mood et al., 2023).

In conclusion, the negative health effects of agrochemical use in LMICs are not only prevalent but systematically underreported and underestimated. The persistence of unsafe pesticide use practices, combined with the emerging threat of hormone-disrupting chemicals, demands urgent policy intervention. Health education, regulation of hazardous substances, and promotion of safer alternatives to chemical pesticides are critical to reducing the health burden on fresh produce farmers and their communities.

2.1.3 Agrochemical use trends

Frequently changing global environmental and climatic conditions pose a serious threat to global agriculture by putting an extra burden in the form of environmental biotic and abiotic factors and a challenge to food security, and thus, the global population. To ensure food security, optimal production of agriculture is essential (Abbass et al., 2022). Judicious and safe use of agrochemicals like chemical fertilizers, agrochemicals, and plant growth regulators has enormous potential to boost the agriculture productivity to meet the food demand of rapidly growing world population, but excessive agrochemical use causes serious damage to the environment, contaminate the soil, water, and whole ecosystem, thus threatening the soil micro biota and human health. The continuous use of agrochemicals often results in the accumulation of metals/polychlorinated biphenyls and other

contaminants in soil and water, and thus the food chain ultimately damages human and animal health (Gill, 2022).

The eradication of hunger and malnutrition is still a significant challenge in most low and middle-income countries (LMICs), which rely on agriculture as a source of food and livelihoods. Concomitantly, these countries are faced with an exponential increase in non-communicable diseases (NCDs), which are disproportionately related to their unhealthy diets. The urgency to produce nutritious foods in abundance through subsistence farming to control hunger and reduce NCDs is often in conflict with the profitability and livelihood aspects of agriculture (FAO, 2023).

Moreover, the increased risks of climate change have threatened agricultural and environmental stability as a result of increased pests and diseases, and the introduction of new pests to crops. This reality has set the stage for the global demand for agrochemicals. Generally, there is a drastic shift in agricultural activities globally from traditional to non-traditional methods, which have increased the reliance on agrochemicals to increase productivity. The estimated agrochemical-related deaths worldwide are estimated at 200,000 per year, where 99% of these occur in developing countries, even though the utilization of agrochemicals in these countries is only 25% of the global utilization (Calista, 2022).

The conventional methods of raising farm productivity since World War II have centered on employing the use of externally acquired inputs like fertilizers and protection chemicals, among others. Agrochemical is a generic term for various chemical products used in agriculture. Agricultural chemicals include fertilizers, agrochemicals, herbicides, and rodenticides used to eliminate the presence of living things that cause injury or diseases to crops and to improve production (Devi, 2022). Although many kinds of chemicals are used

in agriculture, they can be categorized into simple groups according to the functions they perform. This includes insecticides, herbicides, fungicides, molluscicides, fertilizers, growth stimulants, and rodenticides (UNEP, 2022).

Agriculture mortality rates have remained consistently high throughout the world in the last decade, in contrast to other dangerous occupations. Farm workers are at a very high risk of occupational diseases due to exposure to agrochemicals resulting from inadequate education, training, and safety systems. In developed countries such as the US, farmers and farm workers comprise only 3% of the workforce, but they account for as much as 8% of all work-related accidents (El Khayat, 2022). Developing countries are known to consume less than 20% of the world's production of agrochemicals, which are responsible for as many as 1.1 million (70%) of the total cases of acute poisoning in the working population (Magauzi, 2021).

In most parts of sub-Saharan Africa, smallholder agriculture is characterized by significant financial and infrastructural limitations, which directly impact the methods used for agrochemical application. Due to a lack of access to capital and limited credit facilities, the vast majority of African farmers are unable to acquire modern, mechanized equipment such as motorized boom sprayers or drone-based applicators. Instead, they rely on rudimentary tools such as knapsack sprayers, buckets, handheld brushes, and even brooms to apply pesticides, herbicides, and other agrochemicals to their crops (Food and Agriculture Organization - FAO, 2023). While these tools are relatively affordable and easy to use, they offer limited control over dosage and dispersion, increasing the risk of both environmental contamination and human exposure to toxic chemicals.

The use of manual application methods not only compromises the efficacy of agrochemical treatment but also exacerbates occupational exposure risks for farmers and their families. The lack of adequate training on safe agrochemical use further worsens the situation, especially when improper mixing ratios or application timing results in excessive contact with hazardous substances (Demi & Sicchia, 2021). These exposures are particularly concerning when coupled with low adoption of Personal Protective Equipment (PPE). Studies have found that many farmers do not wear basic protective gear, such as nose masks, goggles, gloves, overalls, or Wellington boots during agrochemical application, largely due to cost constraints, discomfort, lack of awareness, and unavailability in local markets (Demi & Sicchia, 2021).

The implications of this unsafe application environment are severe. Repeated unprotected exposure to pesticides can result in acute toxic symptoms, including skin irritation, headaches, respiratory distress, and eye damage, as well as chronic health outcomes such as reproductive disorders, neurological impairment, and certain cancers. From an environmental perspective, the uncontrolled application of agrochemicals through non-standardized tools increases the risk of soil and water contamination, harming beneficial insects, aquatic organisms, and even contaminating food products (FAO, 2023).

Moreover, gender and youth dynamics further complicate the scenario. In many African farming communities, women and children are frequently involved in agrochemical-related activities either directly through spraying or indirectly by handling contaminated clothing or equipment. This exposure heightens the vulnerability of these groups, especially considering their physiological sensitivity to toxic chemicals and lack of involvement in training or safety initiatives.

Addressing these challenges requires a multi-pronged policy approach. Investment in low-cost but efficient spraying technology, subsidization or local production of PPE, and comprehensive farmer training programs are essential to improving safety standards. Extension services need to integrate climate-smart and health-conscious agrochemical management practices into their outreach models. Furthermore, farmer cooperatives and producer associations should be empowered to pool resources, access safety equipment in bulk, and negotiate better prices for agrochemical inputs and equipment.

According to the Agrochemical Association of Kenya (AAK), agrochemical imports to Kenya have increased rapidly from 6,400 tons in 2015 to 15,600 tons in 2018. However, the imported volume of agrochemicals alone gives little information about the risks to human health. Other factors, such as the toxicity of the substances, methods of application, application rates, or the frequency of application and use of personal protective equipment (PPEs) by the farmers, also play a role.

Detailed statistics on the use of agrochemicals per crop are currently unavailable in Kenya and many other African countries. Due to the lack of systematic collection of such data, sales volumes serve as a proxy. Data on environmental contamination of surface water, groundwater, and soil is also not recorded (Heinrich Böll Stiftung, 2023). Fresh produce is among the crops that currently require the highest volume of toxic agrochemicals. Many of these agrochemicals are proven to cause cancer or genetic defects, impair fertility, or harm unborn children. To ensure consumer protection, these foods need continuous agrochemical residue monitoring (Heinrich Böll Stiftung, 2023). Agrochemicals not only lead to health problems, but many of them are also toxic to the environment and important natural resources like bees, soil, and surface waters. Toxic agrochemicals are cheaper for farmers

despite their negative consequences and are mostly used on fresh produce farming, such as potatoes and tomatoes (Human Rights Watch, 2023).

Occupational health practices refer to the programs and activities that aim at the promotion and maintenance of physical, mental, and social well-being of workers of all occupations (Gikunda & Lawver, 2019). According to data released by Heinrich-Böll-Stiftung in the Agrochemical Atlas Kenyan edition (Heinrich Böll Stiftung, 2023), an estimated forty-four percent of agrochemicals used in Kenya are banned in Europe, amounting to an estimated 1,362 tons. Agrochemical sales data also shows that seventy-six percent of the total volume of agrochemicals sold in Kenya contains one or more active ingredients that are categorized as Highly Hazardous Agrochemicals (HHPs), an estimated 2,353 tons.

These are agrochemicals that are proven to present a particularly high level of acute or chronic risk to health or the environment. Agrochemicals that are not categorized as HHPs only make up 22 per cent. The market value of HHPs is about 46.8 million US dollars, which is sixty-four percent of the country's total market share of agrochemicals. Glyphosate, mancozeb, paraquat, and chlorpyrifos are among the most used active ingredients. The potential of these ingredients to cause severe environmental and human health effects is acceptable. The high use of HHPs in Kenya is worrying because no continuous monitoring takes place, while agrochemical residues on crops are mostly unknown, and chronic health effects are difficult to establish (Heinrich Böll Stiftung, 2023).

In 2020, reports by an expert committee on the agrochemical residues in food showed that fine beans from Kenya were rejected for having higher residue levels of the agrochemical acephate. A recent study found the frequencies of use by respondents/farmers and WHO toxicity ranking as; Nine of the agrochemicals, including parathion, methomyl, endosulfan,

endrin, dieldrin, methoxychlor, heptachlor epoxide, carbofuran and endosulfan sulphate were very toxic (WHO class I) and require adherence to procedures of agrochemical safe handling, while 12 were toxic (WHO class II) and 5 were moderately toxic (WHO class III) (Kimuge, 2023). Fifteen (15) of them were very lipophilic and therefore have great potential to bioaccumulate in the food chain as well as persist in the environment. Similar agrochemicals are in use in Nakuru County (Ngotho, 2020).

2.1.4 Agrochemical Impacts on Farmer Health and the Environment

The impact of agrochemicals on the human immune system has attracted attention from scholars. Studies have shown that long-term low-dose exposure to agrochemicals leads to the development of respiratory diseases such as asthma, reduced sperm quality and sperm count, causing sterility and cancers (Bassi, 2020). Unwanted chemicals in food can result from agrochemicals applied during the growing or harvesting of the crops.

This has a direct negative impact on the food chain and ultimately a negative public health impact on the population. Toxins in food can cause immediate and potentially severe distress when ingested. Many agrochemicals have been linked to a large number of reproductive, developmental, and metabolic diseases, while some residues are known carcinogens (Anaduaka, 2023). For example, the International Agency for Research on Cancer (IARC) lists some organophosphate agrochemicals, including glyphosate, malathion, and diazinon, as probably carcinogenic. The toxicity of polycyclic aromatic hydrocarbons, dioxins, and other environmental contaminants has been extensively documented (Dieter, 2018).

Farming is a major occupation in Africa, especially among rural populations, serving as a means of livelihood. The recent fluctuations experienced by farmers in plant yield, as well as unsteady and fluctuating climatic conditions, with the increasing population in the

developing world and the globe in general, have prompted the need for an improvement in farm produce. The quest for possible strategies to meet the ever-growing food demand has posed additional challenges to the users of agrochemicals. In Nigeria, for example, to feed her growing population, increased food production by 4% per year for a projected 10 years was required (Bassi et al., 2020). To accomplish this, the use of inorganic fertilizers has increased from an average of 10 to 50 kg/ha since organic sources of soil nutrients were not sufficient (Ahmed, 2021).

The agriculture sector contributes fifty-one percent of Kenya's GDP, twenty-six percent directly and twenty-five percent indirectly, accounting for sixty percent of employment and sixty-five percent of exports (World Bank Group, 2018). Agriculture is key to Kenya's economy, accounting for about twenty-two percent of the overall GDP in 2021. The sector employs more than forty percent of the total population and more than seventy percent of people living in rural areas, with a high percentage of women working on farms (Heinrich Böll Stiftung, 2023).

The sector is dominated by fresh produce production on farms of between 0.2 and 3 hectares, which account for seventy-eight percent of total agricultural production and seventy percent of commercial production. Agricultural GDP is driven by horticulture and cash crops, but productivity is low, particularly for cereals. Given that most of the poor are in the agriculture sector, productivity also matters for poverty reduction. Agriculture sector growth accounted for the largest share of poverty reduction between 2005 and 2015 (Birch, 2018). The average age of the Kenyan farmer is widely referred to as being sixty years, An alternative perspective is offered by Jayne et. al (2017) in their cross-country study on the future of work in African agriculture. Drawing on census data, they calculate that the mean age of

Kenyan above fifteen years engaged in agriculture rose from thirty-five in 1999 to thirty-seven in 2009. Of the nine countries studied, three had experienced a small increase in the mean age, three a small decrease, and three were stable (Birch, 2018).

Fresh produce farmers are an important part of the agricultural sector in many developing countries. However, the use of agrochemicals among these farmers has been associated with negative health effects (Demi & Sicchia, 2021). Most African farmers have limited economic incentives and financial resources to afford sophisticated farm machinery to apply agrochemicals; hence, they resort to the use of manual, simple farm tools such as knapsack sprayers, buckets, brushes, and brooms in the application of agrochemicals. Furthermore, many farmers apply agrochemicals without the appropriate Personal Protective Equipment (PPE) such as nose masks, overall coats, goggles, gloves, and safety boots, which further exposes them to chemical poisoning with grievous health and environmental consequences. According to Northern Presbyterian Agriculture Services and Partners (NPASP) of Ghana, 15 farmers died because of chemical poisoning in the Upper East region of Ghana. A study by Demi and Sicchia 2021, found that in Uganda 99.5% of the fresh produce farmers applied agrochemicals without PPE and 92.7% mixed chemicals with their bare hands. 15 Deaths linked to the unsafe use of agrochemicals have also been reported in both Rwanda and Burundi. However, the use of agrochemicals in subsistence farming is increasing in Africa, which is orchestrated by the continuous promotion of agrochemicals in Africa by corporations. Onwona-Kwakye et al. (2020) found that food crop farmers in Ghana used agrochemicals at a rate of 1.3 to 13 times higher than the recommended doses. Overdose application of agrochemicals is also reported among vegetable farmers in Tanzania and fresh produce farmers in Ghana (Demi & Sicchia, 2021).

The danger of highly hazardous agrochemicals is exacerbated in Kenya, where strategies and resources to minimize the effects of exposure are limited or not feasible. The location and size of farms mean buffer zones are impractical for limiting agrochemical drift or runoff to nearby homes, schools, and waterways. An Agrochemicals Association of Kenya study found that only 15 percent of farmers in Kenya wear full protective equipment when using agrochemicals for reasons including cost, lack of availability, or climate. Exposure to hazardous agrochemicals can have severe effects on human health, food safety, drinking water safety, and the environment (Heinrich Böll Stiftung, 2023).

A study published by the Route to Food Initiative (RTFI) reports that in 2020, highly hazardous agrochemicals accounted for over 75 percent of the total agrochemical volume in Kenya, and nearly half were substances already banned in the EU due to their risks to health and the environment. This implies that these banned organochlorines were either still being sold to farmers or recycled as old stock and/or were being used illegally by farmers (Marete, 2021). This is a common pattern across areas practicing farming in Kenya. To date, Kenya has imported 17,803 tons valued at 128 million dollars (PCPB, 2022).

Nakuru County has undergone substantial demographic and land-use changes in recent years. Between 2020 and 2025, the county's population increased from 2.2 million to an estimated 2.45 million, reflecting an 11% growth rate over five years (KNBS, 2024). This population surge has exerted pressure on land resources, leading to fragmentation and a reduction in average farm sizes. The average farm size in Nakuru County is approximately 0.77 hectares, and although larger-scale farms still occupy a significant portion of the land, population-driven subdivision has further reduced the size of individual plots (Debonne, 2021). Urban expansion has compounded these pressures. Between 2012 and 2019, built-up areas in

Nakuru Town nearly doubled, replacing large-scale agricultural land with residential and industrial developments (Tuhkanen, 2025). The combined effects of population growth and urbanization have constrained land availability for farming, compelling smallholder farmers to adopt intensified production strategies, particularly in fresh produce cultivation. For example, tomato farmers increasingly allocate more land to production despite limited plot sizes (Central Bank of Kenya, 2023).

Intensification has, however, increased reliance on agrochemicals, including fertilizers, pesticides, and herbicides, to maintain or improve yields on smaller fragmented plots. While agrochemical use supports productivity, it poses several environmental and health risks. Improper handling and overuse can lead to contamination of soil and water sources, bioaccumulation of toxic substances in crops, and exposure risks to farmworkers (Tudi et al., 2021). In Nakuru County, small-scale farmers may be particularly vulnerable due to limited access to safety training, protective equipment, and proper disposal facilities. Consequently, while intensified farming and agrochemical application are adaptive responses to land scarcity and population pressure, they also create potential hazards that must be managed to safeguard environmental and human health.

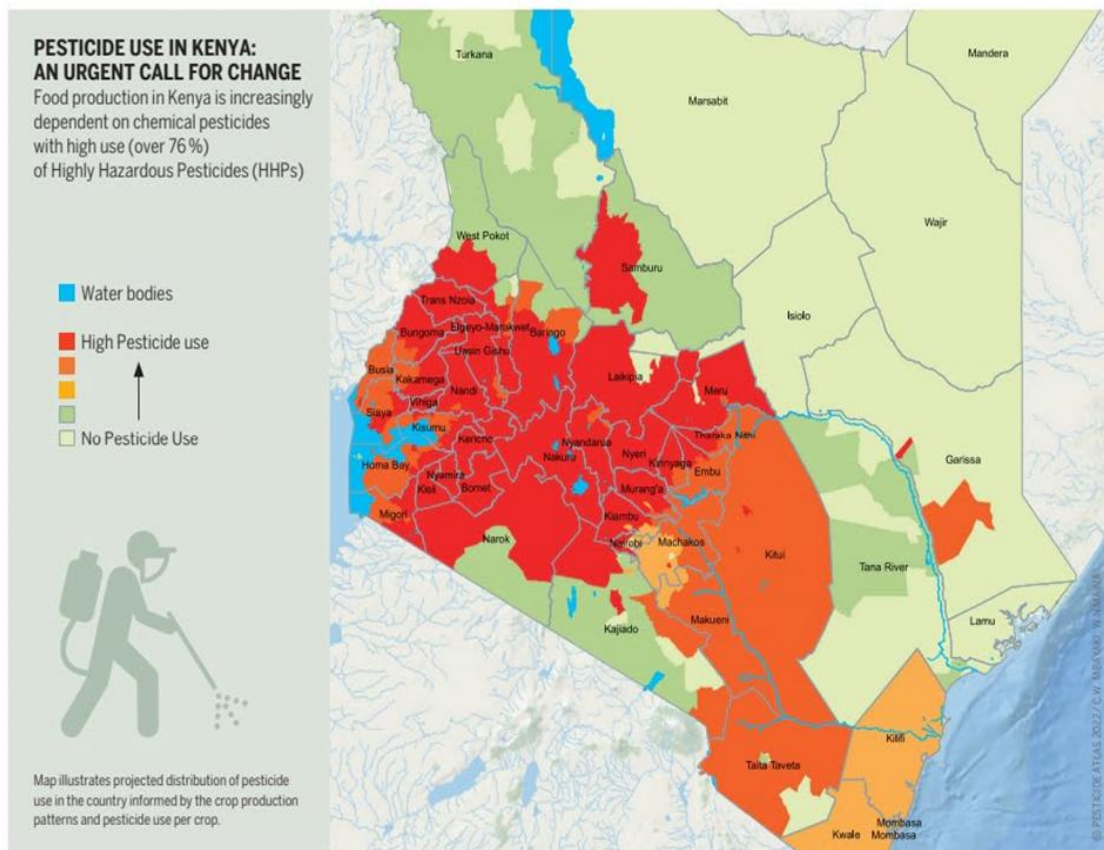
This has led to agricultural intensification and the use of agrochemicals seen to be the only viable options for farmers to maximize yields in pursuit of survival. As a result, understanding, preventing, minimizing, and controlling occupational health and safety as well as environmental hazards associated with agrochemical use remains an important public health concern (UNEP, 2022). Fresh produce farmers whose living conditions depend on the quality and quantity of resources obtained from agricultural land, soil fertility, pest

control, and production maximization represent a particularly critical issue by acting as a chronic poverty trap threatening their food security (Taskin et al., 2021).

Figure 2.1 presents the distribution of agrochemical used in the country informed by the crop production patterns and agrochemical use.

Figure 2.1

Distribution of agrochemical use in Kenya



Source: Heinrich Böll Stiftung, (2023)

Nakuru County is among the counties listed for high agrochemical use in food production in Kenya (Heinrich Böll Stiftung, 2023). Agrochemical use is strongly shaped by crop production patterns, with intensive application concentrated in high-value horticultural and floricultural systems, while staple cereals account for lower per-hectare intensity but larger

aggregate volumes. Floriculture, especially around Lake Naivasha, is the most chemically intensive sector, relying heavily on fungicides to manage disease pressure under humid, irrigated conditions and to meet stringent export market requirements (Mwaura et al., 2021; Nyakundi et al., 2023). Similarly, fresh produce farming including, tomatoes, French beans, and leafy vegetables accounts for frequent pesticide application, particularly fungicides and insecticides, due to high pest and disease incidence (Macharia et al., 2020).

2.1.5 Climate change and agrochemical use

The intersection between climate change and agrochemical use in Sub-Saharan Africa (SSA) has increasingly become a focal point of agricultural and environmental scholarship. In many parts of the region, farmers are grappling with rapidly shifting climatic conditions, including unpredictable rainfall, prolonged droughts, and rising temperatures. These dynamics have not only altered cropping patterns and pest ecology but also reconfigured the reliance on agrochemical inputs such as pesticides, herbicides, and fertilizers. Overdependence on these chemicals has been widely criticized for promoting unsustainable farming practices, undermining natural pest control mechanisms, and accelerating pest resistance (Zinyemba et al., 2021; Anaduaka, 2023). Furthermore, the accumulation of agrochemicals in soils, waterways, and the broader ecosystem raises urgent concerns regarding environmental sustainability, food safety, and human health.

A growing body of evidence indicates that climate change is closely linked to the frequency and intensity of agrochemical application. For instance, rising temperatures and increased humidity can create favorable conditions for pest proliferation, compelling farmers to escalate pesticide use. Similarly, erratic rainfall patterns may foster weed invasions or leach nutrients from soils, prompting more intensive fertilizer use (Demi & Sicchia, 2021). This

pattern has been observed across diverse agricultural contexts in SSA, where the necessity of ensuring crop survival often overrides long-term sustainability considerations. While agrochemicals are undoubtedly critical inputs for safeguarding yields, particularly in fresh produce farming, their misuse and overuse present complex socio-ecological challenges that warrant careful examination.

Overdependence and its consequences, the tendency of smallholder farmers to rely almost exclusively on agrochemicals can be explained by several interrelated factors. First, agrochemicals provide immediate and visible results, often making them a more attractive option compared to labor-intensive integrated pest management (IPM) practices. Second, in regions where extension services are weak or underfunded, farmers often lack access to adequate training on safe and sustainable pest control alternatives (Anaduaka, 2023). This knowledge gap, compounded by aggressive marketing by agrochemical companies, reinforces chemical dependence.

However, overuse of agrochemicals disrupts natural pest control processes. For example, repeated application of broad-spectrum insecticides eliminates beneficial arthropods such as parasitoids and predators, thereby dismantling ecological checks and balances. This can trigger secondary pest outbreaks that further lock farmers into cycles of chemical dependency. Moreover, the phenomenon of pest resistance has become particularly pronounced in SSA. Studies document that continuous application of the same class of pesticides accelerates genetic adaptations in pests, rendering certain chemicals ineffective within a short span of time (Zinyemba et al., 2018). As pests evolve resistance, farmers respond by applying larger quantities or stronger formulations, thereby intensifying the cycle of dependence.

Beyond pest resistance, the ecological footprint of excessive agrochemical use is profound. Bioaccumulation in soils can degrade soil fertility, while runoff contaminates rivers and groundwater, threatening aquatic biodiversity and human populations reliant on untreated water sources. Health impacts include acute poisoning among farmworkers, chronic illnesses linked to long-term exposure, and residual chemical traces in food systems that compromise consumer safety (European Union, 2021). These risks are disproportionately borne by smallholder farmers, who often lack access to protective equipment or medical facilities.

Climate change as a driver of agrochemical use, climate change has reshaped agricultural systems in ways that amplify the perceived necessity of agrochemical inputs. Rising global temperatures have expanded the geographic range of several key agricultural pests. For instance, the fall armyworm (*Spodoptera frugiperda*), once confined to the Americas, has rapidly spread across Africa, devastating maize fields and forcing unprecedented pesticide applications (Demi & Sicchia, 2021). Similarly, erratic rainfall patterns contribute to the persistence of fungal pathogens such as *Phytophthora infestans* (the causative agent of late blight in potatoes), necessitating repeated fungicide treatments.

Climate variability also exacerbates weed pressure. Warmer temperatures and carbon dioxide fertilization can enhance weed competitiveness relative to crops, compelling farmers to intensify herbicide use. For example, *Striga hermonthica* (witchweed), a parasitic plant affecting maize and sorghum, thrives under stressed climatic conditions and has been increasingly reported across SSA. Controlling *Striga* often requires combinations of herbicides and labor-intensive management practices, further straining smallholder systems.

It is therefore not surprising that farmers' agrochemical decisions are influenced not solely by pest occurrence but also by climatic unpredictability. Perceptions of risk, shaped by recurring crop losses due to extreme weather events, often drive a "better safe than sorry" approach, where farmers preemptively apply pesticides or fertilizers in anticipation of problems. This prophylactic use frequently leads to higher overall application rates compared to reactive treatments, further embedding unsustainable practices (Anaduaka, 2023).

Agrochemical use in Fresh Produce Farming, Fresh produce farming represents a particularly high-intensity agricultural sector regarding agrochemical inputs. Fruits and vegetables are vulnerable to a wide array of pests and diseases, many of which thrive in warm and humid climates. Smallholder farmers in SSA, who dominate fresh produce supply chains, often perceive pesticides as indispensable for securing marketable yields. Studies have shown that cosmetic standards in domestic and export markets also contribute to excessive chemical use, as blemish-free produce is more likely to fetch higher prices. Consequently, even when pest pressure is moderate, farmers may still apply pesticides to ensure visual quality (Demi & Sicchia, 2021).

The frequency of agrochemical application in fresh produce farming raises particular concerns regarding human health. Fruits and vegetables are typically consumed with minimal processing, increasing the likelihood of pesticide residues entering diets. Regulatory monitoring systems in many SSA countries are underdeveloped, and enforcement of maximum residue limits (MRLs) is often weak. This regulatory gap exacerbates health risks and underscores the urgent need for interventions promoting responsible pesticide use.

Farmer perceptions and decision-making, farmer perceptions of climate change and pest dynamics significantly shape agrochemical use patterns. Research suggests that smallholder farmers are highly aware of the impacts of climate variability on their crops, even if their scientific understanding is limited. Many farmers associate unpredictable weather with higher pest risks, leading to increased pesticide applications as a precautionary measure. Yet, these perceptions do not always align with empirical pest dynamics, sometimes resulting in unnecessary chemical use.

Socio-economic factors also mediate decision-making. For instance, access to credit and input subsidies often determines whether farmers can afford pesticides and fertilizers. In some cases, subsidies inadvertently encourage overuse by lowering the financial burden of chemical purchases. Conversely, farmers with limited resources may rely on diluted formulations or unsafe alternatives, creating different but equally problematic health and ecological risks. Gender dynamics further complicate this landscape, as female farmers often have less access to extension services and input markets yet remain heavily involved in fresh produce farming.

Policy and intervention efforts, recognizing the intertwined challenges of climate change and agrochemical dependence, international and regional bodies have promoted integrated approaches. The European Union (2021) emphasizes sustainable pesticide use, advocating for integrated pest management (IPM) as a cornerstone of agricultural resilience. Similarly, African Union frameworks have called for climate-smart agriculture that reduces reliance on agrochemicals while enhancing productivity.

Practical interventions include farmer field schools, which aim to improve knowledge of pest ecology and promote alternatives such as biological control agents. For example, the

introduction of natural enemies to control fall armyworm has shown promise in reducing pesticide reliance. Additionally, agroecological practices—such as crop diversification, conservation agriculture, and organic amendments—offer pathways toward more resilient systems. However, adoption remains limited due to structural barriers, including lack of policy support, inadequate funding, and entrenched market preferences for chemical solutions.

The relationship between climate change and agrochemical use in SSA is multifaceted, reflecting ecological, socio-economic, and institutional dimensions. Climate change intensifies pest and weed pressures, indirectly driving up agrochemical reliance. While these inputs safeguard short-term productivity, their overuse undermines long-term sustainability by fostering pest resistance, degrading ecosystems, and posing health hazards. Addressing these challenges requires a nuanced approach that balances the necessity of agrochemicals with strategies that minimize dependence. Central to this effort is empowering smallholder farmers with knowledge, resources, and alternatives that enable adaptive and sustainable responses to climate variability. By situating agrochemical use within the broader discourse of climate resilience, agricultural policy can move toward practices that secure food systems without compromising environmental and human well-being.

2.2 Literature on Fresh produce farmers Agrochemical Use

2.2.1 Socio-economic status of fresh produce farmers and agrochemical use

Agriculture is the backbone of rural livelihoods in Nakuru County and a key pillar of its socio-economic development. The fresh produce subsector supports food security, income generation, and employment. However, despite its potential, optimal productivity remains

constrained by several challenges, including land fragmentation, limited irrigation, climate variability, pest outbreaks, and poor access to agricultural extension services.

One of the critical inputs in modern fresh produce farming is the use of agrochemicals particularly pesticides, herbicides, and fungicides for pest and disease control. However, the ability of farmers to make informed decisions on agrochemical use is significantly influenced by their socio-economic status, including income levels, education, farm size, access to credit, and market linkages (Istriningsih, 2022). Farmers from lower socio-economic backgrounds often lack the technical knowledge, training, and financial resources to safely and effectively use agrochemicals.

Warsaw et al. (2021) emphasize that socio-economic disparities, such as low household income, limited access to quality inputs, and underdeveloped infrastructure, can reduce the ability of farmers to apply agrochemicals appropriately, increasing the risk of misuse and overexposure. These constraints also impact their willingness and capacity to adopt protective measures such as wearing personal protective equipment (PPE) or adhering to recommended pre-harvest intervals (PHIs).

Additionally, Belay Desye et al. (2024) conducted a systematic review and meta-analysis on pesticide safe use practices and acute health symptoms among farmers in developing countries. The study highlighted that farmers with good knowledge, positive attitudes, and education were more likely to adopt safe pesticide practices. However, the overall pesticide safe use practice was found to be 43.1%, with a prevalence of acute health symptoms at 30.36%.

Recent studies have shown that climate change has compounded these socio-economic barriers. Erratic rainfall, prolonged droughts, and increased pest pressure have led to

increased frequency and volume of agrochemical applications among resource-constrained farmers (Tudi et al., 2021). Without targeted training or financial support, these farmers often rely on past experience or peer advice rather than evidence-based recommendations potentially exacerbating health and environmental risks.

Furthermore, evidence suggests that economic vulnerability limits farmers' access to climate-resilient technologies or sustainable alternatives to chemical pest control (Ahumada et al., 2023). These include bio-pesticides, integrated pest management (IPM), or climate-smart irrigation, which are often cost-prohibitive for low-income farmers. This highlights the intersection between socio-economic status, climate adaptation, and agrochemical dependency.

To ensure food safety and farmer well-being, it is therefore essential to consider the socio-economic realities of smallholder farmers in policy formulation, capacity-building programs, and health interventions. Bridging the socio-economic gap through subsidies, cooperatives, financial inclusion, and decentralized training services will be crucial in promoting safer and more sustainable agrochemical use in Nakuru and similar regions.

Fresh produce farmers' knowledge on agrochemical use, studies on the knowledge and application of safe pesticide usage have been performed by many researchers in recent years. Conversely, some scholars indicate that the relationship between knowledge and practice is not always linear. Many studies indicate that merely acquiring knowledge might not be enough to change farmers' behavior about safe agrochemical use. The gap between knowledge and practice, particularly in agrochemical use, has been underlined by several scholars (Istriningsih, 2022). (European Union, 2021) states that the importance of using personal protection equipment (PPE) when handling pesticides is recognized by agricultural

workers. Nevertheless, not all of them wear safety equipment. A similar finding is described by Istriningsih et al. (2022). Poor agrochemical use practices, such as improper agrochemical waste management and neglect of the use of PPE, are common among farmers even when they have a good level of knowledge about the potential dangers of pesticides. (Glasgow, 2019) found that although farmers are aware of the adverse effects of pesticides on human health, they continue to neglect the use of PPE when applying them (Demi and Sicchia, 2021).

Fresh produce farmers with low education levels may struggle to adapt to modern farming practices and to correctly use agrochemicals. They may be unable to read and properly interpret the manufacturer's instructions on the proper use of agrochemicals. This can lead to overuse or inappropriate use of agrochemicals, posing serious acute and chronic health effects to themselves and consumers of the fresh produce (Violet, 2022).

The success of Fresh Produce Farming can be influenced by the local market conditions, including the availability of fresh produce and the seasonality of fresh produce cultivation and harvest. Due to these variables, farmers may be tempted to harvest and sell their fresh produce too early after application of agrochemicals, before the prescribed residual period is over, due to market dynamics. Since Fresh produce farmers would want to sell their produce before market prices fall, they may end up selling fresh produce with high residue levels of agrochemicals, posing a health risk to the consumers (Amare, Shiferaw, Adeyanju, Andam & Mariara, 2024). The products provided in these markets may not always be healthy for the consumers. Markets in low-income areas may have fewer booths and are less diverse compared to affluent areas, further increasing the risk of purchasing contaminated fresh produce (Warsaw et al., 2021).

2.2.2 Agrochemical use practices among fresh produce farmers

Agrochemicals remain an integral part of agricultural activities worldwide. They are often used to increase productivity and the quality of agricultural products. Pesticides are chemical compounds that are used to kill, repel, or control pests to protect plants before and after harvest. Pesticides work by causing damage to target organisms, but the mechanisms by which pesticides work are not specific to one species. The most widely used pesticides are organophosphate, carbamate, and pyrethroid insecticides (Anaduaka, 2023). The impact of pesticide exposure has become a globally developing environmental health problem. Increased vulnerability of farmers to pesticide poisoning is caused by a lack of knowledge about handling pesticides safely and appropriately. Agrochemical poisoning is one of the greatest problems in the world (Tudi, 2022).

According to WHO 2021, there are at least 18.2 per 100,000 agricultural workers who experience pesticide poisoning related to their work. Pesticides can enter the body through inhalation, dermal absorption, and ingestion during the preparation to application of pesticides (European Union, 2021). To reduce exposure to pesticides and protect health, farmers are encouraged to practice the use of PPE during the application of pesticides by the International Labor Organization (ILO) and the World Health Organization (WHO). Acute pesticide poisoning is generally underdiagnosed among farmers. This is often more common in developing countries (Joko, 2020).

The extensive and improper use of chemical inputs in agriculture has triggered various non-point source pollution and accelerated carbon emissions. This has been deteriorating the ecological environment, compounding negative climate change effects, and endangering public physical and mental health. Overuse of inorganic fertilizers during farming is linked

to the accumulation of contaminants in agricultural soils, including arsenic, cadmium, fluorine, lead, and mercury. Agrochemicals, including but not limited to pesticides, fungicides, and herbicides, are frequently found in stream water in agricultural areas (Hoque, 2022). Studies have found that many farmers use agrochemicals, but their knowledge of safety precautions is often limited, and they may fail to appreciate the health and environmental effects of agrochemicals. The major sources of agrochemical information for farmers include agricultural extension workers, agrochemical dealers, farmer colleagues, and the farmers' self-intuitions. Unsafe chemical use practices are high among farmers in Africa, posing serious health and environmental consequences (Demi and Sicchia, 2021).

In a study by Mengistie et al. (2017) on agrochemical use practices among vegetable farmers in Ethiopian Central Rift Valley, it was revealed that farmers apply agrochemicals in violation of the recommendations: they use unsafe storage facilities, ignore risks and safety instructions, and do not use protective devices when applying agrochemicals, and dispose containers unsafely. By applying a social practice approach, they showed that these agrochemical-handling practices are steered by the combination of the system of provision, the farmers' lifestyle, and the everyday context in which agrochemicals are being bought and used (Argüelles & March, 2023). Bringing in new actors such as environmental authorities, suppliers, NGOs, and private actors, as well as social and technological innovations, may contribute to changes in the actual performance of these agrochemical buying and using practices. They argue that a practice approach can represent a promising perspective to analyze agrochemical handling and use and to systematically identify ways to change these practices (Soriano et al., 2023).

Istriningsih et al. (2022) in a study done in Indonesia posit that the gap between knowledge and practice, particularly in pesticide usage, has been underlined by several scholars. They state that the importance of using personal protection equipment (PPE) when handling pesticides is recognized by agricultural workers. Nevertheless, not all of them wear safety equipment. A similar finding is described by Joko et al. (2020). Poor pesticide usage practices, such as a lack of disposal management and the use of PPE, are common among farmers even when they have a good level of knowledge about the potential dangers of pesticides. Glasgow (2019) found that although farmers are aware of the adverse effects of pesticides on human health, they continue to neglect the use of PPE when applying them.

The gap between Fresh produce farmers' knowledge and practice of good agricultural practices for safe pesticide usage in Nakuru County has not been adequately discussed in the scientific literature, and empirical evidence is lacking. According to Sapkota 2023, Kenya has prioritized aspects of agriculture, food, and land use as critical sectors for reducing emissions towards achieving Vision 2030's transformation to a low-carbon, climate-resilient development pathway. However, this ambitious targets still remain off-track, this study aims to provide information on the drivers of this mismatch. However, an analysis of the gap between knowledge and practice might not be sufficient to formulate recommendations for the improvement of implementation at the farmers' level. This study, therefore, employs an Importance-Performance Analysis (IPA) approach to enrich the discussion. IPA can generate insights into critical aspects that require more attention and identify potential resources that could be allocated effectively (Martilla and James, 1977). The IPA model can help to identify areas where resources should be allocated appropriately (McLeay, 2017).

This study aimed to investigate the gap between Fresh produce farmers' knowledge and practice of Agrochemical use to identify potential problems that should be considered and help formulate appropriate recommendations. The results of this study will contribute to the development of interventions to promote safe agrochemical use. This is expected to increase awareness of the phenomenon among Fresh produce farmers and reduce the potential environmental and health-related risks of inappropriate agrochemical use.

2.2.3 OHS Measures in Agrochemical Use by Fresh Produce Farmers

Agriculture is consistently identified as one of the most hazardous occupational sectors worldwide, a fact underscored by the International Labour Organization (ILO, 2024), which ranks it alongside construction and mining in terms of fatalities, injuries, and work-related illnesses. Farmers and farmworkers face heightened risks because of their frequent exposure to agrochemicals, particularly pesticides, which constitute a major occupational hazard. Although the health impacts of pesticide exposure have been widely studied, much of the focus has been on occupational exposure during mixing, loading, and spraying activities, with less attention paid to residential exposures that affect farm families. Farming, therefore, is recognized not only as a dangerous occupation for farmers and employees but also as one that poses risks to family members and rural communities more broadly (Shammi et al., 2020).

The scale of pesticide-related harm is sobering. Estimates from the Food and Agriculture Organization suggest that around three million people are poisoned by pesticides each year, with approximately 200,000 deaths attributed to such exposures. Developing countries bear a disproportionate share of this burden, accounting for an average of 220,000 fatalities annually despite comparatively lower overall chemical use (European Union, 2021). Case

studies highlight this disparity: in Sri Lanka, unsafe pesticide handling has led to roughly 1,000 deaths annually, while in Kenya, estimates point to 350,000 cases of pesticide poisoning each year (Marete et al., 2021). The health effects of pesticide exposure are not confined to acute poisonings. Chronic exposure has been linked to long-term illnesses, including respiratory complications, endocrine disruption, and cancers. Globally, rising rates of non-communicable diseases are increasingly associated not only with urban air pollution but also with pesticide exposure in rural farming landscapes (Glasgow, 2019; Ahmed et al., 2021).

In many developing countries, information on the health impacts of pesticides remains limited. Surveys frequently rely on farmer self-reporting, which introduces bias and often underestimates the real scale of harm. Furthermore, focusing solely on the volume of pesticides applied obscures the true nature of occupational risk. Even when overall application levels appear modest, farmers are at high risk because of unsafe practices such as frequent spraying, prolonged contact during application, and failure to use protective equipment. Studies across Africa have revealed alarmingly low levels of personal protective equipment (PPE) use, with fewer than a quarter of applicators consistently wearing gloves, boots, or masks. Practices such as reusing empty containers for household purposes or storing chemicals in kitchens and bedrooms are widespread, significantly compounding exposure risks (Elias et al., 2024).

Field research in Tanzania illustrates the extent of these unsafe practices: many smallholder farmers spray pesticides on hundreds of days each year, often wearing no protective clothing and engaging in risky behaviors such as eating or drinking while spraying. Comparable studies in Uganda and Ethiopia demonstrate that it is not merely the amount of pesticide

applied that determines risk, but rather the frequency of use, mixing practices, and length of exposure. These behavioral and situational factors have been shown to strongly correlate with adverse health outcomes, making it clear that agrochemical safety assessments must account for exposure intensity and safety practices, rather than focusing exclusively on aggregate quantities (Lekei et al., 2017; Kouadio et al., 2021; Negatu et al., 2022).

Fresh produce farmers, who often handle perishable crops requiring multiple pesticide applications to meet market standards, are particularly vulnerable. Occupational health and safety (OHS) measures for this group therefore require a comprehensive approach, encompassing both knowledge-based and practical interventions. Education and awareness campaigns are a critical starting point, equipping farmers with an understanding of the dangers of agrochemicals and safe practices for handling, storage, and disposal. The consistent recommendation is for farmers to use PPE such as chemical-proof goggles, rubber gloves, boots, and heavy-duty long-sleeved shirts, which can reduce exposure during pesticide handling (Demi & Sicchia, 2021). However, the mere availability of PPE is insufficient. Farmers must be trained in its correct use and motivated to overcome barriers such as discomfort in hot climates or the perception that protective gear slows down their work.

In addition to PPE, first aid preparedness is a fundamental OHS measure. Ensuring access to clean water on farms is essential, as it provides the means to quickly flush out chemicals in the event of accidental contact. Yet in many rural areas, water scarcity undermines this basic precaution, leaving farmers without the ability to respond effectively to emergencies. Similarly, proper chemical storage is often neglected. Best practices call for pesticides to be kept in locked storage cabinets or separate sheds away from food storage and handling areas,

but in reality many households store chemicals in living spaces, increasing risks of accidental ingestion by children. Safe application practices, including adherence to recommended dosages, avoiding spraying during windy conditions, and observing pre-harvest intervals, are equally critical but not consistently observed.

The challenges of unsafe pesticide use are not confined to Africa. Evidence from Bangladesh illustrates the global dimension of the problem: studies there found that nearly half of farmers overused pesticides, only four percent had received formal training, and the overwhelming majority 87 percent used little or no protective gear (Hoque et al., 2022). Comparable findings from Iran reveal that almost half of farmers engaged in unsafe PPE practices, with more than 40 percent displaying unsafe pesticide behaviors overall (Ataei, 2021). These cross-country parallels suggest that the drivers of unsafe pesticide use low training levels, economic pressures, weak regulation, and limited awareness are systemic and not unique to one region.

At the same time, the globalization of food trade adds another layer of complexity. Developing countries seeking access to high-value export markets must comply with stringent residue limits set by international buyers, especially in the European Union. Failure to meet these standards can result in rejected shipments, threatening farmer livelihoods and national economies (FAO/WHO, 2008; Marete et al., 2020). Compliance with international residue standards therefore serves as both a health and economic imperative, further underscoring the importance of robust OHS measures in agrochemical use.

The broader policy context highlights the need for more integrated approaches. Too often, agriculture and health policies have been pursued in isolation, despite clear evidence of their intersection. Agricultural productivity gains achieved through pesticide use frequently carry

hidden health and environmental costs, while inadequate health systems struggle to manage the resulting disease burden (Zinyemba et al., 2021). Strengthening occupational health frameworks within agriculture must therefore be seen not only as a matter of farmer safety but also as a key dimension of sustainable rural development.

Despite growing recognition of the risks, the adoption of OHS measures remains low. Farmers' perceptions of risk play an important role in this gap. Many are aware of the dangers of pesticides in an abstract sense but underestimate their personal vulnerability, especially when symptoms of chronic exposure are not immediately visible. Risk perception studies suggest that interventions that address farmers' beliefs and attitudes are as important as those that provide technical solutions. A farmer who does not perceive risk is unlikely to invest time or money in protective equipment, even when it is available (Shammi et al., 2020).

Occupational health and safety in agrochemical use among fresh produce farmers is shaped by a complex interplay of behavioral, institutional, and economic factors. While the volume of agrochemicals used in African agriculture may appear modest on a global scale, unsafe handling practices and weak safety cultures ensure that exposure risks remain disproportionately high. Effective interventions must therefore go beyond promoting protective gear or issuing regulations. They must tackle the structural barriers of poverty, literacy, and weak extension services, while also reshaping risk perceptions among farmers and farmworkers. As the evidence makes clear, safeguarding the health of those who grow fresh produce requires a holistic commitment to education, training, regulation, and behavioral change, grounded in the realities of smallholder farming systems.

2.2.4 Climate change and agrochemical use

Climate change is causing global shifts in temperature, precipitation patterns, as well as an increase in unpredictable, extreme weather patterns. It is already known that climate change has a significant impact on global crop yields and will continue to do so into the future but climate change is also directly and indirectly influencing the distribution and severity of crop pests, i.e. any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products across the globe which is further affecting crop yields. In many areas of the world, new invasive species are also appearing, facilitated by climate change. Without effective monitoring and management systems in place, these invasive species have the potential to also become important pests in these new areas (Heeb et al., 2019).

Although some climate change effects can be beneficial, evidence suggests that, overall, pest problems are likely to become more unpredictable and larger in magnitude. However, predicting the effects of climate change on pests is not easy due to the complicated interacting influences of increasing atmospheric CO₂ concentration, changing climatic regimes, and altered frequency/intensity of extreme weather events. Projections are further challenged by the fact that climate change can also exert its effects on pests indirectly, for example, through the differing responses of host crops and natural enemies of pests. For example, differences in the thermal preferences of crop pests and their natural enemies can lead to a loss of synchronization between the two and an increased risk of host outbreaks (EEA, 2023).

Other indirect pest responses result from changes in the efficacy of pest control strategies including biological control and synthetic pesticides (Heeb et al., 2019) as well as changes

in land use and crop management practices, which can often have a greater effect on pest pressure than the direct effects of climate change alone.

If changing climatic factors are examined in isolation, the following impacts on pests are a few examples of the direct and indirect effects that can transpire, temperature increases even if these are small can increase the severity of diseases caused by pathogens of crops such as oilseed rape, cereals and potatoes. Such increasing pest populations and pressures can lead to more numerous applications in volumes and frequencies of pesticides and fungicides, as illustrated in the USA, where increasing temperatures leading to larger insect populations in southern regions have resulted in greater insecticide use compared to cooler, higher latitude regions (Glasgow, 2019).

A specific example of this is where pesticide sprays for the control of Lepidoptera insect pests in sweet corn are much higher in Florida (15–32 applications per year) compared with Delaware (4–8 applications per year) and New York (0–5 applications per year). Such increases in pesticide applications can exert significant negative effects on environmental and human health (Larsen et al. 2017).

Temperature increases can also reduce the effectiveness of certain pesticides. For example, the toxicities of two pyrethroids (lambda-cyhalothrin and bifenthrin) and a spinosyn (spinosad) to *Ostrinia nubilalis* (Hübner) (Lepidoptera: Crambidae) were found to decrease as post-exposure temperature increased (Glasgow, 2019). Even small changes in thermal conditions have also been found to influence the effectiveness of parasitoids in controlling pest species as well as the expression of defensive traits used by insect pests against their larval parasitoids (Moradhaseli et al., 2019a; Iltis et al., 2018). Another study in grassland systems in New Zealand demonstrated that although higher temperatures positively affected

biomass production, the absolute and relative biomass of herbivores increased disproportionately, and parasitoids did not show any significant response to the changing temperature. The study also concluded that assessing the overall effects of temperature at multiple trophic levels remains difficult; however, a reduction in top-down regulation can coincide with an increase in herbivory, which is likely to have further impacts on other ecosystem processes (Barnett et al., 2021; Barnett et al., 2021).

Changing precipitation, excessive or insufficient, can have substantial effects on crop–pest interactions, because many species are favoured by warm and humid conditions, including plant pathogens, which are highly responsive to humidity and rainfall. Also, crops suffering from water stress are more vulnerable to damage by pests. Outbreaks of the desert locust are exacerbated by changes in precipitation events, as exemplified by their invasion of more than 10 countries in western, eastern, and northern Africa following heavier-than-normal rains; this resulted in significant crop losses and food shortages (Skendžić et al., 2021).

Locust outbreaks are only going to become more common with the increase in frequency and severity of precipitation events predicted in the future. Increasing CO₂ levels can directly lead to enhanced crop yields, but any gains in yield may be offset partly or entirely by losses caused by insects, plant pathogens, and weeds. For example, cabbage loopers, *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae) in North America are found to consume a greater volume of leaves under increased CO₂ levels, which is thought to be a result of the reduced nitrogen levels found in cabbage leaves growing under these conditions (Omotoso & Omotayo, 2024).

Extreme weather events can influence the interactions between crops, pests and diseases unpredictably, potentially failing some crop protection strategies and subsequent reductions

in yields (Heeb et al., 2019). For example, a study by Tabebordbar et al. (2022) revealed that extremely dry and hot weather reduced the populations of the egg parasitoid *Trichogramma evanescens* Westwood so much so that there was no record of successful parasitism of European corn borer eggs that year. Strong air currents in storms can also transport disease agents such as fungal spores or insects from overwintering sites to areas where they can cause further problems. Thus, winds associated with Hurricane Wilma spread citrus canker widely in Florida, destroying 170,000 acres of commercially grown fruit trees. Ecosystems that have been disturbed due to extreme climatic events are automatically more susceptible and vulnerable to invasions of alien and native species (Heeb et al., 2019). Although climate change-induced pest impacts are variable and subject to numerous interacting factors, changing climatic environments and the resulting changes in land use are anticipated to cause an overall global pattern of increasing latitudinal and altitudinal range of crop pests (Skendži'c et al., 2021).

Increase in pests, coupled with erratic weather conditions, has led to an increase in volume and frequency of use of agrochemicals to increase crop yield and enhance food security. As a result, bioaccumulation of these chemicals in the environment, soil, water bodies, and fresh produce has increased over time, further endangering the health of the consumers. In Nakuru County, fish from Lake Nakuru have been condemned as unfit for human consumption due to high residue levels of endosulfan that were above the European Union standard, whereas the target hazard quotient of heptachlor epoxide was above 1, therefore making them unsafe for human consumption. The study results indicated that most organochlorine pesticides, though banned in Kenya, are still detected in the environment, posing potential long-term health hazards to humans (Nantongo et al., 2023).

Up to forty percent of the world's food supply is already being lost to pests and as climate continues to change and further intensifies damage and/or creates new pest threats, it is more important than ever that farmers across the globe start adapting their farm and landscape management practices to protect food production and their livelihoods. Action should not be restricted to the farm level only, though (World Health Organization & Food and Agriculture Organization of the United Nations, 2024). The impact of enhanced pest pressure and crop losses extends beyond the farm to local, national, and international food security, as well as environmental, economic, and social sustainability. Immediate action is therefore needed on multiple levels and geographical scales, particularly as pest-related yield losses due to climate change and increased use of agrochemicals have so far gained little attention compared to human or animal health affected by climate change (FAO, 2020).

2.2.5 Health and safety interventions adopted by fresh produce farmers

Agrochemicals remain the dominant method of pest control in agriculture worldwide, even though their application does not always result in reduced crop losses. In Sub-Saharan Africa, smallholder farmers engaged in fresh produce farming tend to rely heavily on pesticides, a pattern shaped by systemic challenges such as weak extension services, limited access to alternative methods, and the economic pressures of producing marketable crops that meet cosmetic quality standards. This dependence has raised serious concerns about environmental and human health risks, with evidence showing that unsustainable pesticide use disrupts natural pest control mechanisms, contaminates ecosystems, and exposes farmers and consumers to both acute and chronic health effects (Magauzi et al., 2021; Rösli et al., 2022).

In response, a range of health and safety interventions has been proposed and, in some contexts, adopted to mitigate the risks associated with pesticide use. At the regulatory level, governments and international agencies have attempted to restrict or phase out highly hazardous pesticides, often aligning with international conventions such as the Rotterdam and Stockholm Conventions. For example, Kenya's Pest Control Products Board has periodically reviewed its registration system to remove harmful substances from circulation (PCPB, 2022).

Yet, enforcement remains inconsistent and farmers sometimes continue to access banned products through informal markets, raising doubts about the effectiveness of such interventions when alternatives are not easily available or affordable. Similarly, regulations that require farmers to wear protective gear during spraying are important in principle, but in practice many smallholders struggle to comply because protective equipment is either too costly, poorly suited to hot climates, or simply unavailable in rural markets. Technological solutions, particularly the use of personal protective equipment and safer pesticide application devices, have been widely promoted as immediate ways to reduce exposure. Gloves, respirators, boots, and protective clothing can greatly minimize contact with toxic chemicals during mixing and spraying. However, adoption rates remain low across the region because of issues related to affordability, comfort, and awareness. Efforts to design lightweight, low-cost protective gear better suited to tropical conditions are ongoing, with some donor-funded projects subsidizing equipment for farmer groups. Advances in sprayer design also provide some promise, with improved nozzles and motorized devices that reduce pesticide drift, while experimental approaches such as drone spraying have begun to attract

attention in certain East African farming systems, even though the costs remain prohibitive for most smallholders (Magauzi et al., 2021).

Knowledge-based interventions represent another key strategy in addressing unsafe agrochemical practices. Studies consistently show that many farmers lack training on pesticide handling, storage, and disposal, often reusing containers for household purposes or discarding leftover chemicals in open fields. Farmer field schools and extension training programs have been shown to improve awareness and reduce risky behavior, particularly when they emphasize practical demonstrations such as correct dosage measurement, safe storage, and environmentally sound disposal. Yet, extension services in many parts of Sub-Saharan Africa remain severely underfunded, which limits the scale and consistency of these interventions. Even when training is delivered, changing long-standing behaviors is not straightforward, as many farmers view pesticide use as a necessary safeguard against crop losses. Programs that combine technical training with behavior change communication and peer-to-peer learning tend to show more durable results because they shift perceptions as well as practices (Röösli et al., 2022).

Ecological interventions, particularly Integrated Pest Management (IPM) and Climate-Smart Pest Management (CSPM), have attracted considerable attention as alternatives that reduce dependence on chemicals while enhancing resilience to climate variability. IPM encourages farmers to use biological, cultural, and mechanical control methods first, resorting to pesticides only when absolutely necessary. Research shows that IPM can cut pesticide use by as much as half without reducing yields. CSPM extends this concept by integrating pest management into the broader framework of climate-smart agriculture. It emphasizes adaptation to climate-driven shifts in pest dynamics by promoting practices such as crop

diversification, trap cropping, biopesticide use, and pest-resistant varieties (Heeb et al., 2019; Bouri et al., 2023). Both approaches highlight the dual goals of safeguarding farmer health while ensuring long-term sustainability. Agroecological farming goes further still by challenging the very premise of chemical dependence. Through intercropping, conservation agriculture, crop rotations, and soil organic amendments, agroecology seeks to restore ecological balance while enhancing system resilience, and it has been increasingly advocated as a solution to both health risks and climate change pressures (Rose, 2023).

Another dimension of intervention is health monitoring and surveillance. Despite the widespread use of agrochemicals, few countries in SSA have robust health monitoring systems that routinely test and track pesticide-related illnesses among farmers. Integrating pesticide exposure screening into rural health services could help identify risks earlier, while community-based surveillance initiatives, where trained local volunteers monitor and report pesticide-related health issues, have shown promise in improving both awareness and policy responsiveness (Röösli et al., 2022).

These systems not only generate data for research and policy but also empower communities to take a more active role in safeguarding their health. While these interventions collectively represent a diverse set of strategies, significant challenges remain. Cost continues to limit the adoption of protective technologies and ecological practices, while institutional weaknesses undermine training programs and regulatory enforcement. Policy frameworks often lack coherence, with health, agriculture, and environmental sectors working in silos, which reduces the impact of interventions. Market forces also play a critical role, as consumers and exporters demand blemish-free produce, thereby incentivizing chemical use regardless of health or ecological costs.

In conclusion, the literature shows that health and safety interventions in fresh produce farming must be multifaceted, integrating regulatory oversight, affordable technology, farmer training, and ecological approaches. While agrochemicals continue to dominate farming systems, approaches such as CSPM and agroecology demonstrate that it is possible to balance productivity with sustainability and health protection. For this balance to be realized, interventions must be context-specific, adequately resourced, and designed with farmer participation at their core. By focusing on both the technical and social dimensions of pest management, it is possible to create systems that not only protect human health and the environment but also ensure resilient livelihoods in the face of climate change.

2.3 Theories Underpinning the Study

Despite the known adverse health and environmental effects of the toxic agrochemicals in the market, farmers continue to use them to their detriment and negatively impact public health. The following theories are discussed briefly and try to explain this phenomenon. A better understanding of the factors that influence farmers' intentions is critical to enhancing the safe use of agrochemicals. Farmers' intentions can be assessed by behavioral models that are used in the field of healthcare (Haakenstad et al., 2022).

This study proposes to employ the Social Cognitive Theory (SCT), predicting how social and cognitive factors influence health behavior, the health belief model (HBM) to address farmers' intention and the Theory of Planned Behavior (TPB) to offer a comprehensive framework for explaining human behavior in contexts where choices are influenced by personal attitudes, social expectations, and perceived control over resources. The study aims to identify the impact of the constructs of SCT, HBM and TPB (perceived susceptibility, health motivation, perceived severity, perceived benefits, perceived self-efficacy, perceived

barriers, choices, personal attitudes, social expectations, perceived control over resources and cues to action) on farmer attitudes and practices in the use of agrochemicals. The results of the study can be used by planners and public health practitioners in developing appropriate interventions to mitigate the negative health effects resulting from agrochemical use among Fresh produce farmers in Nakuru County and other regions.

2.3.1 The social cognitive theory (SCT)

The Social Cognitive Theory (SCT) was proposed by Albert Bandura (1986) to predict how social and cognitive factors influence health behavior (Luszczynska & Schwarzer, 2015). In principle, Bandura postulated that observations of the social norms had a significant impact on learning and that learning, ultimately, influenced the health behaviors that were practiced by individuals. The SCT is underscored by a three-dimensional relationship among cognitive, environmental, and supportive behavior factors. These three factors were postulated as determinants of health promotion and disease prevention (Martin & Guerrero, 2020), which makes the SCT an appropriate theory to support the investigation of the relationship between individual characteristics of farmers, agriculture practices/behaviors, and potential health outcomes.

The relationship between the personal cognitive factors, socioeconomic or environmental factors, and supportive behavior is referred to as reciprocal determinism, emphasizing the interplay between the components of the theory and the effect on health outcome (Martin & Guerrero, 2020). In relation to cognitive influences on behavior, the constructs of the SCT are self-efficacy that is the belief that one can perform a behavior that will lead to a particular outcome, outcome expectation including assessment of the consequences of an

action, and knowledge such as information about how to act and the risks and benefits (Glasgow, 2019).

In relation to environmental influences on health, the constructs of the theory include observational learning that is learning behaviors through cultural norms in a society, normative belief which is belief about the normalcy and acceptability of a cultural norms, social support including support that is provided through interaction with peers, colleagues, family and other members of the society, and barriers and opportunities that are external factors that facilitate or hinder a behavior (Martin & Guerrero, 2020). Regarding supporting behaviors, the constructs of the SCT are behavioral skills, personal capacity to perform a behavior, intentions including considerations about adding or modifying behaviors, and reinforcement and punishment that helps in providing or removing incentives for acting.

The knowledge generated will help in understanding fresh produce farmers' attitudes toward agrochemical use and provide constructive information for designing intervention measures to mitigate the negative climate change and health impacts of agrochemical use in Nakuru County. The Social Cognitive Theory (SCT) is the most appropriate theory to be applied in this study since it covers the variables under consideration. It is therefore chosen as the theory that shall be used for the study.

Social Cognitive Theory (SCT) offers a powerful, process-oriented framework for understanding how fresh-produce farmers form beliefs, make decisions, and enact practices relevant to both climate change adaptation and agrochemical including pesticide and fertilizer use. SCT, developed and elaborated by Bandura, emphasizes reciprocal determinism among personal factors beliefs, knowledge, and self-efficacy, behavioral patterns practices such as pesticide application, and environmental influences social norms,

institutional supports, climatic stressors. Central SCT constructs self-efficacy, outcome expectations, observational learning modeling, and reciprocal determinism map directly onto the cognitive and social drivers that shape farmer decisions about agrochemical reliance and climate-sensitive practices (Bandura, 1986; Bandura, 2001).

Self-efficacy farmers' belief in their capacity to implement specific practices is arguably the single most consequential SCT construct for agrochemical stewardship and climate adaptation. High self-efficacy increases the likelihood that a farmer will try and persist with alternative pest-management practices (e.g., integrated pest management, biocontrols, reduced-risk pesticides, or cultural controls) when confronted by pest pressure exacerbated by climate change for example altered pest phenology. Conversely, low self-efficacy channels farmers towards familiar strategies often increased agrochemical application as a risk-minimizing response when they doubt their ability to control pests using non-chemical methods (Bandura, 2001). Empirical work in agriculture repeatedly finds that training, demonstration plots, and incremental skill development raise self-efficacy and thereby increase adoption of both adaptation and safer pesticide practices.

Outcome expectations and perceived risks mediate how farmers translate climate observations into action. Farmers who believe that continued agrochemical intensification will maintain yields despite climate variability may prioritize chemical solutions even when they acknowledge environmental or health risks. By contrast, when farmers perceive that alternative practices will yield equivalent or superior agronomic and economic outcomes especially under changing climatic conditions, they are more likely to shift behavior. Interventions that alter outcome expectancies for example, through field demonstrations

showing that soil health practices sustain yields during drought thereby operate through SCT mechanisms to change behavior (Sawitri, 2015; Boon-Falleur et al., 2022).

Observational learning and social modeling are central to farmer decision-making in many agrarian contexts. Because many farming practices are complex and context-sensitive, farmers often learn by watching trusted peers, extension agents, or lead farmers implement techniques. Observability of results for example seeing neighbours achieve similar or better yields with reduced pesticide regimes creates vicarious experiences that augment collective efficacy and shift normative expectations about acceptable practice. Where strong endorsement exists from locally reputable farmers or institutions, behaviour change such as adoption of integrated pest management (IPM) or climate-smart agronomy can diffuse rapidly via social networks (Han, 2022).

The notion of SCT reciprocal determinism underscores the bidirectional links between climate stressors and agrochemical use. Climate change such as warmer temperatures, altered rainfall can increase pest pressure, leading farmers to intensify pesticide use; intensified chemical use, in turn, can degrade agroecosystem resilience soil biota, natural pest populations, creating a feedback loop that makes farmers more dependent on chemicals over time. SCT points to multiple intervention points personal knowledge and efficacy, social norms and networks, and structural market access, policy and extension support to break maladaptive feedback loops. Empirical studies of farmer adaptation find that access to institutional supports training, subsidies for alternatives, markets for sustainably grown produce moderates this feedback by changing environmental affordances that shape behaviour (Bandura, 2001; Han, 2022).

Applying SCT to design interventions targeted training programs that combine mastery experiences hands-on practice, vicarious experiences including demonstration plots, verbal persuasion from trusted extension agents, and reduction of physiological as well as emotional barriers by clarifying safety and reducing fear of yield loss are predicted to increase adoption of low-chemical, climate-smart practices. Randomized and quasi-experimental field evidence in recent literature supports these pathways: farmers receiving participatory training plus ongoing technical assistance show stronger increases in self-efficacy and greater uptake of adaptive practices than those receiving information alone (Erfanian et al., 2024; Song et al., 2025). Such programs that target multiple SCT mechanisms skill building, normative change, and enabling resources are the most robust route to durable behaviour change.

Barriers and constraints exist, SCT does not imply that cognition alone is sufficient. Resource constraints such as capital, access to inputs, credit, market incentives including buyers demanding cosmetically perfect produce, and institutional failures such as weak regulation of highly hazardous pesticides, lack of timely extension create structural limits that constrain agency. SCT strength is to locate these constraints in the environment node of reciprocal determinism, they are legitimate explanations for inaction and simultaneously targetable through policy for example subsidies for biocontrol inputs, market linkages for sustainably certified produce that alter the environmental context to enable individual and collective agency (Bandura, 1986; Dentzman et al., 2025).

Measurement and evaluation considerations, applying SCT in agricultural research requires careful measurement of self-efficacy at a task-specific level, outcome expectancies including economic and health, social norms, and structural affordances. Mixed-methods designs

combining quantitative scales of self-efficacy and observed behavioural outcomes for example pesticide quantities applied with qualitative social-network analysis yield the richest understanding of how SCT constructs operate in situ. Recent specialty crop research demonstrates that including measures of social modelling including who farmers look up to and collective efficacy such as community coordination for practices like area wide pest management improves predictive power beyond individual psychological variables alone (Han, 2022; Sattler, 2023).

Health and cognitive feedback form an important, under-appreciated SCT loop, evidence that pesticide exposure can impair cognition complicates the assumption that farmers can continuously and rationally process risks and training messages. If cognitive function is degraded by chronic exposure, interventions must account for reduced capacity to learn or change practices strengthening the case for structural protections, regulation, and safer alternatives alongside capacity building (Finhler et al., 2023). SCT accommodates this by recognizing physiological states as personal factors that influence both perceived efficacy and behaviour.

Policy and programmatic implications, an SCT informed strategy to reduce harmful agrochemical dependence while improving climate resilience should combine participatory, hands-on extension that builds self-efficacy and models alternatives, social-network-based dissemination that leverages respected local models, market and regulatory changes that change outcome expectations for example premiums for low-residue produce, restrictions on the most hazardous compounds and investments in enabling resources including credit, input supply of biologics, and weather advisories. Evaluation should measure both intermediate cognitive outcomes self-efficacy, normative change and distal behaviors pesticide use

metrics, adoption of agroecological practices to trace causal pathways implied by SCT. Demonstration projects that embed SCT mechanisms have shown promising results in increasing adaptive actions among resource-constrained farmers.

In conclusion SCT provides a nuanced, action oriented explanatory model for the intertwined problems of climate change and agrochemical dependence among fresh produce farmers. By specifying how beliefs, social contexts, and environmental structures interact to produce behaviour, SCT points to multi-levelled interventions skill building, social modelling, market and policy change that are both theoretically coherent and empirically supported. Integrating SCT principles into agricultural extension, climate adaptation programming, and pesticide governance creates a principled pathway to reduce hazardous agrochemical reliance while strengthening smallholder resilience to climate change.

The Social Cognitive Theory (SCT) is pertinent to this study as it underscores the reciprocal interactions between individual behavior, social influences, and environmental conditions. In the context of fresh produce farming in Nakuru County, climate change has intensified environmental stressors such as erratic rainfall, recurrent droughts, and pest outbreaks, which in turn drive farmers toward increased agrochemical use. SCT provides a lens to examine how these external pressures interact with farmers' self-efficacy, observational learning, and outcome expectations, shaping their decisions regarding agrochemical application and protective practices. Moreover, community norms and peer behaviors strongly influence the adoption of agrochemical practices, making SCT valuable for understanding the socio-environmental dynamics that underlie climate-related adaptations in farming.

2.3.2 The Health Belief Model (HBM)

The health belief model (HBM) was first developed by a group of social psychologists of the US General Health Service in the 1950s. HBM is a comprehensive model mostly used to prevent diseases. The model is based on individuals' motivation to perform a behavior. The theory emphasizes how an individual's perception creates motivation and movement and makes him/her perform a behavior. Overall, HBM focuses on the changes in beliefs, which in turn lead to changes in behavior (Ataei et al., 2021). The Health Belief Model states that people's beliefs influence their health-related actions or behaviors. According to the Health Belief Model, readiness to take action is based on individual's perception on the following beliefs or conditions: I am susceptible to this health risk or problem, The threat to my health is serious, I perceive that the benefits of the recommended action outweigh the barriers or costs, I am confident I can act successfully, Cues to action are present to remind me to take action (Washburn, 2020).

Since the green revolution, agrochemicals have been an essential tool to increase crop production (Palis et al., 2002; Hashemi et al., 2009; Rajabi and Karjo Kasmaie, 2012; Ataei et al., 2018; Izadi et al., 2019). As a result, the use of agrochemicals has increased rapidly so that it has turned into a necessary component of farming systems throughout the world. The residuals of these agrochemicals in drinking water or foodstuffs menace human health. Accordingly, the world is faced with challenges like increased levels of diseases, degradation of natural ecosystems, and a plethora of environmental ramifications.

There is extensive evidence that farmers do not adopt protective behaviors when using agrochemicals (Ataei et al., 2021). It is therefore necessary to assess how farmers use agrochemicals and what factors influence their behavioral intention to use agrochemicals.

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According to the HBM, two main types of beliefs influence people to make adoption decisions: beliefs related to readiness to take action and beliefs related to modifying factors that facilitate or inhibit action (Washburn, 2020). In other words, the basic components of the HBM depend primarily on two variables: the value of a goal to an individual and the individual's appraisal of the likelihood of an action achieving that goal. This theory holds that a decision is more likely to be taken about health behaviors when individuals want to stay healthy and believe that these behaviors can improve and promote their health (Moradhaseli et al., 2019).

HBM focuses on two dimensions of health behavior: perceived risk and behavioral assessment. In addition to these two dimensions, cues to action and self-efficacy have also been added to the constructs of this model. Self-efficacy refers to an individual's readiness to address health issues. Indeed, self-efficacy refers to an individual's perception of the ease or difficulty of performing an intended behavior or the extent to which an individual has conscious control over a behavior (Ataei et al., 2021). In Kenya, studies that have focused on the aspects of SCT, HBM and TPB with respect to farmers' protective behaviors in using agrochemicals are scarce. This study, therefore, will seek to assess these aspects and help fill the existing knowledge gap (Ahmadipour, 2024).

Understanding why farmers adopt, modify, or reject protective practices when handling agrochemicals is essential for designing interventions that reduce health and environmental

harms. The Health Belief Model (HBM), originally developed to explain uptake of preventive health services provides a useful theoretical lens for explaining farmers' pesticide-related behaviours and for designing behaviour-change interventions that account for climate change pressures on pest dynamics and agrochemical reliance (Rosenstock, 1966; Becker, 1974). This discussion synthesises HBM theory and evidence from agricultural health research to explain how climate change influences farmers' perceived risks and benefits around pesticide and fertiliser use, and how interventions grounded in HBM can promote safer agrochemical practices among fresh-produce farmers.

The Health Belief Model: core constructs, the HBM proposes that an individual's likelihood of taking a health-protective action is determined primarily by six constructs: perceived susceptibility, perceived severity, perceived benefits, perceived barriers, self-efficacy, and cues to action (Champion & Skinner, 2008; StatPearls, 2024). In agricultural settings these map onto, farmer belief about their vulnerability to pesticide poisoning or climate-exacerbated disease susceptibility, beliefs about the seriousness of such outcomes severity, beliefs that particular protective measures such as PPE, integrated pest management (IPM), altered timing of application will reduce those risks benefits, perceived costs, time, effort, and social constraints that impede adoption barriers, confidence in performing protective behaviours self-efficacy and triggers such as extension messages, visible crop damage, community events, or regulatory enforcement that prompt action (Champion & Skinner, 2008; Carpenter, 2010).

Climate change has reshaped HBM constructs for fresh-produce farmers by, altering pest populations, disease pressures, and the predictability of growing seasons, which in turn change farmers perceptions and behaviours concerning agrochemical use. Perceived

susceptibility and severity. Warmer temperatures, altered rainfall patterns, and expanded ranges for pests and pathogens can increase the frequency and unpredictability of outbreaks in fresh produce systems. Farmers experiencing more frequent crop loss may perceive higher susceptibility to pest damage and higher severity of economic loss, which can increase willingness to use agrochemicals as a rapid-control strategy (StatPearls, 2024). However, perceived personal health susceptibility to pesticide exposure may remain low if chronic effects are invisible, delaying protective action (Rosenstock, 1966).

Perceived benefits, when climate-induced pest pressure is acute, farmers may attribute clear and immediate benefits to chemical control including rapid knockdown and yield protection. This perceived effectiveness often outweighs perceived long-term health risks, particularly when alternative non-chemical strategies are seen as slower, less reliable, or more technically complex (Champion & Skinner, 2008). Perceived barriers, climate variability can increase labour scarcity, input costs, and time pressure during critical windows. These stresses raise the perceived barriers to adopting safer practices such as proper PPE use, calibrated application, or IPM tactics that require monitoring and timing since because such behaviours are time-consuming or require resources (Ahmadipour et al., 2024; Abdollahzadeh et al., 2021).

Self-efficacy repeated and unpredictable pest events can erode farmer confidence in non-chemical methods if those methods have not previously provided reliable control under changed climatic conditions. Conversely, training and participatory trials can increase self-efficacy for IPM and safe-handling practices (Ahmadipour et al., 2024). Cues to action, climate events themselves for example heavy rains followed by fungal outbreaks serve as powerful cues that may trigger immediate pesticide application. Extension services, media

reports about pesticide poisonings, or neighbour practices also operate as cues; the source and credibility of cues influence whether the subsequent action prioritises health or short-term crop protection (Carpenter, 2010).

Multiple empirical studies have applied HBM to understand pesticide behaviours. Research indicates that perceived barriers and low self-efficacy are consistently associated with unsafe agrochemical practices, while targeted education that increases perceived severity, clarifies benefits of safer practices, reduces barriers through subsidised PPE, and builds self-efficacy can improve safety behaviour (Abotaleb et al., 2016; Ahmadipour et al., 2024). Studies predicting PPE use and intentions to adopt protective measures have shown the HBM constructs explain a meaningful proportion of variance in farmer protective intentions and actions (Abdollahzadeh et al., 2021; Abotaleb et al., 2016).

Mechanisms linking HBM, climate change interrelates with HBM constructs through several pathways: Temporal immediacy vs. delayed risks, Farmers under immediate economic pressure from climate-driven crop loss value short-term benefits such as rapid chemical control more highly than the delayed, often intangible health consequences of exposure. This is a classic temporal discounting issue that HBM helps to conceptualise this relationship (Champion & Skinner, 2008). Risk trade-offs and adaptive capacity, where adaptation resources are limited, perceived barriers including cost, access to IPM inputs, availability of labour may increase even when susceptibility and severity of health harms are recognised, high barriers reduce adoption of safer options (Ahmadipour et al., 2024).

Social norms and observational learning, in contexts where neighbours and supply-chain actors normalise intensive agrochemical use to maintain quality standards for fresh produce markets, cues to action and perceived benefits align toward chemical reliance, weakening

individual-level health motives (Carpenter, 2010). Interventions to reduce harmful agrochemical exposure in the context of climate change should intentionally target HBM constructs. This will increase accurate perceived susceptibility and severity (risk communication). Use locally relevant, evidence-based messages that balance crop-protection needs with personal and community health risks. Messages are most effective when they link observable short-term harms, for example acute poisoning symptoms, reduced worker productivity to unsafe handling behaviours, reducing the psychological distance of health outcomes (Champion & Skinner, 2008).

Emphasis on perceived benefits of safer alternatives. Demonstration plots and participatory trials showing how IPM, biocontrol, or decision-support systems can work under climate-altered conditions increase beliefs in effectiveness. Framing benefits in economic as well as health terms highlighting reduced input costs, access to premium markets for low-residue produce helps align incentives. Reduce perceived barriers, subsidies or group procurement of PPE, availability of calibrated knapsacks, mobile advisory services on pest alerts, and simplified decision algorithms reduce real and perceived costs of safe practice (Ahmadipour et al., 2024).

Enhance self-efficacy, skills-based training, peer-learning, and on farm coaching increase confidence in using PPE correctly, interpreting pest thresholds, and implementing IPM at times when climatic variability makes pests less predictable (Abdollahzadeh et al., 2021).

Create effective cues to action. Timely pest-forecast SMS alerts, market-based certification requirements, and visible community commitments (pledges, public demonstrations) act as reminders and normative signals that can prompt safer decision-making even under climatic stress. HBM-informed interventions can be most effective when embedded in supportive

policies and supply-chain incentives. Regulatory frameworks that limit highly hazardous pesticides, strengthen worker protection laws, and create market incentives for low-residue produce reconfigure perceived benefits and barriers at the system level. Climate adaptation policies that provide access to resilient seed varieties, weather insurance, and extension capacity reduce the acute economic pressures that push farmers toward high-intensity chemical strategies (Carpenter, 2010; StatPearls, 2024).

While HBM explains individual cognitive determinants of behaviour, it is less suited to capturing structural, cultural, and economic drivers that operate beyond individual perception. Mixed-method and multilevel studies that combine HBM constructs with analyses of market forces, gender relations, and institutional capacity are needed to design interventions fit for climate-stressed fresh-produce systems. Longitudinal studies would clarify whether changes in perceived susceptibility due to climate events translate into sustained safer practices (Carpenter, 2010).

The Health Belief Model offers a practical, evidence-based framework for understanding and changing farmers' agrochemical behaviours in the face of climate change. By mapping climate-driven changes in pest pressure and economic risk onto HBM constructs, practitioners can design interventions that increase perceived relevance of health risks, demonstrate benefits of safer practices, reduce barriers, build self-efficacy, and provide timely cues to action. Embedding these efforts within supportive policies and market incentives will be essential for sustainable reduction of agrochemical harms in fresh-produce sectors under a changing climate.

The Health Belief Model (HBM) complements this perspective by focusing on individual perceptions of health risks associated with agrochemical use. Farmers' behaviors are shaped

by their perceived susceptibility to pesticide-related illnesses, the perceived severity of potential health outcomes, and the perceived benefits versus barriers of adopting protective measures such as personal protective equipment or integrated pest management strategies. Climate change not only amplifies reliance on agrochemicals but also heightens the health risks linked to exposure, making risk perception central to behavior change. HBM, therefore, offers a framework to analyze how farmers weigh health risks against productivity needs, while highlighting the role of cues to action such as extension services or personal illness experiences in prompting protective responses.

2.3.3 Theory of Planned Behavior (TPB)

The Theory of Planned Behavior (TPB), developed by Ajzen (1991), offers a comprehensive framework for explaining human behavior in contexts where choices are influenced by personal attitudes, social expectations, and perceived control over resources. The theory expands on the earlier Theory of Reasoned Action by incorporating perceived behavioral control as a determinant of intention and action, thereby recognizing that behavior is not only a function of motivation but also of the ability to overcome external and internal constraints (Ajzen, 2011). In the context of agrochemical use in fresh produce farming, the TPB provides a useful lens for analyzing how climate change shapes farmer agrochemical use practices. As climate-related stressors exacerbate production risks, farmer beliefs, intentions, and subsequent behaviors regarding agrochemical use are influenced by a dynamic interplay of attitudinal, normative, and control-related factors.

Fresh produce farming is highly sensitive to climatic conditions such as rainfall variability, temperature extremes, and the occurrence of extreme weather events. Climate change has been shown to alter pest and disease dynamics, reduce soil fertility, and increase the risk of

crop losses, all of which intensify farmers' reliance on agrochemicals such as pesticides and synthetic fertilizers (Mwalusepo et al., 2020). In many African contexts, including Kenya, shifts in rainfall and rising average temperatures have expanded the distribution and reproduction cycles of pests such as the fall armyworm, whiteflies, and aphids, thereby increasing the demand for pesticides among smallholder farmers (Krell et al., 2021). Likewise, erratic rainfall patterns often compel farmers to increase fertilizer applications to compensate for nutrient losses due to leaching and soil degradation (Müller et al., 2020). These adaptive responses, though rational from the farmer perspective, raise concerns about health risks, environmental degradation, and long-term sustainability. Understanding the behavioral mechanisms that shape farmer decisions in this context requires a theoretical framework that captures both psychological and contextual determinants of agrochemical use, which TPB provides.

Attitudes Toward Agrochemical Use under Climate Stress, attitude toward behavior refers to the degree to which an individual evaluates performing the behavior as favorable or unfavorable (Ajzen, 1991). For fresh produce farmers, attitudes toward agrochemical use are strongly shaped by their beliefs about the consequences of agrochemical inputs under climate change conditions. Positive attitudes often emerge when farmers perceive agrochemicals as reliable tools for mitigating climate-induced risks such as pest infestations, nutrient deficiencies, and reduced yields. For instance, farmers may associate pesticide use with immediate protection against climate-enhanced pest outbreaks, thereby viewing such practices as essential for safeguarding income and food security (Krell et al., 2021).

However, negative attitudes may also arise due to growing awareness of the adverse impacts of agrochemical dependency. Farmers who recognize the potential health hazards of

pesticide exposure, soil degradation, and water contamination may develop ambivalent or unfavorable attitudes toward excessive chemical use (Mwalusepo et al., 2020). Climate change awareness campaigns and exposure to training on sustainable farming practices can further shift attitudes toward integrated pest management (IPM), organic fertilizers, or other climate-smart agricultural techniques (Pretty et al., 2018). Thus, attitudes toward agrochemical use under climate change are not fixed but shaped by a dynamic balance between perceived benefits and risks. The TPB framework highlights this duality, showing that behavioral intentions depend on the relative weight of positive versus negative evaluations.

Subjective Norms and the Social Context of Agrochemical Use, subjective norms in the TPB refer to the perceived social pressures to perform or avoid a particular behavior (Ajzen, 1991). In agricultural communities, these pressures often come from peers, family members, extension agents, cooperatives, and market actors. Climate change intensifies these pressures by heightening the collective urgency to maintain production and market standards. For instance, when climate stressors such as prolonged drought or unseasonal rains increase pest pressures, farmers often observe and emulate their peers who intensify pesticide use, thereby reinforcing social norms favoring agrochemical reliance (Mavrodieva et al., 2019).

Markets and buyers also shape subjective norms by demanding blemish-free produce that meets stringent quality standards. Under climate change conditions, when crops are more vulnerable to pest damage, farmers may feel compelled to apply agrochemicals more frequently to satisfy consumer expectations and maintain market access (Harrison et al., 2019). Conversely, regulatory frameworks and certification schemes and organic labeling introduce countervailing norms that discourage excessive agrochemical use. These programs

often create new normative expectations within farming communities, promoting reduced pesticide use and encouraging the adoption of safer or climate-smart alternatives (Ndungu et al., 2021). Social learning further amplifies the role of subjective norms. In communities where farmers share experiences and coping strategies, climate-induced risks can trigger collective behavioral shifts. If influential farmers adopt agroecological practices or IPM in response to climate challenges, these behaviors may diffuse through the community, creating new norms that challenge reliance on agrochemicals (Pretty et al., 2018). Thus, under climate change, subjective norms exert powerful influence by shaping how farmers interpret risks, evaluate acceptable practices, and respond to external pressures. Perceived Behavioral Control and Resource, refers to an individual's perception of their ability to perform a behavior given available resources, skills, and external barriers (Ajzen, 2011). PBC is especially salient in the context of climate change, where resource constraints and environmental shocks significantly limit farmers' options.

Farmers with strong PBC may feel confident in their ability to adapt to climate variability through judicious agrochemical use, timely application, and adoption of alternatives. By contrast, those with weak PBC may perceive themselves as trapped in cycles of dependency, unable to reduce agrochemical use due to lack of financial capital, limited access to alternatives, or inadequate knowledge.

Climate change often reduces farmers' perceived control by exacerbating production risks. For example, extreme weather events can increase pest proliferation, forcing farmers to apply pesticides even when they are aware of health risks and long-term environmental costs (Mwalusepo et al., 2020). Limited institutional support, such as inadequate agricultural extension services or weak enforcement of pesticide regulations, further undermines PBC by

leaving farmers without reliable information or guidance on safer alternatives (Ndungu et al., 2021). On the other hand, interventions that improve access to climate-resilient technologies, provide subsidies for organic inputs, or enhance farmer training can strengthen PBC by expanding the perceived feasibility of reducing agrochemical dependency.

Behavioral Intentions and Actual Agrochemical Practices, In the TPB framework, behavioral intention is the immediate antecedent of actual behavior. Intentions are shaped by the combination of attitudes, subjective norms, and PBC, but actual behavior may diverge if unforeseen barriers arise (Ajzen, 1991). For fresh produce farmers facing climate stress, intentions to intensify agrochemical use often translate into practice due to the immediacy of climate-related threats. Farmers who intend to reduce agrochemical reliance may nonetheless revert to chemical inputs when pest infestations threaten crop survival, highlighting the gap between intention and behavior under conditions of uncertainty.

The alignment between intentions and behavior also depends on the stability of external conditions. When climate variability introduces frequent shocks, farmer intentions may be constantly revised, creating a reactive pattern of decision-making. For example, a farmer who intends to apply pesticides sparingly may increase frequency of application following unexpected pest outbreaks. TPB's recognition of PBC as both a predictor of intention and a direct predictor of behavior captures this reality, emphasizing that perceived and actual control critically shape whether intentions are realized. **Implications for Policy and Climate-Smart Interventions,** the application of TPB to climate change and agrochemical use underscores the need for interventions that target not only structural factors but also the psychosocial drivers of behavior. Interventions that aim to reshape attitudes can focus on raising awareness of health and environmental risks associated with overreliance on

agrochemicals, while simultaneously highlighting the benefits of sustainable alternatives. Efforts to influence subjective norms may involve mobilizing community leaders, peer farmers, and markets to reinforce positive practices such as IPM adoption or reduced pesticide reliance. Strengthening PBC requires enhancing farmers' access to resources, training, and institutional support, ensuring they perceive viable alternatives as within their reach. Policymakers and development practitioners can thus leverage TPB to design more effective climate adaptation strategies. By understanding how climate change alters attitudes, norms, and control perceptions, interventions can be tailored to promote safer agrochemical practices that balance productivity with long-term sustainability. Moreover, recognizing the gap between intention and behavior highlights the importance of structural support systems, such as credit facilities, extension services, and regulatory frameworks, in ensuring that farmers' intentions translate into sustainable practices.

The Theory of Planned Behavior provides a valuable theoretical foundation for analyzing the effects of climate change on agrochemical use among fresh produce farmers. By situating farmer decisions within the constructs of attitudes, subjective norms, and perceived behavioral control, TPB reveals the psychosocial dynamics that underlie adaptive responses to climate stress. Climate change shapes farmer beliefs about the consequences of agrochemical use, intensifies social pressures to maintain productivity, and constrains or enhances perceived control through resource availability and institutional support. These factors interact to shape behavioral intentions and practices, often reinforcing reliance on chemical inputs while simultaneously creating opportunities for the adoption of sustainable alternatives. Applying TPB to this context underscores the importance of integrated interventions that address both psychological determinants and structural barriers, thereby

fostering adaptive strategies that enhance resilience, safeguard health, and promote environmental sustainability.

The study applied constructs from the Social Cognitive Theory (SCT), Health Belief Model (HBM) and the Theory of Planned Behaviour (TPB) including perceived susceptibility, health motivation, perceived severity, perceived benefits, perceived self-efficacy, perceived barriers, and cues to action to examine factors shaping farmer attitudes and practices in agrochemical use, particularly at the intersection of climate change, agrochemical application, and associated health outcomes. Together, SCT, HBM and TPB provide a comprehensive theoretical foundation to examine both the socio-environmental drivers and cognitive determinants of agrochemical use and health outcomes in the context of climate change.

2.4 Conceptual Framework

Fresh produce farmers encounter various factors that influence their decision-making process aimed at maximizing their utility and productivity. Socioeconomic attributes such as level of education, age, gender, household size, farming experience, farm size, and risk perception affect farmers' decisions in the use of agrochemicals. Institutional factors such as access to credit, extension services, training programs, social networks, and access to information also affect productivity and the choice of pest management methods on the farm. Risk perception, institutional, and socioeconomic factors have a great influence on farmers' decisions on the level of agrochemical usage. Furthermore, institutional and socioeconomic attributes, as well as risk perception, affect farmers' decisions on the intensity of adoption of alternative pest management methods (Catherine et al., 2019).

Figure 2.2 presents the conceptual framework showing the interrelationship of factors that can influence farmer decisions on the use of agrochemicals, risk perception, and adoption of safety practices when using agrochemicals.

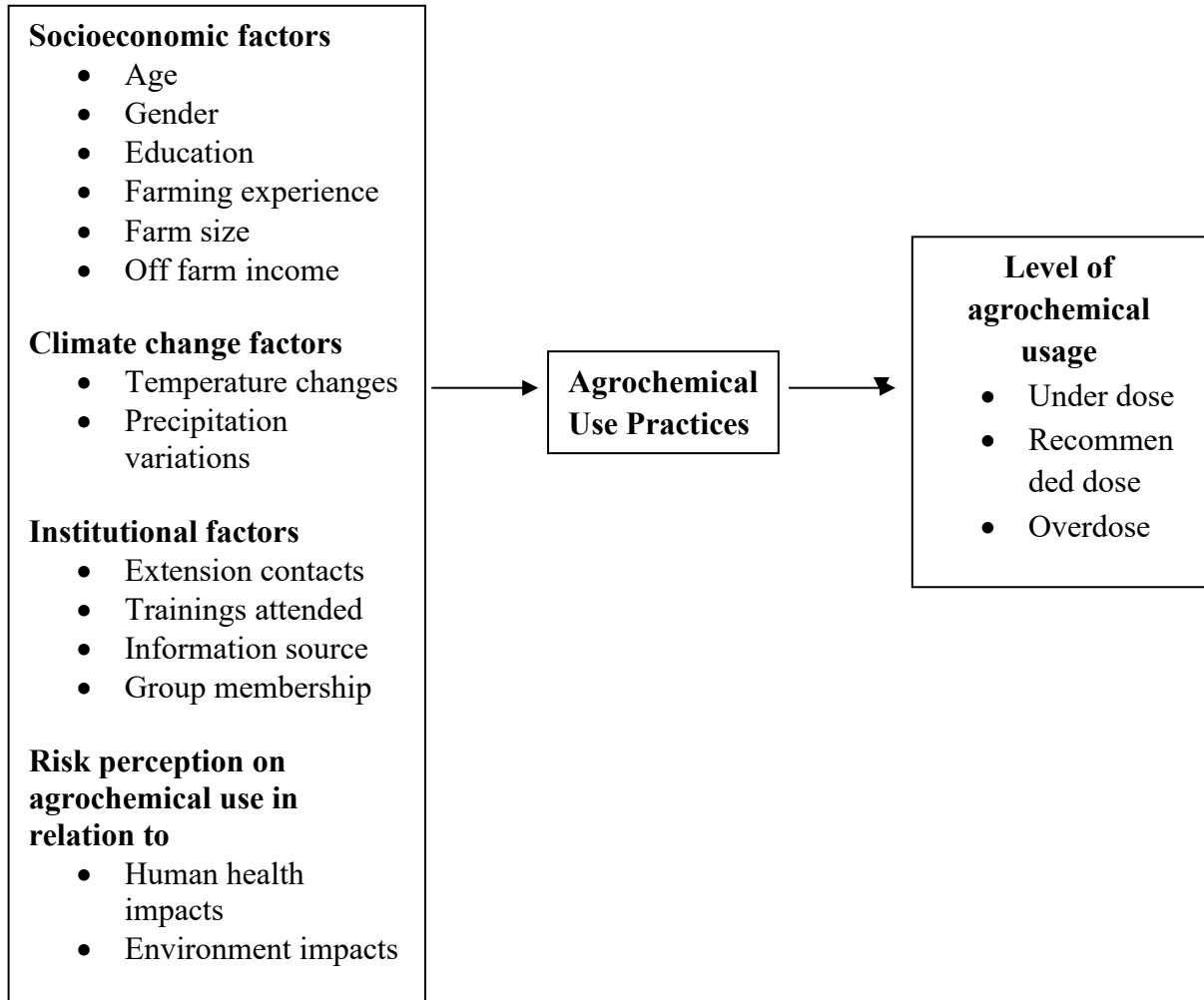
Figure 2. 2

Conceptual Framework

Independent Variables

Intervening Variable

Dependent Variable



Source: Adapted from Modified Catherine et al., (2019).

CHAPTER THREE: METHODOLOGY

3.0 Introduction

This chapter discusses the study design, study location, study population, sampling procedures and sample size determination, research instruments, data collection procedures, data analysis, and ethical considerations that were applied in the study.

3.1 Study Design

The study adopted a descriptive community-based cross-sectional study design. The study design was chosen because it is neutral, valid, and reliable. The study design also allowed for the generalization of the findings and was within the budgetary and time limitations anticipated. Primary data was reviewed and analyzed to help examine the socio-economic status of fresh produce farmers, determine their agrochemical use practices, identify safety measures taken in protecting themselves from health risks of agrochemical use and determine the association between climate change and agrochemical use which helped develop an agrochemical use and health effects reduction intervention among fresh produce farmers in Nakuru County.

The study design adopted both quantitative and qualitative approaches, this approach aimed to describe the association between climate change, agrochemical use, and health effects among Fresh produce farmers in Nakuru County. The study examined the demography, distribution, and the relationships between the farmers' socio-economic statuses, education level, and risk perception in the use of agrochemicals in relation to the climate change and health challenges they suffered in Nakuru County, Kenya.

3.2 Study Location

The study was carried out in Nakuru County. The County is located in the southeastern part of the Rift Valley Province. Nakuru County borders 7 Counties with Baringo to the north, Laikipia to the northeast, Nyandarua to the east, Kajiado to the south, Narok to the south west, with Bomet and Kericho to the west. Administratively, Nakuru County is subdivided into eleven sub-counties and fifty-five 55 wards. Nakuru County's population is multicultural and profoundly diverse. Nakuru County covers an area of 7,495.1 square kilometers. This includes 5,039.40 square kilometers of arable land, 852.1 square kilometers of non-arable land, 202 square kilometers of water mass covering lakes Naivasha, Elementaita, and Nakuru, as well as 679.6 square kilometers of gazetted forest. Agriculture is the lifeline of the economy of Nakuru County, as seventy percent of the 7,495.1 square kilometers of the county's land, which translates to 5,039.40 square kilometers, is arable and highly productive. Farmers in Nakuru County can have two seasons per year as the county has a bimodal rainfall pattern with a high of 1800mm and a low of 500mm. Nakuru County usually has long rains between March, April, May, and June, while short rains occur between October and November (County Government of Nakuru, 2023).

Over the last decade, Nakuru County has witnessed growing interactions between climate change, agrochemical use, and public health. Rising temperatures and rainfall variability have intensified pest pressures, increasing reliance on pesticides and fertilizers (Ochieng, Kirimi, & Mathenge, 2016; World Bank, 2022). This trend has heightened health risks through occupational exposure, contaminated food, and environmental pathways. Occupational health data show that 14% of flower farm workers in Naivasha have acetylcholinesterase inhibition, while 38% report neuropathy, with musculoskeletal pain and

skin irritation also common (Mathenge, Ojola, & Mwangi, 2024). Food safety indicators highlight frequent pesticide residues in horticultural crops, with produce occasionally exceeding international maximum residue limits (MRLs) resulting from agrochemical overuse especially under climate-driven pest outbreaks (Gitahi et al., 2020; Muriithi, Okello, & Narrod, 2022).

Environmental and dietary exposure studies show persistent contaminants, including chlorpyrifos in soils and excessive fluoride in staple crops such as potatoes, beans, and peas, raising risks of fluorosis and neurotoxicity (Gevera, Mouri, & Maronga, 2019; Njenga et al., 2023; Moturi, Tole, & Davies, 2002). Despite interventions such as *Ukulima True*, adoption of safe practices, including PPE use, remains limited (Njuguna & Kinyanjui, 2021). Overall, key health indicators in Nakuru County related to agrochemical use include, neurological and dermatological disorders, pesticide residues in food, chronic dietary exposures, and limited farmer awareness. These aspects reflect intensified agrochemical dependence under climate stress that is common in the study location.

3.3 Study Population

Nakuru is County number 32 out of the 47 Kenyan Counties. With an area of 7,496.5 KM², it is the 19th largest County in size. However, it has the third-largest population after Nairobi and Kiambu. Nakuru County has an estimated population of 2,162,000 as per the 2019 census (County Government of Nakuru, 2023).

The population of the county is estimated at 2,162,000 persons as per the 2019 census (KNBS, 2023). This population consisted of 1,165,380 males and 1,182,469 females. The county's population annual growth rate was 3.4% according to the 2019 census, which is higher than the national average of 2.0%. Given the trend, the county population was

projected to have grown to 2,347,849 by the end of 2023. The number of households in the county was estimated at 616,046, with a population density of 314.6/km² (KNBS, 2023).

Table 3. 1

Nakuru County population trends from 1979 - July 2023

<u>Name</u>	<u>Status</u>	Census 1979-08- 24	Census 1989-08- 24	Census 1999-08- 24	Census 2009-08- 24	Census 2019-08- 24	Projection 2023-07-01
<u>Nakuru</u>	County	522,709	849,096	1,187,039	1,603,325	2,162,202	2,347,849

Source: KNBS, (2023)

The population structure for Nakuru County is presented below:

Table 3. 2

Population Structure

Age Groups	Persons
0-14 years	811,228
15-64 years	1,457,704
65+ years	78,917

Urbanization (2019)

Rural	1,115,122
Urban	1,047,080

Source: KNBS, (2023)

According to Mutuku (2023), a larger population proportion is in the rural areas and are involved in agricultural production activities as indicated in Table 3.2. This renders them more vulnerable to exposure to agrochemicals in their daily occupational activities (Nantongo et al., 2023).

Table 3. 3

Nakuru County – Sub-Counties and Population

S/No.	Sub-County	Population
1	Naivasha	355,383
2	Njoro	238,773
3	Rongai	199,906
4	Nakuru Town West	198,661
5	Nakuru Town East	193,926
6	Gilgil	185,209
7	Molo	156,732
8	Kuresoi North	175,074
9	Bahati	162,985
10	Kuresoi South	155,324
11	Subukia	85,164
Total		2,107,137

Source: Ryan Mutuku, (2023)

The study population was individuals living in rural areas and primarily fresh produce farmers who are routinely exposed to agrochemicals in their daily occupational activities.

The target population was the individuals involved in the direct application of agrochemicals on the farms and other farm workers coming in contact with agrochemicals.

Kenya's agricultural landscape is predominantly characterized by smallholder farmers. A study by the AgResults Kenya Randomized Rural Household Survey (RRHS) estimated that approximately 1.53 million households in the Rift Valley region, which includes Nakuru County, are engaged in smallholder farming (AgResults, 2024). Given that Nakuru is a significant agricultural hub within the Rift Valley, it is reasonable to infer that a substantial proportion of these households are involved in various forms of agriculture, including horticulture.

According to the Kenya National Bureau of Statistics (KNBS), Nakuru County had approximately 284,495 farming households as of the 2019 Agricultural Census (KNBS, 2025). This figure encompasses all forms of agriculture, including crop and livestock production. Integrating available agricultural household data, smallholder farming statistics, and indicators of fresh produce farmer engagement provides a reasonable estimate. This estimate underscores the significant role of fresh produce farming in Nakuru's agricultural sector. Specific published data on the exact number of fresh produce farmers in Nakuru County is scarce.

However, several indicators suggest a high level of engagement in fresh produce farmer activities providing a basis for estimation of the population. Training Programs, Nakuru County Government's Agriculture, Livestock, Fisheries, and Veterinary Services Sub-Sector Report (2024) indicates that over 3,270 farmers across the county have been trained on Climate-Smart Agriculture (CSA) technologies, which often include fresh produce farmer practices (Nakuru County Government, 2024). Farmer Groups, the report also notes that 494

farmers participated in training sessions focused on improving fresh produce farming through the Smallholder Horticulture Empowerment and Promotion (SHEP) approach (Nakuru County Government, 2024). These figures suggest that a significant number of farming households in Nakuru County are engaged in horticultural activities.

3.3.1 Inclusion criteria

The inclusion criteria for the study participants were that they were Fresh produce farmers. Be a resident of Nakuru County and have lived in the County for at least two years. Those who willingly signed the consent form and were willing to participate in the study.

3.3.2 Exclusion criteria

Fresh produce farmers without a person able to comprehend the study questions as presented by the interviewer at the time of the visit were excluded, as well as those who were unwilling to be included in the study by refusing to sign the consent form.

3.4 Sampling Procedure and Sample Size

3.4.1 Sampling procedure

Sampling of study participants was done using a modified WHO 30-cluster survey sampling technique (WHO, 2017). This is a two-stage sampling technique that involved a random selection of clusters (sub-counties) in the region based on probability proportional to size (PPS) approaches, followed by random selection of fresh produce farmers in the selected clusters.

Nakuru county has 11 sub-counties (clusters). Applying this sampling procedure, 4 sub-counties were randomly selected. Probability proportional to size (PPS) approaches were used in selecting the number of fresh produce farmers to be considered in the study. This was necessary due to the varying population size across the different clusters. Households of

fresh produce farmers to be interviewed were selected systematically by selecting the 7th households linearly within each chosen cluster. The head of the selected household was considered as the respondent for the study.

Nakuru County was purposively selected for the study due to its agro-ecological features, agricultural activities, in particular fresh produce farming and vast use of agrochemicals. The use of agrochemicals is critical in this county, where various types of agrochemicals are applied in large-scale and small-scale farming ventures (Constantine et al., 2023).

Table 3.4: Shows the study sample selected from the clusters (Sub-Counties) with Proportion to the size Population

Table 3. 4

Study Sample Selected from Sub-Counties

S/No.	Sub County	Population	Study Sample
1	Njoro	238,773	128
2	Kuresoi North	175,074	94
3	Molo	156,732	84
4	Bahati	162,985	88
	Total	733,564	394

Source: Researcher (2024)

3.4.2 Sample size determination

According to (KNBS, 2023), the proportion of the population living in rural areas in Nakuru County accounts for an estimated 65% of the county population. This translates to a projected population estimated at 1,115,122 individuals. Approximately 60% of Nakuru County's households are engaged in agricultural activities, encompassing both crop and

livestock farming (Commission on Revenue Allocation [CRA], 2023). Agriculture remains a cornerstone of the county's economy, contributing significantly to local livelihoods and economic activity (Modern Energy Cooking Services [MECS], 2022). The sector is diverse, including the cultivation of maize, beans, potatoes, wheat, and livestock rearing, supported by the county's fertile soils and favorable climate (CRA, 2023; MECS, 2022). Populations involved in agricultural activities are at risk of exposure to agrochemicals. The sample size was determined by the Cochran's formula, Cochran (1977) equation to yield a representative sample for proportions of a large sample as follows.

$$n = (z^2 * p * q) / e^2 \quad (1)$$

To estimate the sample, the desired confidence level z was taken to be 95% (1.96).

The desired level of precision of estimates e was at $\pm 5\%$ (0.05).

An estimated proportion of individuals in the agricultural sector of 60% (0.6) was assumed for Nakuru County (CRA, 2023).

Inserting this in the formula;

Required minimum sample size = n

Individuals engaged in agricultural activities, $p = 60\%$ (0.6)

Desired level of precision of estimates, $e = \pm 5\%$ (0.05)

The desired Confidence level, $z = 95\%$ (1.96)

Therefore;

$$n = \frac{((1.96))^2 * 0.6 * (1 - 0.6)}{((0.05))^2} \cong 358$$

The total minimum sample size derived was 358. The sample size was raised by 10% to 394 to compensate for the study participants who were non-responsive and the ones who were unreachable (Israel, 1992).

Qualitative sample for the study was purposively selected. Key informant interview participants were selected from agricultural extension officers, farmer group leaders and public health officials from the selected clusters. Focused group discussion participants were selected from each cluster based on willingness and availability to participate in FGDs during the data collection period in the selected clusters.

3.5 Research Instruments

3.5.1 Overview and Rationale

High-quality research instruments are essential for obtaining valid, reliable, and ethically sound data. In this mixed-methods investigation of agrochemical use trends among fresh-produce farmers, four complementary tools were developed and deployed:

Structured household questionnaire (quantitative survey), Key Informant Interview (KII) schedule (qualitative, semi-structured), Focus Group Discussion (FGD) guide (qualitative, participatory), and Structured field-observation checklist (qualitative/quantitative). The deliberate integration of these instruments reflects a convergent parallel mixed-methods design, in which quantitative and qualitative strands are collected concurrently and then merged to generate a holistic understanding of drivers and consequences of agrochemical use.

This multi-instrument strategy follows international best practices in agricultural health research, which emphasize triangulation—the use of multiple sources or methods to examine the same phenomenon, thereby improving confidence in the findings (Creswell & Plano-Clark, 2018).

3.5.2 Instrument Development Process

Instrument development followed a systematic, iterative pathway consistent with recommended guidelines for social-science survey tools (Ranganathan et al., 2023; de Vaus, 2014). Conceptual mapping, drawing from theory and literature including studies of pesticide exposure in smallholder systems (Okonya et al., 2022; Lekei et al., 2020) the researcher identified key constructs: magnitude and temporal trends of agrochemical use, determinants of changes in use including climatic, economic, institutional, farmer knowledge, attitudes, and practices regarding integrated pest management (IPM) and personal protective equipment (PPE), adoption of risk-mitigation behaviors. These constructs guided item generation for both quantitative and qualitative instruments. Item generation and drafting, preliminary questions were crafted in English, incorporating both closed-ended items multiple choice,

Likert-type scales for statistical analysis and open-ended prompts for rich qualitative insights. Care was taken to avoid leading questions and double-barreled wording, and to ensure cultural and linguistic appropriateness. Expert Review for Content Validity. Three independent experts, a public-health toxicologist, an agricultural extension specialist, and a survey-methodology scholar assessed the draft instruments for relevance, comprehensiveness, and alignment with study objectives. A Content Validity Index (CVI) was calculated for each domain, and items with $CVI < 0.80$ were revised or discarded.

Translation and Back-Translation because many respondents were more comfortable in Swahili, questionnaires and interview guides were translated and back-translated by professional bilingual translators. This procedure safeguarded semantic equivalence and minimized misinterpretation across languages.

Pilot Testing and Cognitive Debriefing, a formal pilot study in Nyandarua County (see Section 3.6.3 of the dissertation) evaluated clarity, flow, and administration logistics. Cognitive interviewing techniques (Willis, 2015) helped reveal hidden ambiguities and respondent thought processes, prompting refinement of wording, skip patterns, and response categories.

Finalization and Formatting, the final instruments were formatted for both paper and pencil and electronic data capture using KOBO Toolbox to facilitate real-time error checking and secure storage.

3.5.3 Structured Household Questionnaire

The primary quantitative instrument was a structured questionnaire (Appendix 3). It comprised six sections designed to capture the breadth of variables relevant to agrochemical use trends: Socio-demographic characteristics, age, gender, education level, household size, primary occupation, and years of farming experience. Farm characteristics total land size, cropping patterns, irrigation practices, and market orientation.

Agrochemical use patterns, detailed questions on types of pesticides, fungicides, and herbicides; frequency and timing of applications; dosages relative to manufacturer recommendations; mixing practices; and storage/disposal behaviors. Integrated Pest Management (IPM) adoption, use of biological control, crop rotation, resistant varieties, and other IPM strategies, protective behaviors and health outcomes, ownership and frequency of PPE use, self-reported acute symptoms after spraying, and access to medical care.

Temporal trends and perceptions, five-year recall of changes in agrochemical types and quantities, perceptions of pest pressure, and climate-related drivers.

Question Formats and Scaling: Closed-ended questions employed nominal, ordinal, and ratio scales, enabling both descriptive and inferential analyses. Likert-type items captured attitudes toward risk and regulation. Where recall was required for example for the five-year trends, bounded recall techniques anchored responses to salient events such as notable droughts or national elections were to reduce telescoping bias.

Administration and Quality Control: Trained enumerators administered the questionnaire face-to-face to minimize literacy barriers and allow clarification of technical terms. Skip logics were automated in KOBO Collect Toolbox to reduce interviewer error. Daily synchronization of data to a secure cloud server enabled the principal investigator to run real-time logic checks for completeness and consistency.

3.5.4 Key Informant Interview (KII) Schedule

Key informant interviews targeted individuals with specialized knowledge of agricultural practices, regulatory frameworks, and farmer support services. Participants included: County agricultural extension officers, agrochemical input suppliers, representatives from farmer cooperatives, public-health and environmental-health officers

The semi-structured KII schedule (Appendix 4) contained open-ended questions organized into thematic domains: Historical trends in pesticide availability and regulation, observed changes in pest prevalence and climate patterns, effectiveness of extension and training programs, perceived barriers to adoption of IPM and PPE, recommendations for policy or practice improvements. Interviews lasted 45–60 minutes, were audio-recorded with consent, and were conducted in venues chosen for participant comfort and privacy. The flexible guide allowed probing for unanticipated issues while ensuring coverage of core topics.

3.5.5 Focus Group Discussion (FGD) Guide

FGDs (Appendix 5) were used to capture collective norms, peer influences, and shared experiences that may not emerge in individual interviews. Separate groups were held for male and female farmers to reduce gender-related response inhibition. Each group included 8–10 participants, purposively selected to ensure diversity in age, farm size, and market engagement. Discussion prompts explored: Community perceptions of pest and disease trends, social drivers of agrochemical choices (e.g., neighbor influence, cooperative norms), experiences with climate shocks and their impact on pesticide demand, group attitudes toward regulatory enforcement and health risks, sessions were moderated by an experienced facilitator fluent in Kiswahili and the local dialect, assisted by a note-taker. Activities such as ranking exercises and problem-tree analysis encouraged active participation. Audio recordings were transcribed verbatim and translated into English for analysis.

3.5.6 Field Observation Checklist

To complement self-reported data and reduce social desirability bias, a structured observation checklist (Appendix 6) was applied during farm visits. Enumerators recorded: Evidence of agrochemical storage conditions such as locked cabinets, labeling, type and condition of spraying equipment, actual use of PPE during ongoing pesticide applications, disposal practices for empty containers and wash water, observational data served two critical functions: Validation of farmers' self-reports, and generation of objective exposure indicators for subsequent regression modeling.

3.5.7 Measurement of Study Variables

The study's principal variables particularly agrochemical use trends were operationalized with precision to allow rigorous statistical analysis. Dependent Variables, Quantity of active

ingredient applied per hectare (kg/ha), frequency of pesticide application (applications/season), adoption of PPE (binary and ordinal scales).

Independent Variables included Socio-demographic factors: education, gender, and age. Farm characteristics: size, cropping diversity, and type of farming. Institutional factors: access to extension services and credit availability. Environmental factors: perceived pest pressure and climate-related shocks.

Analytical Strategy: Descriptive statistics summarized prevalence and intensity of pesticide use. Trend analysis compared reported practices across five-year recall periods. Multivariable regression models examined predictors of increased agrochemical use and adoption of protective measures, controlling for potential confounders such as education level, farm size, and access to extension services. Qualitative data from KIIs and FGDs were analyzed thematically to contextualize quantitative findings and identify emergent drivers of change.

3.5.8 Ensuring Validity and Reliability

Because the credibility of conclusions depends on instrument quality, extensive measures were taken to maximize validity and reliability. Content and Face Validity: Expert panel review and pilot feedback ensured comprehensive coverage and cultural appropriateness. Construct Validity, Exploratory factor analysis on pilot data verified hypothesized domains for example risk mitigation behaviors. Criterion Validity, Observational checklist data served as an external benchmark for self-reported pesticide use. Internal Consistency: Cronbach's alpha coefficients above 0.70 confirmed reliability of multi-item scales, test-retest reliability, a subset of pilot participants completed the questionnaire twice, two weeks

apart, yielding correlation coefficients > 0.75 . Inter-Rater Reliability, Paired observations during pilot farm visits produced agreement rates above 90%.

3.5.9 Ethical and Practical Considerations

All instruments incorporated clear informed consent statements, voluntary participation clauses, and confidentiality assurances. Questions were designed to avoid stigmatizing respondents or exposing proprietary farm information. The combined use of interviewer-administered questionnaires and electronic data capture minimized literacy-related exclusion and reduced transcription errors.

3.5.10 Integration and Triangulation

The ultimate strength of this research lies in the integration of findings across instruments. Quantitative data quantified magnitude and trends, while qualitative insights illuminated underlying motivations, institutional barriers, and contextual nuances. Triangulating self-reports with direct observations and key-informant testimony allowed the researcher to identify and reconcile discrepancies, producing a nuanced and credible account of agrochemical use under changing climatic conditions.

3.6 Pilot Testing, Validity, and Reliability of the Research Instruments

Rigorous instrument development is fundamental to ensuring that the data collected in this study are both credible and scientifically defensible. Before large-scale fieldwork commenced, the researcher implemented a three-pronged strategy consisting of, a pilot study, an in-depth assessment of validity, and comprehensive checks of reliability. Together, these processes provided a robust foundation for the main survey of fresh-produce farmers.

3.6.1 Pilot Study

Purpose and Rationale

A pilot study is widely recognized as an essential precursor to large surveys, serving as a “dress rehearsal” that exposes weaknesses in research design, instrumentation, and field procedures before costly full implementation (Presser et al., 2004; Willis, 2015). For this research, the pilot sought to: Assess clarity and comprehension of every questionnaire item to ensure that respondents interpreted the questions as intended. Evaluate logistics, including time required for completion, sequencing of questions, and data-recording procedures. Test recruitment and consent protocols, safeguarding adherence to ethical standards. Generate preliminary data for exploring item variability and potential refinement of scales.

Site Selection: The pilot was conducted in Nyandarua County, a high-potential agricultural area of Kenya whose demographic and agro-ecological characteristics closely mirror those of the main study counties. This choice enhanced external validity because farmers there grow similar vegetables and fruits, use comparable pest management techniques, and market their produce through similar channels. Importantly, Nyandarua was not part of the main study area, avoiding contamination of the final sample.

Sampling and Participants: A purposive sample of fresh-produce farmers was selected using the same inclusion criteria intended for the primary survey namely, smallholder farmers engaged in commercial vegetable and fruit production for at least one year. The sample size represented roughly 10 % of the projected main-study sample, a proportion recommended in survey methodology literature for meaningful pre-testing without unnecessary resource expenditure.

Implementation Procedures: Data collection followed exactly the same protocol planned for the main survey research assistants, after intensive training (see Section 3.6.2), administered the draft questionnaire face to face in either English, Swahili, depending on the respondent's preference. Each session began with verbal explanation of the study objectives and informed consent procedures, mirroring the ethical approach for the full survey. Field conditions including scheduling, travel logistics, and respondent recruitment replicated those anticipated during the actual study to reveal any practical constraints.

Evaluation and Feedback, immediately after each interview, both the enumerator and the respondent participated in a brief debriefing session. Respondents identified confusing words or culturally ambiguous phrases, while enumerators recorded observations about question flow, skip patterns, and the overall interview experience.

Key Findings and Adjustments, analysis of pilot data revealed several actionable issues: Complex phrasing in items measuring frequency of pesticide use led to inconsistent interpretations. These items were simplified and provided with illustrative examples. The Likert-scale questions produced limited variance, suggesting overly narrow response options. Additional categories were introduced to capture nuanced attitudes. Average interview duration exceeded the targeted 45 minutes. To reduce respondent fatigue, redundant demographic questions were removed and skip instructions clarified. These refinements resulted in a final instrument that was clearer, shorter, and more contextually grounded, ensuring that the full survey would yield high-quality data.

3.6.2 Validity of the Instrument

Conceptual Framework, validity concerns the extent to which an instrument measures what it is intended to measure (Polit & Beck, 2021). To establish strong evidence of validity, the

study employed multiple, complementary approaches: content validity, face validity, construct validity, and procedural validity.

Content Validity, content validity ensures that the questionnaire comprehensively covers all relevant aspects of the constructs under investigation in this case, occupational health and safety (OHS) practices among fresh-produce farmers. The instrument was developed after a systematic review of empirical and theoretical literature on agricultural OHS, pesticide exposure, and smallholder risk behaviors. Draft items were then evaluated by a panel of three subject-matter experts representing agricultural extension, public health, and research methodology.

Panelists assessed each question for relevance, clarity, and representativeness, using a four-point relevance scale. Items with a Content Validity Index (CVI) below the recommended threshold of 0.80 were either reworded or discarded. Face Validity, face validity, while more subjective, is vital for ensuring that respondents perceive the instrument as logical and credible. Pilot participants in Nyandarua County reviewed the questionnaire not only as respondents but also as informal evaluators, confirming that items were culturally appropriate and free of jargon. Their feedback led to minor modifications such as replacing technical pesticide names with commonly used trade names and adding illustrative photographs of protective equipment.

Construct Validity, Construct validity examines whether the instrument truly captures the theoretical dimensions it purports to measure. Preliminary exploratory analyses of pilot data, including item-total correlations, supported the hypothesized structure of key domains such as “use of personal protective equipment,” “knowledge of chemical hazards,” and “attitudes toward safety training.” Where correlations were weak, items were refined or combined.

Procedural Validity, beyond the questionnaire itself, procedural validity was safeguarded through standardized training and close supervision of research assistants. Training emphasized consistent administration, culturally sensitive interviewing, and adherence to ethical guidelines, ensuring that the manner of data collection would not distort the meaning of questions or answers. Together, these layered strategies provided compelling evidence that the final instrument possessed strong validity, aligning measurement operations with the conceptual framework of the study.

3.6.3 Reliability of the Instrument

Reliability refers to the consistency and stability of measurement across time, items, and different observers (Tavakol & Dennick, 2011). The study employed several techniques to assess and enhance reliability. Internal Consistency, using the pilot data, internal consistency was evaluated through Cronbach's alpha for each multi-item scale. Alpha coefficients exceeding 0.70 were considered acceptable, with subscales for "protective gear usage" and "chemical-handling knowledge" achieving values of 0.81 and 0.78, respectively. Items that lowered the alpha value were examined for ambiguity and either revised or removed. Test-Retest Reliability, to assess temporal stability, a sub-sample of pilot participants completed the questionnaire a second time after a two-week interval. Pearson correlation coefficients between Time 1 and Time 2 responses exceeded 0.75 across key domains, demonstrating satisfactory stability.

Inter-Rater Reliability, because the survey relied on multiple research assistants, consistency across interviewers was critical. During training, mock interviews and role-playing exercises were used to calibrate probing techniques and ensure uniform interpretation of open-ended

questions. Inter-rater agreement was further checked during the pilot when two enumerators independently scored a subset of responses; agreement exceeded 90 %.

Ongoing Reliability Checks in Main Study, reliability was not treated as a one-off pilot activity. During full data collection, daily field debriefings allowed the principal investigator to review completed questionnaires for completeness and logical consistency. Random spot checks of interviews were conducted to verify adherence to standardized procedures. Any discrepancies or protocol deviations triggered immediate refresher instructions to enumerators. These strategies collectively ensured that the measurement process was both dependable and reproducible, thereby strengthening the credibility of the findings.

3.6.4 Synthesis

By systematically conducting a pilot study, rigorously establishing validity, and meticulously ensuring reliability, this research safeguarded against common threats to data quality such as measurement error, respondent misinterpretation, and interviewer bias. The process exemplifies best practice in field survey research and aligns with international standards for doctoral level empirical work.

3.7 Data Collection Procedure

The study was conducted between January 2023 and January 2025. Quantitative and qualitative data were collected for the study. Quantitative data was collected using structured questionnaires modified to suit the study objectives. A self-administered questionnaire was nested and issued electronically on the Kobo Collect Toolbox using handheld android devices. Qualitative data was collected through interview schedule for key informant interviews (KII) for leaders of farmer groups, agriculture extension officers and county public health officials. A Focused Group Discussion (FGD) guide was used to collect data

from the farmers where four FGDs were carried out per cluster with eight participants for each session. An observation guide was used to collect data on the farmer's agrochemical use practices and their visible health effects was also recorded. Data was collected with guidance of research assistants trained in quantitative and qualitative data collection techniques.

3.8 Data Analysis Plan

A robust and well-structured data analysis plan is critical to transforming the raw information collected during fieldwork into meaningful evidence that answers the study objectives. This research employed a mixed methods approach, integrating quantitative and qualitative strands to investigate the relationships between agrochemical use and health outcomes among fresh produce farmers. The analysis plan was therefore designed to describe the patterns of agrochemical use and associated health symptoms, test statistical associations between key predictors and health outcomes, and interpret farmer narratives to provide a nuanced understanding of underlying drivers and contextual factors.

3.8.1 Overview of data flow

The analytical process began immediately after data collection with a structured data management workflow to ensure completeness, accuracy, and consistency. Primary Data Capture Quantitative data were recorded in the Kobo Toolbox mobile platform. This choice allowed for real-time validation through skip logics, range checks, and mandatory fields, minimizing entry errors. Qualitative data including key informant interviews (KIIs), focus group discussions (FGDs), and observational field notes were recorded using digital voice recorders and field notebooks.

Data Export and Integration, the completed Kobo Toolbox forms were exported to Microsoft Excel in comma-separated value (CSV) format. Each record retained a unique identifier to facilitate merging with observational data and to link repeated measurements. Interview recordings were transcribed verbatim and stored in text formats compatible with qualitative software.

Data Cleaning and Coding, before analysis, the dataset underwent rigorous cleaning. Steps included: Identification and correction of duplicate records. Logical checks including ensuring pesticide application frequency did not exceed biologically plausible limits. Coding of categorical variables using numeric representations for ease of analysis in IBM SPSS Statistics version 28.

Creation of the Master Analytical File, cleaned quantitative data were stored in a single SPSS. sav file with clear variable labels and value definitions. Parallel codebooks documented every variable, its measurement level, and coding scheme.

3.8.2 Quantitative Analysis

Quantitative analysis was structured in several phases: descriptive statistics, bivariate tests of association, and multivariable modelling.

3.8.3 Descriptive Statistics

Descriptive analysis provided an initial understanding of the sample and the distribution of study variables: Socio-demographic characteristics including age, gender, education level, farm size, and farming experience were summarized using means and standard deviations for continuous variables and frequencies with percentages for categorical variables. Agrochemical use patterns including types of pesticides, herbicides, and fungicides;

frequency of application; and adherence to label dosages were described using cross-tabulations and bar graphs.

Protective measures such as use of gloves, masks, or other personal protective equipment (PPE) were summarized to reveal compliance levels with recommended safety practices. Health outcomes (self-reported acute symptoms like headaches, respiratory irritation, or chronic conditions) were tabulated by severity and duration. Descriptive outputs served two purposes: first, to check for data anomalies, and second, to generate baseline evidence of farming and exposure conditions.

3.9 Bivariate Analysis

To examine preliminary relationships between agrochemical exposure and health effects, several inferential tests were applied: Chi-square (χ^2) tests of independence assessed associations between categorical variables. For example, the relationship between PPE use (yes/no) and incidence of respiratory symptoms was evaluated. Where expected cell counts were below five, Fisher's exact test provided more reliable inference. Independent-samples t-tests compared mean values—such as average number of spraying days per month between farmers who reported health symptoms and those who did not. Correlation analysis, (Pearson or Spearman depending on variable distributions) assessed the strength of linear relationships among continuous variables such as farm size and total volume of agrochemicals applied. All bivariate analyses were conducted at a 95 % confidence level, and results with $p < 0.05$ were considered statistically significant.

3.9.1 Multivariable Modelling

Because agrochemical exposure and health outcomes are influenced by multiple factors simultaneously, multivariable regression techniques were applied to isolate independent

predictors: Binary Logistic Regression. This model estimated the odds of experiencing specific health effects such as acute pesticide poisoning symptoms as a function of explanatory variables such as frequency of spraying, type of chemical, PPE use, education, and farm size. Adjusted odds ratios (AORs) with 95 % confidence intervals quantified the magnitude and direction of these relationships.

Multinomial Logistic Regression: For outcomes with more than two unordered categories—such as severity of symptoms categorized as none, mild, moderate, or severe—multinomial models provided estimates of the relative risk ratios for each level.

Binomial Regression for Proportion Data: When analysing prevalence rates (e.g., proportion of farmers adopting integrated pest management practices), binomial regression allowed estimation of risk differences and ratios.

Interaction Terms and Confounding Control: Interaction terms tested whether the association between agrochemical exposure and health outcomes varied by key modifiers such as gender or age group. Potential confounders—including education level, years of farming, and access to extension services—were entered into models using a forward stepwise approach and retained if they altered the exposure–outcome coefficient by more than 10 %.

Model Diagnostics: Goodness-of-fit was evaluated using the Hosmer–Lemeshow test, while multicollinearity was checked through variance inflation factors (VIF). Residual analysis identified influential observations.

3.9.2 Handling Missing Data

Missing responses were inevitable in self-reported surveys. The following strategies were adopted: For variables with <5 % missingness, listwise deletion was applied. Where

missingness exceeded this threshold and was deemed missing at random (MAR), multiple imputation using the Markov Chain Monte Carlo method generated plausible values, improving statistical power without biasing estimates.

3.9.3 Sensitivity Analyses

To assess robustness, sensitivity analyses re-estimated key models after (a) excluding participants with extreme exposure values and (b) applying alternative categorizations of chemical use frequency.

3.9.4 Qualitative Data Analysis

While quantitative analysis identifies statistical associations, understanding the why behind agrochemical practices requires qualitative exploration. The qualitative component followed a thematic analysis framework using NVivo version 14 which was the latest release compatible with our computing environment.

3.9.5 Transcription and Data Preparation

Audio recordings from KIIs and FGDs were transcribed verbatim. Transcripts were reviewed alongside field notes for accuracy and de-identified to maintain participant confidentiality. Each transcript received a unique code linked to metadata (location, participant role, date).

3.9.6 Coding

A preliminary coding framework was developed deductively from the research questions for example drivers of chemical use, perceptions of health risk, access to extension services and inductively from initial readings of the transcripts. Two independent analysts coded a subset of transcripts to establish intercoder reliability, achieving a Cohen's kappa of 0.82, which indicates substantial agreement.

3.9.7 Theme Development

Codes were organized into higher-order categories and emergent themes. Key themes included: Perceptions of pest pressure and climate variability. Economic incentives for high-frequency chemical application. Barriers to PPE use, including cost and discomfort. Awareness of and attitudes toward integrated pest management. Matrix coding queries in NVivo enabled cross-tabulation of themes by farmer gender, age group, and farm size, enriching the contextual understanding of quantitative findings.

3.9.8 Integration with Quantitative Findings

Qualitative insights were used to explain unexpected statistical relationships (for instance, why some highly educated farmers still engaged in risky spraying practices). Identify pathways of exposure not captured by the structured questionnaire (such as pesticide storage inside homes). Provide illustrative quotes for triangulation in the discussion chapter.

3.9.9 Data quality assurance

Ensuring the validity and reliability of analytical results required meticulous quality control: Pilot Testing of Instruments, Questionnaires and interview guides were pre-tested in a comparable farming community to check clarity and timing. Feedback informed minor revisions. Training of Enumerators, Data collectors received intensive training on KoBoToolbox usage, ethical considerations, and interview techniques. Real-Time Monitoring, Supervisors reviewed daily submissions to identify inconsistencies or missing fields for immediate correction. Audit trails, every transformation of the dataset was logged, ensuring transparency and reproducibility.

3.10 Ethical considerations in data handling

Confidentiality was paramount. Digital files were password-protected, and identifying information was stored separately from survey responses. Data sharing for peer verification will occur only in de-identified form and with approval from the institutional ethics committee.

3.10.1 Presentation of results

Findings will be presented using a combination of tables, graphs, and narrative descriptions: Quantitative outputs, included frequency tables, cross-tabulations with χ^2 statistics, and logistic regression tables showing odds ratios and 95 % CIs. Qualitative findings were illustrated with verbatim quotes and thematic diagrams. Mixed-methods integration appears in the discussion section, where numerical trends are interpreted in light of farmer lived experiences.

3.10.2 Rationale for analytical choices

The selection of analytical techniques reflects both the nature of the data and the research objectives: KOBO Collect Toolbox was chosen for its offline functionality and built-in validation rules, ideal for rural fieldwork with intermittent internet. SPSS offers a user-friendly interface and robust statistical packages suitable for complex regression modelling. NVivo provides advanced tools for managing large volumes of qualitative text and for executing mixed-methods queries. Alternative software such as R or Stata was considered, but SPSS and NVivo were preferred given the researcher expertise and the need for efficient integration of outputs into the university's reporting standards.

3.10.3 Anticipated challenges and mitigation

Potential challenges included: Recall Bias, where Farmers may have inaccurately reported past agrochemical use. This was mitigated by using bounded recall anchored to memorable agricultural seasons and climatic events. Social Desirability Bias, to minimize respondents overstating safe practices, interviews were conducted in neutral locations and assurances of confidentiality were emphasized. Complex Exposure Patterns, Multiple chemicals and varied application frequencies create analytical complexity. Detailed coding and hierarchical modelling addressed this issue.

3.11 Ethical Considerations

Research ethics are the moral principles and professional standards that guide investigators in the responsible conduct of research involving human participants. They protect the dignity, rights, safety, and well-being of study participants while ensuring scientific integrity and public trust in the research enterprise. This section details the ethical framework, approvals, and safeguards that governed this study of agrochemical use and health effects among fresh produce farmers in Nakuru County, Kenya.

The procedures described comply with: Kenyan regulatory requirements, notably the National Commission for Science, Technology and Innovation (NACOSTI) Act and related guidelines. Institutional requirements, including the Meru University of Science and Technology Institutional Research Ethics Review Committee (MIRERC). International principles, including the *Declaration of Helsinki* (2013 revision), the *Belmont Report* (respect for persons, beneficence, and justice), the *Council for International Organizations of Medical Sciences* (CIOMS) guidelines (2016), and relevant data-protection frameworks

such as the EU's General Data Protection Regulation (GDPR) and the Kenyan Data Protection Act (2019).

By integrating these overlapping standards, the study ensured that every stage from design through dissemination adhered to the highest global norms of responsible research.

Ethical Approvals and Regulatory Compliance: Institutional Review Board (IRB) Clearance: Prior to any fieldwork, the complete research protocol, consent forms, questionnaires, and recruitment materials were submitted to the Meru University of Science and Technology Institutional Research Ethics Review Committee (MIRERC). Approval was granted under reference number MIRERC 039/2024. MIRERC's mandate, recognized by the National Bioethics Committee of Kenya, ensures that studies meet internationally accepted ethical and scientific standards. **National Licensing:**

Following institutional approval, a research license was obtained from the National Commission for Science, Technology and Innovation (NACOSTI) under permit number NACOSTI/P/24/41056. NACOSTI is Kenya's statutory authority for regulating and monitoring research activities to safeguard participants and ensure alignment with national priorities. **Local Administrative Permissions:** Because fieldwork occurred in Nakuru County, additional written authorization was sought and obtained from the Nakuru County Health Department and from local health-facility management committees where recruitment and interviews occasionally occurred. These permissions ensured that county authorities were informed, potential overlaps with ongoing health programs were minimized, and community leaders were supportive of the research.

Respect for Persons and Informed Consent: Voluntary Participation: The principle of respect for persons demands recognition of individual autonomy. Participation in this study was

entirely voluntary. No inducements or coercive incentives were offered beyond modest reimbursement for transport where appropriate. Informed Consent Process, written informed consent was obtained before any data collection. Key elements included Information Disclosure, participants received a clear, jargon-free explanation of the study's purpose, procedures, potential risks and benefits, confidentiality measures, and their right to withdraw without penalty.

Comprehension Checking, research assistants used teach-back techniques asking participants to restate key points to ensure understanding, especially important in populations with varying literacy levels. Language and Accessibility, consent forms were translated into both English and Kiswahili. Participants could choose the language they best understood. Documentation, participants signed or thumb-printed consent forms. For those unable to write, an impartial witness attested to verbal consent. Special provisions were made for focus group discussions (FGDs) where participants gave consent both for individual participation and for audio-recording of the collective conversation.

Beneficence and Risk–Benefit Assessment: According to the *Belmont Report*, researchers must maximize benefits and minimize harm. Risk Identification, risks included potential psychological discomfort when discussing health symptoms, inadvertent disclosure of pesticide misuse, or minor inconvenience due to the length of interviews. Risk Mitigation, interviews were scheduled at times convenient to participants, conducted in private settings, and limited to non-intrusive questions. Participants could skip any question or end the interview at any time. Potential Benefits, though participants received no direct monetary compensation, the study generated knowledge that may inform safer agrochemical practices, improved agricultural extension services, and evidence-based policies to reduce pesticide-

related health hazards. Safety Precautions, field staff were trained to recognize signs of participant distress and to pause or terminate interviews if necessary. Where acute health issues were observed, participants were referred to local health facilities.

Justice and Fair Participant Selection: The principle of justice requires equitable distribution of research burdens and benefits. Sampling fairness, Farmers were recruited across diverse age groups, genders, and farm sizes to avoid systematic exclusion. No group was targeted merely for convenience or vulnerability. **Protection of Vulnerable Populations,** the study avoided enrolling minors. If adolescents were present during farm observations, no identifying information was collected about them. For any incidental contact, assent and guardian permission would have been sought, although none were ultimately required.

Privacy, Confidentiality, and Data Protection: Protecting participant confidentiality was a central ethical obligation. Data de-identification and coding each participant received a unique alphanumeric code. Names, addresses, or other direct identifiers were stored separately from survey responses. **Secure Data Storage,** digital files were encrypted and stored on password-protected servers at Meru University of Science and Technology. **Hardcopy consent forms** were locked in cabinets accessible only to the principal investigator. **Controlled Access,** only authorized team members principal investigator and three trained research assistants could access identifiable data. Access logs were maintained to track data use. **Compliance with Data Protection Laws** Procedures complied with the Kenya Data Protection Act (2019) and, by extension, key principles of the General Data Protection Regulation (GDPR), including data minimization, purpose limitation, and the right to erasure should a participant withdraw.

Data Retention and Sharing, de-identified data will be retained for five years for potential secondary analysis. Any sharing with collaborators will use anonymized datasets and require data-sharing agreements approved by MIRERC.

Ethical Conduct of Research Staff, the integrity of fieldwork depends on the competence and ethical awareness of data collectors. Recruitment and Training, three research assistants were recruited based on experience in community health surveys. Training covered: Research objectives and methodology, informed consent procedures, cultural sensitivity and respectful communication, confidentiality obligations and secure data handling, recognition of distress and referral procedures. Ongoing Supervision, daily debriefings allowed immediate correction of ethical or methodological issues. Enumerators signed confidentiality agreements binding them even after project completion.

Community Engagement and Respect for Local Norms: International guidance on the importance of community involvement. Stakeholder Consultations were done before commencing fieldwork, meetings were held with county agricultural officers, local farmer cooperatives, and community leaders to explain objectives and address concerns. Cultural Sensitivity Interviews respected local customs regarding gender dynamics, timing of visits, and appropriate greetings. Research assistants fluent in local dialects facilitated rapport. Feedback of Findings: After analysis, summary results will be shared with participating communities and county health authorities in accessible formats including community meetings, policy briefs, and ensuring reciprocity.

International Ethical Standards, the study explicitly aligned with globally recognized codes. Declaration of Helsinki (2013), Mandates scientifically sound research, independent ethical review, informed consent, and protection of vulnerable groups. Belmont Report (1979),

Emphasizes respect for persons, beneficence, and justice the foundation of our consent process and sampling strategy. CIOMS Guidelines (2016), Provided direction on community engagement, risk–benefit analysis, and data sharing. International Conference on Harmonization Good Clinical Practice (ICH-GCP), Although primarily for clinical trials, its principles of transparency, documentation, and quality assurance informed field procedures.

Management of Incidental Findings Because field visits included observation of farming practices and health discussions, researchers anticipated possible incidental findings such as unsafe pesticide storage or acute illness. Action Protocol, if a participant displayed symptoms of pesticide poisoning or if hazardous practices were noted, the team provided immediate advice and referrals to the nearest health facility or agricultural extension office.

Dissemination and Responsible Reporting, ethical responsibility extends to the communication of results. Anonymized reporting, Publications, presentations, and policy briefs will present only aggregated data. Quotes from interviews will use pseudonyms and remove identifying details. Open Science Considerations, in line with international movements for data sharing, de-identified datasets may be deposited in recognized repositories. Any such sharing will follow FAIR (Findable, Accessible, Interoperable, Reusable) principles and be conditioned on MIRERC approval.

Post-Study Obligations, researchers have a duty to ensure that study findings benefit participants and society. Policy Engagement. Results will be shared with Kenyan ministries of health and agriculture to inform safer agrochemical policies. Capacity Building, local agricultural officers will receive training materials and briefs derived from the research to strengthen extension services.

Continuous Ethical Monitoring, ethical oversight did not end with initial approval. Progress Reports, regular updates were submitted to MIRERC and NACOSTI outlining recruitment numbers, challenges, and any protocol amendments. Adverse Event Reporting, although none occurred, the protocol specified immediate reporting to MIRERC if unexpected harm arose. By securing multiple levels of approval, ensuring rigorous informed consent, safeguarding privacy, and engaging with the community, this study embodies the highest standards of ethical research practice. Compliance with Kenyan law, institutional requirements, and international frameworks such as the *Declaration of Helsinki* ensures that the dignity, rights, and welfare of all participants remain paramount. These measures not only protect individuals but also enhance the credibility and societal value of the findings on agrochemical use and health outcomes.

CHAPTER FOUR: RESULTS

4.0 Introduction

This chapter discusses the results of the study. It presents the demographic characteristics of the Fresh produce farmers, distribution of Fresh produce farmers by type of farming, the socio-economic status of Fresh produce farmers using agrochemicals and their associated health effects, Agrochemical use practices among Fresh produce farmers, the Occupational Health and Safety measures adopted by Fresh produce farmers using agrochemicals, the association between climate change and agrochemical use trends among Fresh produce farmers and health and safety interventions that can be adopted by Fresh produce farmers using agrochemicals.

4.1 Geographical Distribution of Respondents within the Study Location

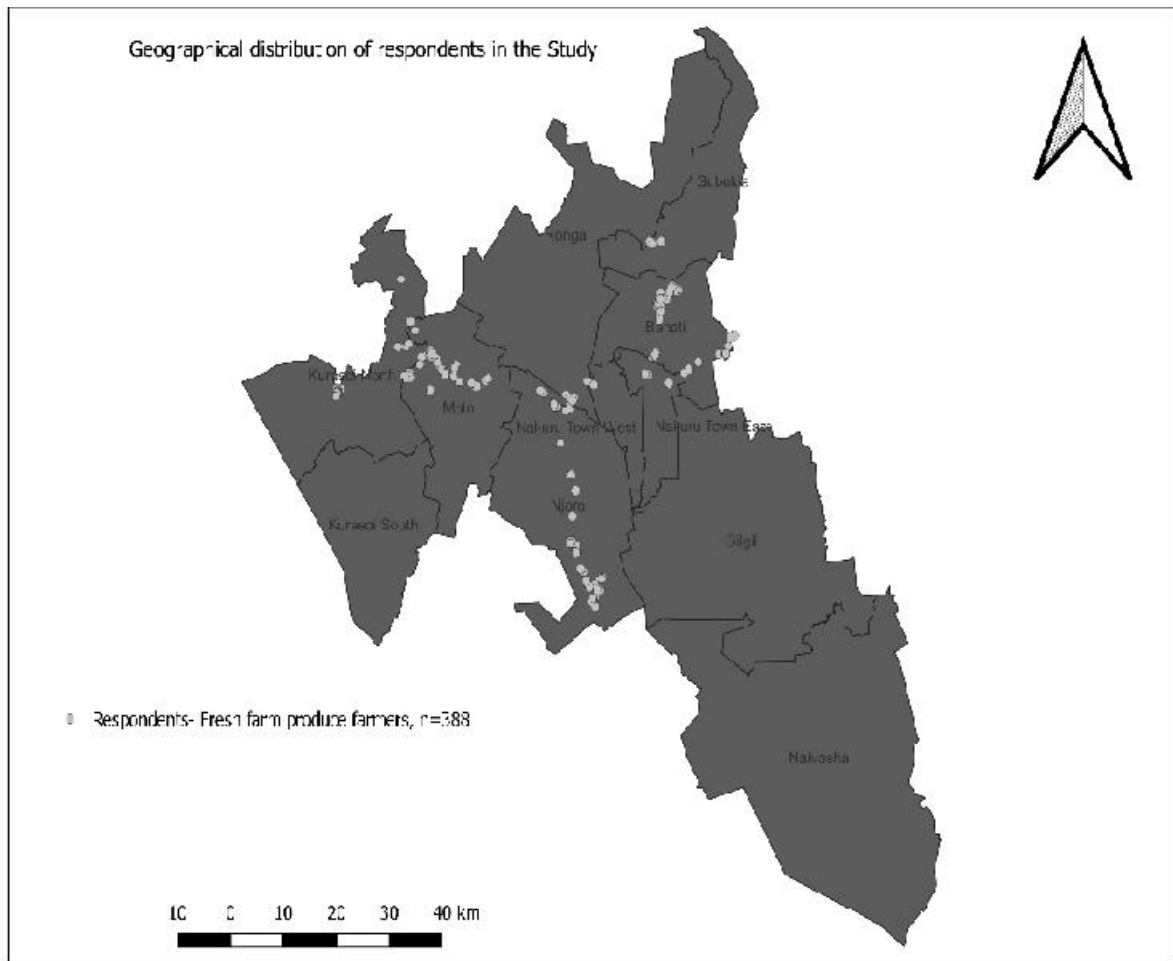
The study was conducted in four sub-counties within Nakuru County, Kenya: Molo, Njoro, Kuresoi North, and Bahati. The sub-counties were selected using a modified WHO 30-cluster survey sampling method, applying a two-stage sampling technique that involved a random selection of clusters (sub-counties) in the region based on probability proportional to size (PPS) approaches, followed by random selection of fresh produce farmers in the selected clusters to be considered for the study. The study participants had to meet the inclusion criteria of active engagement in fresh produce farming, which included the cultivation of vegetables, fruits, and other fresh produce. Each of these sub-counties represents a unique agro-ecological zone within Nakuru, contributing to the diversity of farming practices, exposure levels to agrochemicals, and the potential impact of climate variability on agricultural productivity.

Out of the targeted population, 388 respondents provided valid and complete responses to the survey questionnaire. This represents an exceptionally high response rate of 98.5%, indicating a strong level of engagement and willingness among the Fresh produce farmers to participate in the study. The high response rate can be attributed to effective mobilization strategies, collaboration with local agricultural extension officers, and the perceived relevance of the study to the respondents' livelihoods and health concerns.

Figure 4.1 provides a visual representation of the geographical distribution of the respondents across the four sub-counties. The distribution ensured balanced coverage and facilitated a comparative analysis of agrochemical use practices, exposure levels, and climate change awareness across different sub-regions within Nakuru County. Notably, the inclusion of both highland including Molo and Njoro and mid-altitude Bahati and Kuresoi North areas allowed for a comprehensive examination of how geographical and climatic variations influence agricultural decision making and farmer health outcomes. By focusing on these sub-counties, the study effectively captured the heterogeneity of fresh produce farming in Nakuru County, providing a strong foundation for the generalizability of the findings and the formulation of localized policy and practice recommendations.

Figure 4. 1

Geographical Mapping of the respondents



Source: GPS (2023)

4.2 Demographic Characteristics of Respondents

Table 4.1 summarizes the demographic profile of the 388 respondents. The gender distribution was nearly balanced, with slightly more females (51.8%) than males (48.2%). A majority of respondents were aged between 41 and 60 years (58.7%), while only a small proportion (3.4%) were aged 20–30 years.

In terms of education, over half (51.8%) had completed secondary school, 29.1% had attained primary education, and 16.5% had vocational or technical training. Very few

respondents had university-level qualifications (2.6%), and none reported having no formal education. Most respondents were married (82.5%), while 11.6% were single, 5.4% widowed, and 0.5% divorced. These characteristics indicate that the farming population in Nakuru County is primarily middle-aged, moderately educated, and household based.

Table 4. 1

Demographic Characteristics of Respondents

Variable	Frequency	Percentage (%)
Gender		
Male	187	48.2
Female	201	51.8
Age (years)		
20–30	13	3.4
31–40	74	19.1
41–50	103	26.5
51–60	125	32.2
Over 60	73	18.8
Education level		
Primary school	113	29.1
Secondary school	201	51.8
Vocational/technical	64	16.5
Bachelor’s degree	9	2.3

Master's degree	1	0.3
Marital status		
Single	45	11.6
Married	320	82.5
Divorced	2	0.5
Widowed	21	5.4

Note. Percentages are based on N = 388 respondents.

Source: Researcher (2024)

4.21 Socio-Economic Characteristics

The socio-economic characteristics of respondents were assessed in relation to their capacity to use agrochemicals safely and their reported health outcomes. These characteristics include household income levels, financial constraints, primary sources of livelihood, and cooperative membership. Table 4.3 summarizes these findings.

Most respondents (53.9%) reported being in the middle-class income bracket, followed by 33.8% in the lower-middle class. Only 0.8% were below the poverty line, while 9.8% and 1.8% identified as upper-middle and upper class, respectively. Despite a majority reporting middle-class status, 66.2% indicated experiencing financial constraints.

In terms of livelihoods, 88.4% relied primarily on fresh produce farming, while 7.5% reported business and 4.1% reported formal employment as their main sources of income.

Cooperative membership was relatively low, with only 36.3% of respondents belonging to farmer groups or cooperatives, compared to 63.7% who were not affiliated. This distribution indicates that most farmers operated outside formal support structures.

Table 4. 2*Socio-Economic Characteristics of Respondents*

Variable	Frequency	Percentage (%)
Household income		
Below the poverty line	3	0.8
Lower middle class	131	33.8
Middle class	209	53.9
Upper middle class	38	9.8
Upper class	7	1.8
Financial constraints		
Yes	257	66.2
No	131	33.8
Primary source of income		
Business	29	7.5
Employment	16	4.1
Fresh produce farming	343	88.4
Membership in cooperatives		
Yes	141	36.3
No	247	63.7

Note. Percentages are based on N = 388 respondents.

Source: Researcher (2024)

4.3 Association Between Socio-Economic Characteristics and Health Effects from Agrochemical Use

This section presents the results of statistical analyses examining the association between farmers' socio-economic characteristics and the reported incidence of health effects related to agrochemical use. A chi-square test was applied to determine significant associations, and logistic regression was used to estimate the strength of these relationships.

4.3.1 Type of farming

The analysis revealed a significant association between the type of farming and reported health effects ($\chi^2 = 10.25$, $p = 0.006$). As shown in Table 4.3, farmers engaged in commercial (33.3%) and mixed farming (41.8%) reported higher rates of health effects compared to those practicing subsistence farming (19.0%).

4.3.2 Financial constraints

Financial status was strongly associated with health outcomes ($\chi^2 = 24.15$, $p < .001$). Farmers who reported financial constraints had a higher incidence of health effects (41.6%) than those without constraints (13.0%).

4.3.3 Membership in farmer groups

Membership in farmer groups or cooperatives also showed a significant association ($\chi^2 = 4.10$, $p = 0.043$). Non-members reported more frequent health effects (38.3%) compared to members (28.3%).

4.3.4 Years of farming experience

Farming experience was another important factor ($\chi^2 = 16.85$, $p = 0.001$). Farmers with more than 15 years of experience reported higher health incidences (41.2%) compared to those with fewer years. Respondents with 10–15 years of experience also reported relatively high

levels of health effects (41.5%), while those with 6–10 years reported fewer incidences (21.3%).

Table 4. 3

Association Between Socio-Economic Characteristics and Health Effects from Agrochemical Use

Variable	No (%)	Yes (%)	Total	χ^2 p-value
Type of farming				0.006
Commercial (n=225)	150(66.7)	75(33.3)	225	
Mixed (n=79)	46(58.2)	33(41.8)	79	
Subsistence (n=84)	68(81.0)	16(19.0)	84	
Financial constraints				<0.001
Yes (n=257)	150(59.4)	107(41.6)	257	
No (n=131)	114(87.0)	17(13.0)	131	
Membership in groups				0.043
Yes (n=141)	87(61.7)	54(38.3)	141	
No (n=247)	177(71.7)	70(28.3)	247	
Years of experience				0.001
0–5 years (n=100)	76(76.0)	24(24.0)	100	
6–10 years (n=94)	74(78.7)	20(21.3)	94	
10–15 years (n=41)	24(58.5)	17(41.5)	41	
Over 15 years (n=153)	90(58.8)	63(41.2)	153	

Note. Chi-square test of independence applied. Source: Researcher (2024)

4.3.5 Regression analysis

Logistic regression further examined the strength of associations (Table 4.4). Financial constraints were the strongest predictor of adverse health outcomes (OR = 4.75, 95% CI [2.60, 8.70], $p < 0.001$). Years of experience were also significant, with farmers having 10–15 years (OR = 2.20, $p = 0.026$) and over 15 years (OR = 2.05, $p = 0.014$) showing higher likelihoods of reporting health issues compared to the 0–5 years’ reference group. Farming type and group membership were not statistically significant predictors in the regression model after controlling for other variables.

Table 4. 4

Logistic Regression Results for Association Between Socio-Economic Characteristics and Health Effects

Variable	Category	OR	95% CI	p-value
Type of farming	Commercial	Ref	–	–
	Mixed	1.25	0.70–2.20	0.450
	Subsistence	0.55	0.28–1.05	0.070
Financial constraints	Yes	4.75	2.60–8.70	<0.001
	No	Ref	–	–
Membership in groups	Yes	1.37	0.85–2.20	0.202
	No	Ref	–	–
Years of experience	0–5 years	Ref	–	–
	6–10 years	1.10	0.60–2.00	0.750
	10–15 years	2.20	1.10–4.40	0.026

>15 years 2.05 1.15–3.70 0.014

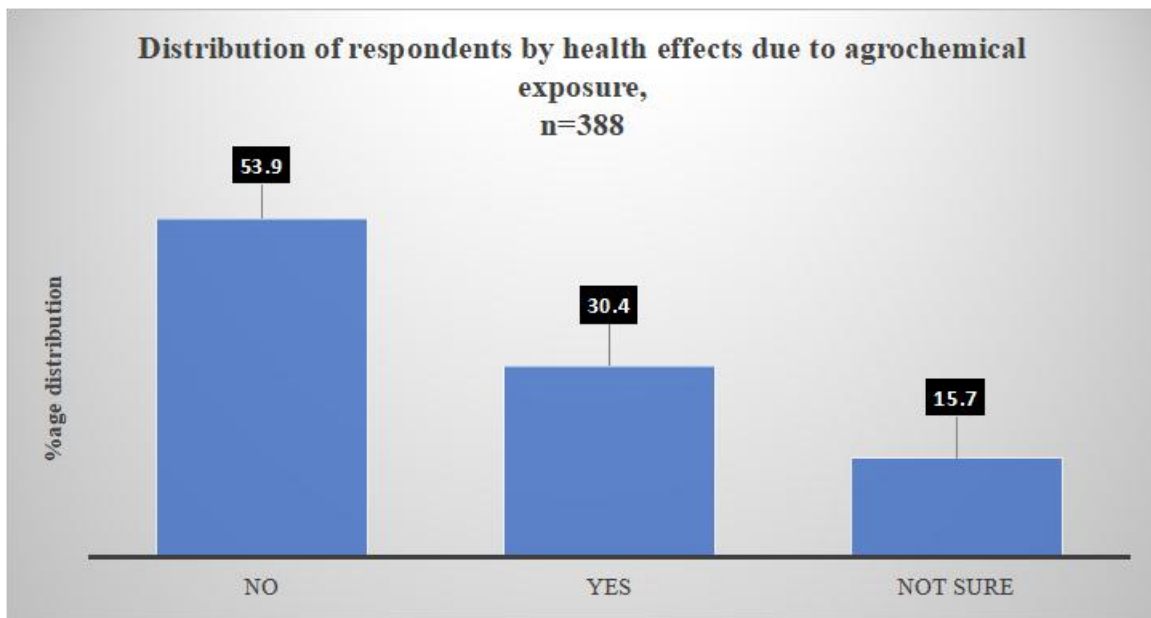
Source: Researcher (2024)

4.3.6 Development of health effects due to agrochemical exposure

Respondents were also asked about self-reported health effects linked to agrochemical exposure. As shown in Figure 4.2, 53.9% indicated no health effects, 30.4% reported experiencing health symptoms, and 15.7% were unsure whether their symptoms were related to agrochemical use.

Figure 4. 2

Distribution of Respondents by Self-Reported Health Effects



Source: Researcher (2024)

4.4 Agrochemical Use Practices Among Fresh Produce Farmers

4.4.1 Nature of farming practices and types of fresh produce cultivated

The study examined the types of farming systems and fresh produce cultivated by respondents. As shown in Table 4.5, most respondents (58.0%) engaged in commercial

farming, 21.6% practiced subsistence farming, and 20.4% practiced mixed farming. Vegetables were the most commonly cultivated crops, reported by 70.9% of respondents, while herbs were the least cultivated at 1.3%. Fruits, tubers, and legumes were grown in smaller proportions.

Table 4. 5

Nature of Farming Practices and Types of Fresh Produce Cultivated

Variable	Frequency	Percentage (%)
Type of farming		
Commercial	225	58.0
Subsistence	84	21.6
Mixed	79	20.4
Type of produce		
Vegetables	275	70.9
Fruits	25	6.4
Others (e.g., tubers, legumes)	83	21.4
Herbs	5	1.3

Note. Percentages are based on N = 388 respondents. Source: Researcher (2024)

4.4.2 Factors influencing agrochemical use

Respondents were asked to indicate the factors influencing their decision to use agrochemicals. Table 4.6 shows that pest infestation (98.5%) and climate change (85.3%) were the most frequently cited factors. Disease management was also commonly mentioned

(71.6%). Government regulations (0.5%) and cost-effectiveness (3.9%) were the least reported factors.

Table 4. 6

Distribution of Respondents by Factors Influencing Agrochemical Use

Factor	Yes n (%)	No n (%)	Total
Pest infestation	382 (98.5)	6 (1.5)	388
Weed control	202 (52.1)	186 (47.9)	388
Disease management	278 (71.6)	110 (28.4)	388
Cost-effectiveness	15 (3.9)	373 (96.1)	388
Government regulations	2 (0.5)	386 (99.5)	388
Climate change	331 (85.3)	57 (14.7)	388

Source: Researcher (2024)

4.4.3 Decision-Making on agrochemical use

Focus group discussions revealed that farmers relied on peers, agro-veterinary dealers, or personal experience when selecting agrochemicals. A farmer from Njoro explained:

“You just consult with other farmers... you just copy from other farms that had good harvests.”

Another farmer from Kuresoi North noted:

“If it is for peas and groundnuts, there is this illness called rust, which affects peas and not potatoes, but aphids attack all potatoes, peas, and cabbages; one will use the same chemical to kill those pests. Though it depends on one’s pocket, there is one for 200 and another for 700, that is the only difference.”

4.4.4 Agrochemical handling practices

The study also assessed respondents' practices in agrochemical handling, including purchase, storage, and disposal methods. As shown in Table 4.7, most farmers purchased agrochemicals from local agro-veterinary shops (91.5%), while only 8.5% sourced them from cooperatives or farmer groups.

In terms of storage, 63.7% reported storing chemicals inside the house, while 36.3% stored them in separate facilities. Disposal practices varied, with burning empty containers being the most common method (56.7%), followed by burying (21.1%) and reusing for domestic purposes (12.4%).

Table 4. 7

Agrochemical Handling Practices

Practice	Frequency	Percentage (%)
Purchase source		
Agro-veterinary shops	355	91.5
Cooperatives/groups	33	8.5
Storage		
Inside the house	247	63.7
Separate facility	141	36.3
Disposal		
Burn	220	56.7
Bury	82	21.1
Reuse (domestic use)	48	12.4

Other methods	38	9.8
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Source: Researcher (2024)

4.4.5 Use of Personal Protective Equipment (PPE)

Respondents were asked about their use of PPE during agrochemical application. Table 4.8 indicates that gloves (55.9%), gumboots (68.3%), and overalls (51.5%) were the most frequently reported protective items. Fewer respondents reported using goggles (9.5%) and respirators (6.2%).

Table 4. 8

Use of Personal Protective Equipment (PPE) During Agrochemical Application

PPE Item	Yes n (%)	No n (%)
Gloves	217 (55.9)	171 (44.1)
Gumboots	265 (68.3)	123 (31.7)
Overalls	200 (51.5)	188 (48.5)
Goggles	37 (9.5)	351 (90.5)
Respirator	24 (6.2)	364 (93.8)

Source: Researcher (2024)

4.4.6 Frequency and methods of application

Most respondents (69.1%) reported applying agrochemicals once per week, while 20.6% applied them more than once per week. A smaller proportion (10.3%) applied less frequently than once a week. Knapsack sprayers were the predominant application method, used by 95.1% of respondents.

Table 4. 9

Frequency and Methods of Agrochemical Application

Variable	Frequency	Percentage (%)
Frequency of application		
Less than once/week	40	10.3
Once/week	268	69.1
More than once/week	80	20.6
Application method		
Knapsack sprayer	369	95.1
Other methods	19	4.9

Source: Researcher (2024)

4.4.7 Farmers' Perceptions of Agrochemical Risks

Qualitative responses indicated varied perceptions of risks associated with agrochemical use. Some farmers noted awareness of potential health impacts, while others minimized perceived risks. One participant from Nakuru East commented:

“We know the chemicals are dangerous, but if you don't use them, you lose your crop.”

Another respondent highlighted economic consideration:

“Sometimes you can't afford the protective clothes, so you just spray carefully and hope nothing happens.”

4.5 Occupational Health and Safety Measures Adopted by Fresh Produce Farmers

4.5.1 Handwashing and changing of clothes

The majority of respondents (97.0%) reported washing their hands after applying agrochemicals, while 3.0% did not consistently practice this behavior. Changing of clothes after spraying was less common, though most indicated some form of hygiene practice following chemical use.

Figure 4. 3

Handwashing and changing clothes after agrochemical application.



Source: Researcher (2024)

4.5.2 Observance of Pre-Harvest Interval (PHI)

Most respondents did not consistently adhere to recommended pre-harvest intervals (PHI). Focus group discussions across Njoro, Bahati, and Mau Narok revealed that farmers often harvested crops shortly after spraying due to market demands and perishability concerns. Knowledge of PHI varied, with only a few farmers able to recall specific withdrawal periods for commonly used agrochemicals.

One farmer from Bahati remarked:

“We harvest when the market calls. If we wait long, the buyer goes elsewhere. Sometimes we spray and harvest the next day.”

Another farmer from Mau Narok added:

“Sometimes we are hungry, and we eat before washing off the chemicals properly.”

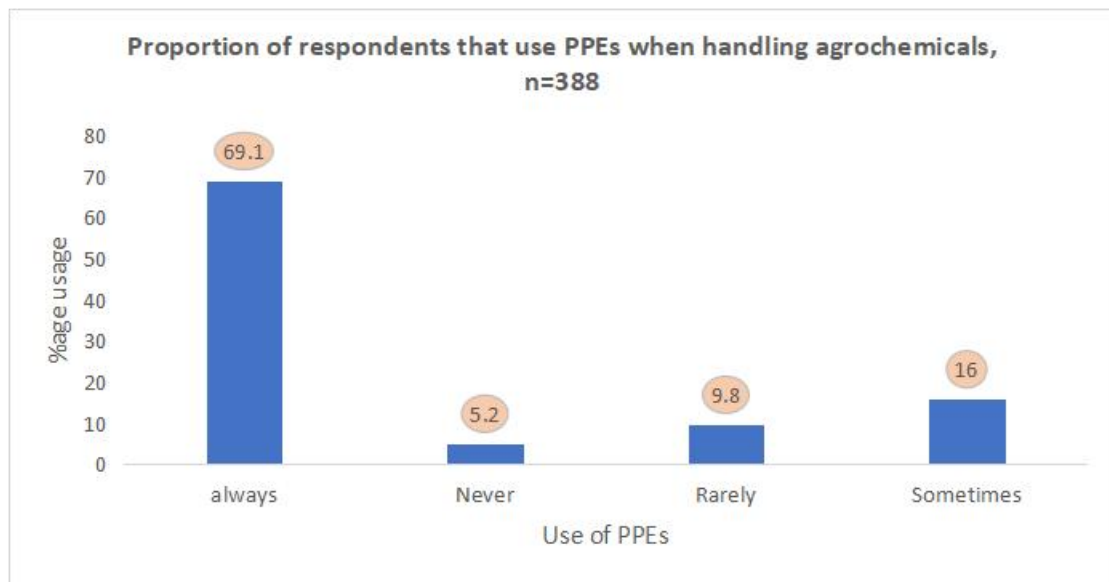
These accounts indicated limited knowledge and inconsistent observance of PHI across sub-counties.

4.5.3 Use of Personal Protective Equipment (PPE)

A total of 69.1% of respondents reported using some form of PPE when handling agrochemicals, while 5.2% reported never using any PPE. Items used most often included gloves, boots, and masks.

Figure 4. 4

Distribution of respondents by PPE use



Source: Researcher (2024)

Focus group discussions revealed considerably lower reported use compared to survey data. Many participants stated that full protective gear was rarely used, with simple masks being the most common item.

A farmer from Bahati explained:

“We don’t have them, they are minimal. Maybe 2% use full protection.”

An agricultural extension officer from Mau Narok reported:

“The reason most farmers haven’t bought the protective gear is that they are expensive. So before a farmer could afford it, they feel it is a waste of money.”

Observations also indicated that many farmers sprayed without checking equipment for leaks or changing clothes afterward.

4.5.4 Reported health effects

Respondents reported a range of health symptoms associated with agrochemical use. Commonly reported conditions included: Dermatological issues, itching, rashes, and skin irritation. Respiratory issues, coughing, sneezing, chest tightness, and breathing difficulties. Neurological issues, headaches, dizziness, and nausea. Asthmatic farmers noted that spraying aggravated their conditions.

One farmer from Bahati noted:

“Early on, I did not know they were the chemicals affecting me. Now I was told that with my age, I am not supposed to be using the chemicals.”

Another farmer from Mau Narok stated:

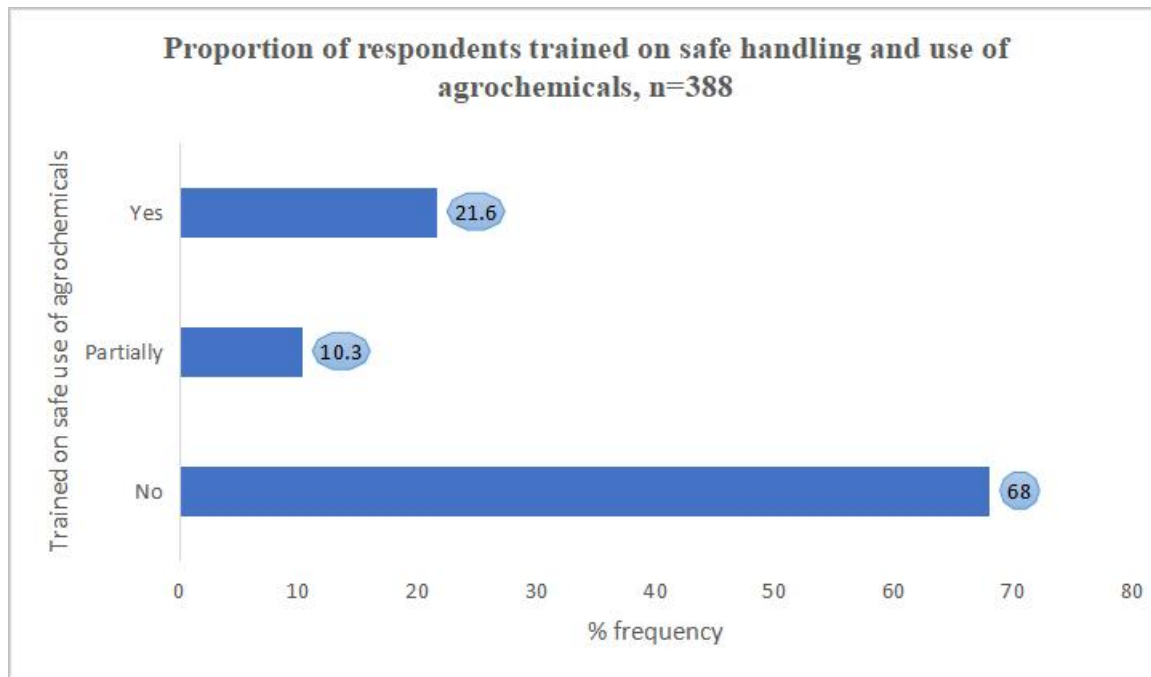
“We get headaches, stomach aches, and sneezing throughout. If it has been sprayed here, you will feel its smell and start sneezing, and you can't work on that farm until later.”

4.5.5 Training on safe handling and application

Survey findings indicated that 68.0% of respondents had never received any formal training on safe agrochemical handling. About 22.0% reported having undergone comprehensive training, while 10.0% had received partial or informal training.

Figure 4. 5

Distribution of respondents by level of training



Source: Researcher (2024)

In focus groups, some farmers reported receiving training but considered it ineffective due to a lack of follow-up. Many noted they relied on observing successful farmers or advice from experienced sprayers.

A farmer from Mau Narok explained:

“Most farmers emulate those farmers who have become rich through farming. If they used a certain agrochemical, next time you will use that chemical on your farm.”

A farmer from Njoro added:

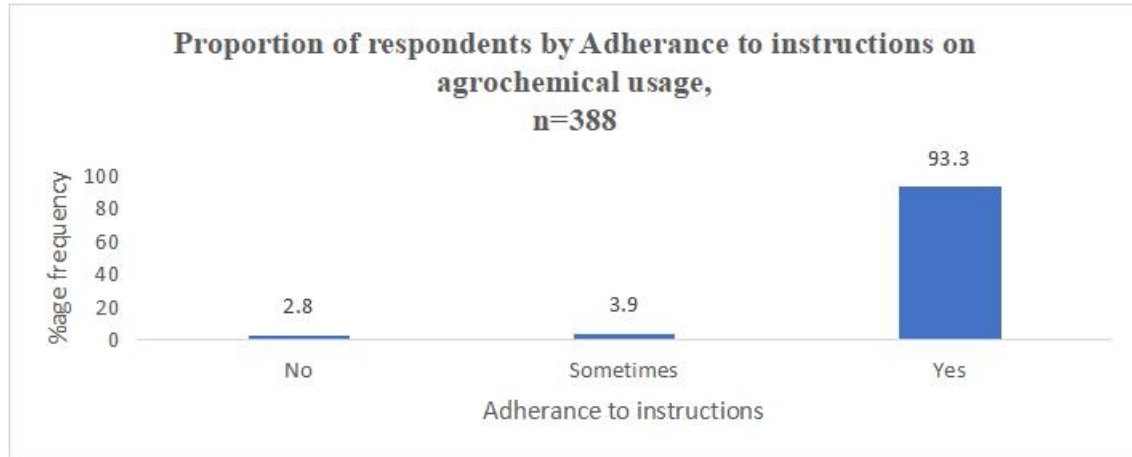
“Those who come to train these farmers don’t make any follow-ups. In other areas, they use a model farm so that other farmers can see how you use the agrochemicals.”

4.5.6 Adherence to instructions on agrochemical labels

Most respondents (93.3%) reported reading and following instructions on agrochemical labels.

Figure 4. 6

Adherence to label instructions



Source: Researcher (2024)

Despite this, focus group discussions suggested that farmers often only followed dosage and expiry details, while other instructions such as PHI or safety measures were overlooked.

A farmer from Bahati stated:

“The area that we are keen on is the amount to be used and the time. We don’t read the rest.”

Another farmer from Mau Narok commented:

“The writings are so tiny that you can’t even see well, and that is where a lot of information is hidden.”

Some farmers reported deliberately increasing chemical concentrations beyond recommended levels, citing concerns about product effectiveness.

A farmer from Bahati explained:

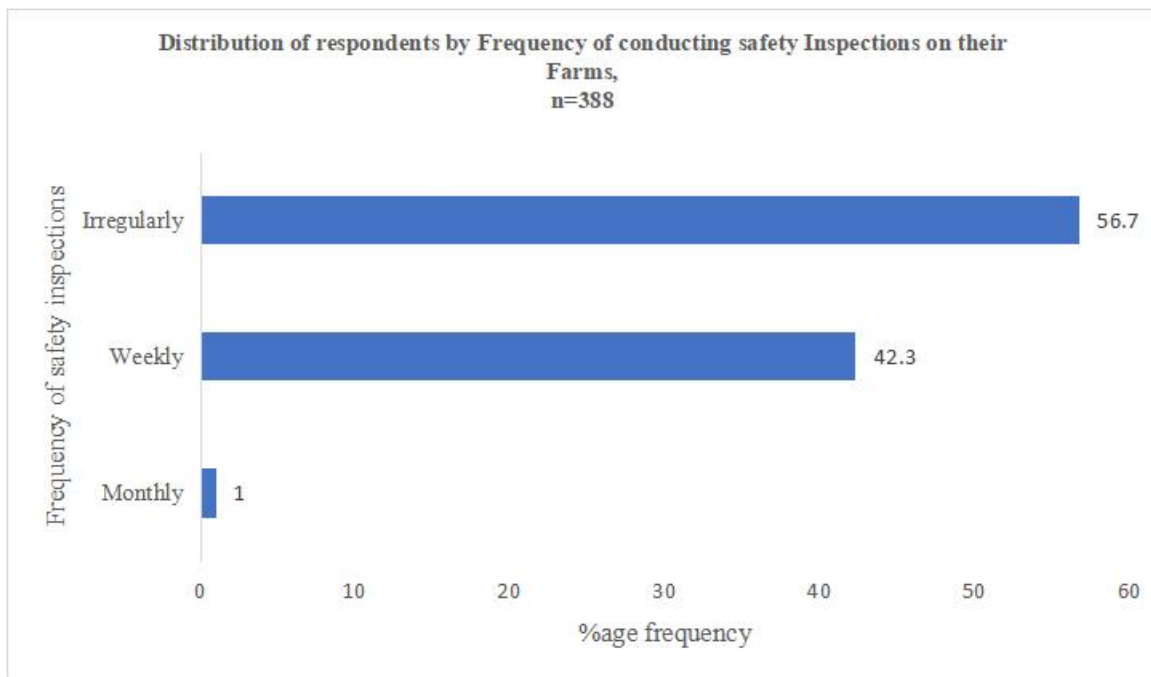
“If the instructions say 200 grams, we tend to add more to make it concentrated, though that is not farmers’ fault. It is because sometimes they don’t work.”

4.5.7 Frequency of farm safety inspections

Findings indicated that 57.0% of respondents conducted irregular farm safety inspections, 42.0% performed weekly inspections, and 1.0% conducted monthly inspections.

Figure 4. 7

Distribution of safety inspections among respondents



Source: Researcher (2024)

4.5.8 Regular monitoring of health

Only 2.0% of respondents reported undergoing regular health checkups related to agrochemical exposure, while 98.0% did not seek any formal health monitoring services.

4.6 Association Between Climate Change and Agrochemical Use Trends

4.6.1 Perceptions of climate and weather changes

Respondents reported observable shifts in weather patterns, including increased temperatures, irregular rainfall, extended dry periods, and unpredictable onset and cessation of rains. Farmers also noted changes in seasonality, with less predictable planting and harvesting periods, and reported increased frequency of pest and disease outbreaks, particularly during warm and wet seasons.

One farmer from Bahati explained:

“No, they are different. Differently, let us say for instance potatoes, when it is sunny, you don’t use too many chemicals to control, but when it is rainy or cold, instead of after two weeks, you use it in a week, you go spray. The weather changes control you. That is why, as he has said, you have to do scouting, and the weather controls you by the way.”

A farmer from Mau Narok added:

“Because of climate change, farmers prefer to spray in the evening or early in the morning before the sun rises. But the more we use the agrochemicals, the more resistant pests become, so we keep spraying them over and over.”

In Njoro, farmers emphasized reliance on fertilizers and pesticides due to reduced soil fertility:

“In the past, we didn’t use agrochemicals to a great extent, but right now, if you miss using pesticides or boosters, you won’t have a harvest.”

4.6.2 Socio-Demographic factors and climate change awareness

There was no statistically significant association between gender and awareness of climate change ($p = 0.188$). Both males and females reported moderate awareness levels. Age group also showed no association with climate change awareness ($p = 0.221$).

Level of education was significantly associated with climate change awareness ($p < 0.001$). Respondents with bachelor's and master's degrees reported the highest levels of awareness, while those with primary and secondary education included participants with no awareness.

Type of farming was significantly associated with awareness ($p < 0.001$). Awareness increased with level of farming, with commercial farmers reporting the highest levels of awareness.

Economic viability of farming was also associated with awareness ($p = 0.022$), with higher viability linked to greater awareness. Primary source of income was significantly associated with awareness ($p = 0.028$), with fresh produce farmers reporting the highest levels of awareness.

Membership to a farmers' cooperative ($p = 0.006$) and years of experience in farming ($p < 0.001$) were both significantly associated with climate change awareness.

Household income level and marital status were not significantly associated with awareness.

Table 4. 10

Sociodemographic factors and climate change awareness

Variables	Awareness of climate change				Chi-square p-value
	Not aware	Slightly aware	Moderately aware	Very aware	

Gender					0.188
Male	1 (0.5%)	41 (21.9%)	95 (50.8%)	50 (26.7%)	
Female	4 (2.0%)	50 (24.9%)	109 (54.2%)	38 (18.9%)	
Age group					0.221
20-30	0 (0.0%)	2 (15.4%)	11 (84.6%)	0 (0.0%)	
31-40	1 (1.4%)	19 (25.7%)	37 (50.0%)	17 (23.0%)	
41-50	3 (2.9%)	26 (25.2%)	58 (56.3%)	16 (15.5%)	
51-60	1 (0.8%)	26 (20.8%)	63 (50.4%)	35 (28.0%)	
Over 60	0 (0.0%)	18 (24.7%)	35 (47.9%)	20 (27.4%)	
Level of education					<0.001
Primary	1 (0.9%)	29 (25.7%)	53 (46.9%)	30 (26.5%)	
Secondary	4 (2.0%)	44 (21.9%)	113 (56.2%)	40 (19.9%)	
Vocational	0 (0.0%)	0 (0.0%)	47 (73.4%)	17 (26.6%)	
Bachelor's	0 (0.0%)	0 (0.0%)	0 (0.0%)	9 (100.0%)	
Master's degree	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (100.0%)	
Marital status					0.112
Divorced	0 (0.0%)	1 (100%)	0 (0.0%)	0 (0.0%)	
Single	1 (2.2%)	16 (35.6%)	24 (53.3%)	4 (8.9%)	
Married	3 (0.9%)	68 (21.2%)	170 (53.0%)	80 (24.9%)	
Widowed	1 (4.8%)	6 (28.6%)	10 (47.6%)	4 (19.0%)	
Type of farming					<0.001
Commercial	2 (0.9%)	38 (16.9%)	121 (53.8%)	64 (28.4%)	
Mixed farming	1 (1.3%)	21 (26.6%)	39 (49.4%)	18 (22.8%)	

Subsistence	2 (2.4%)	32 (38.1%)	44 (52.4%)	6 (7.1%)	
HH income level					0.371
Below poverty line	0 (0.0%)	1 (33.3%)	0 (0.0%)	2 (66.7%)	
Lower middle class	3 (2.3%)	34 (26.0%)	71 (54.2%)	23 (17.6%)	
Middle class	1 (0.5%)	50 (23.9%)	105 (50.2%)	53 (25.4%)	
Upper middle class	1 (2.6%)	5 (13.2%)	23 (60.5%)	9 (23.7%)	
Upper class	0 (0.0%)	1 (14.3%)	5 (71.4%)	1 (14.3%)	
Economic viability of farming					0.022
Not viable	0 (0.0%)	6 (33.3%)	11 (61.1%)	1 (5.6%)	
Somewhat viable	3 (2.7%)	39 (34.5%)	48 (42.5%)	23 (20.4%)	
Viable	2 (0.9%)	42 (18.2%)	131 (56.7%)	56 (24.2%)	
Very viable	0 (0.0%)	4 (15.4%)	14 (53.8%)	8 (30.8%)	
Primary source of income					0.028
Business	0 (0.0%)	12 (41.4%)	15 (51.7%)	2 (6.9%)	
Employment	0 (0.0%)	7 (43.8%)	8 (50.0%)	1 (6.3%)	
Fresh produce farming	5 (1.5%)	72 (21.0%)	181 (52.6%)	85 (24.8%)	
Membership to farmers' cooperative					0.006
Yes	1 (0.7%)	21 (14.9%)	77 (54.6%)	42 (29.8%)	
No	4 (1.6%)	70 (28.3%)	127 (51.4%)	46 (18.6%)	
Years of experience					<0.001

0-5	1 (1.0%)	39 (39.0%)	47 (47.0%)	13 (13.0%)
6-10	2 (2.1%)	24 (25.5%)	54 (57.4%)	14 (14.9%)
10-15	0 (0.0%)	8 (19.5%)	20 (48.8%)	13 (31.7%)
Over 15	2 (1.3%)	20 (13.1%)	83 (54.2%)	48 (31.4%)

Source: Researcher (2024)

4.6.3 Climate change and agrochemical use practices

Perceived changes in climate were significantly associated with the methods of agrochemical application and decision-making criteria for agrochemical selection. A negative correlation was found between the number of methods used to apply agrochemicals and awareness of climate change ($r = -0.270$).

Farmers perceiving climate change were more likely to rely on previous experience when selecting agrochemicals.

Table 4. 11

Associations between climate change and agrochemical use trends.

Variable	Climate change		p-value (chi-square)
	Yes	No	
Frequency of use			0.084
Never	0 (0.0%)	1 (100%)	
Daily	2 (25.0%)	6 (75.0%)	
Weekly	92 (39.0%)	144 (61.0%)	
Monthly	4 (36.4%)	7 (63.6%)	
Occasionally	33 (25.0%)	99 (75.0%)	

Decision-making			<0.001
Previous experience	103 (31.2%)	227 (68.8%)	
Recommendation from agriculture experts	20 (64.5%)	11 (35.5%)	
Recommendation from other farmers	8 (29.6%)	19 (70.4%)	
Method of application			
Foliar			
Yes	13 (12.4%)	92 (87.6%)	<0.001
No	118 (41.7%)	165 (58.3%)	
Fertigation			
Yes	0 (0.0%)	4 (100%)	0.151
No	131 (34.1%)	253 (65.9%)	
Drenching			
Yes	1 (33.3%)	2 (66.7%)	0.987
No	130 (33.8%)	255 (66.2%)	
Number of methods used			
One	63 (22.4)	218 (77.6)	0.014
Two	35 (34.3)	67 (65.7)	
Three	3 (60.0)	2 (40.0)	
Type of agrochemical			
Insecticides			
Yes	62 (26.8%)	169 (73.2%)	<0.001
No	69 (43.9%)	88 (56.1%)	

Fungicides			
Yes	52 (21.2%)	193 (78.8%)	<0.001
No	79 (55.2%)	64 (44.8%)	
Herbicides			
Yes	25 (15.5%)	136 (84.5%)	<0.001
No	106 (46.7%)	121 (53.3%)	
Pesticides			
Yes	127 (34.0%)	247 (66.0%)	0.676
No	4 (28.6%)	10 (71.4%)	

Source: Researcher (2024)

4.6.4 Logistic regression of climate change perception and agrochemical practices

Logistic regression analysis was conducted to examine the association between farmers' perceptions of climate change effects and their agrochemical practices. The results are presented in Table 4.12.

Farmers who perceived climate change effects were significantly more likely to apply agrochemicals on a daily basis compared to a weekly basis (OR = 2.50, 95% CI [1.30, 4.70], $p = 0.005$). Similarly, reliance on experts for decision-making was strongly associated with higher odds of agrochemical use compared to reliance on previous experience (OR = 3.90, 95% CI [2.00, 7.60], $p < 0.001$). In contrast, reliance on other farmers compared to previous experience did not show a significant association (OR = 0.85, 95% CI [0.35, 2.00], $p = 0.710$).

With respect to specific chemical practices, perceiving climate change effects was associated with significantly lower odds of foliar application (OR = 0.25, 95% CI [0.12,

0.55], $p < 0.001$). Conversely, it was associated with greater odds of fungicide use (OR = 2.90, 95% CI [1.70, 5.00], $p < 0.001$) and herbicide use (OR = 3.25, 95% CI [1.85, 5.70], $p < 0.001$). No statistically significant association was found for insecticide use (OR = 1.45, 95% CI [0.90, 2.35], $p = 0.110$) or general pesticide use (OR = 1.25, 95% CI [0.45, 3.45], $p = 0.676$).

Furthermore, adoption of three methods of agrochemical application compared to one method was associated with significantly higher odds of agrochemical use (OR = 4.80, 95% CI [1.05, 21.80], $p = 0.042$).

Table 4. 12

Logistic regression results of climate change perception and agrochemical practices
(Predictor = Climate change perceived effect, Outcome = agrochemical practice)

Agrochemical outcome	OR (Yes vs No)	95% CI	p-value
Daily vs Weekly	2.50	1.30 – 4.70	0.005
Decision-making			
Experts vs Previous experience	3.90	2.00 – 7.60	<0.001
Other farmers vs Previous experience	0.85	0.35 – 2.00	0.710
Foliar application (Yes vs No)	0.25	0.12 – 0.55	<0.001
Fungicide use (Yes vs No)	2.90	1.70 – 5.00	<0.001
Herbicide use (Yes vs No)	3.25	1.85 – 5.70	<0.001
Insecticide use (Yes vs No)	1.45	0.90 – 2.35	0.110
Pesticide use (Yes vs No)	1.25	0.45 – 3.45	0.676
Three methods vs One	4.80	1.05 – 21.8	0.042
OR= odds ratio			

CI= Confidence interval

Source: Researcher (2024)

4.6.5 Regression of climate change perceptions and agrochemical application methods

Regression analysis examined the association between perceived climate change effects and the number of agrochemical application methods used. The results are summarized in Table 4.13. Respondents who perceived changes in weather patterns were significantly less likely to increase the number of agrochemical application methods (aOR = 0.87, 95% CI [0.78, 0.97], p = 0.012). No significant associations were observed for perceptions of climate change impacts on farming practices (aOR = 1.10, 95% CI [0.99, 1.22], p = 0.082) or changes in pest pressure (aOR = 0.97, 95% CI [0.75, 1.27], p = 0.8412)

Table 4. 13

Regression results for climate change effects and methods of agrochemical applications.

Variable	Coef (β)	Exp(β)	95% CI (OR)	p-value
intercept	1.1698	3.22	(1.60, 6.47)	<0.001
<i>Changes in weather patterns</i>	<i>-0.14214</i>	<i>0.87</i>	<i>(0.78, 0.97)</i>	<i>0.0117</i>
Climate change on farming practices	0.09202	1.10	(0.99, 1.22)	0.0821
Changes in pest pressure	-0.02689	0.97	(0.75, 1.27)	0.8412

OR= Odds ratio

CI= Confidence interval

Source: Researcher (2024)

4.6.6 Regression of Climate Change Perceptions and Agrochemical Usage Decisions

A second regression model was conducted to assess the influence of climate change perceptions on agrochemical usage decisions. As shown in Table 4.14, respondents who

perceived changes in weather patterns were significantly more likely to alter their agrochemical usage decisions (aOR = 1.21, 95% CI [1.06, 1.38], p = 0.005). Perceptions of climate change impacts on farming practices (aOR = 0.94, 95% CI [0.83, 1.07], p = 0.370) and changes in pest pressure (aOR = 1.09, 95% CI [0.80, 1.50], p = 0.577) were not significantly associated with usage decisions.

Table 4. 14

Regression modelling of associations between climate change and agrochemical usage decisions.

Variable	Coef (β)	Exp(β)	95% CI (OR)	p-value
intercept	1.15681	3.18	(1.60, 6.34)	<0.001
<i>Changes in weather patterns</i>	<i>0.19047</i>	<i>1.21</i>	<i>(1.06, 1.38)</i>	<i>0.005</i>
Climate change on farming practices	-0.05730	0.94	(0.83, 1.07)	0.370
Changes in pest pressure	0.09062	1.09	(0.80, 1.50)	0.577

OR= Odds ratio

CI= Confidence interval

Source: Researcher (2024)

4.6.7 Attitudes Toward Climate Change and Agrochemical Use

Belief That Climate Change Poses a Threat

There was a statistically significant relationship between farmers' belief that climate change poses a threat to fresh produce farming and their frequency of agrochemical use (p < 0.001).

All respondents who reported using agrochemicals occasionally acknowledged climate change as a threat. Among daily users, 75% reported the same belief.

Table 4. 15

Association between attitudes toward climate change as a threat and agrochemical use frequency.

Variable	Belief that climate change poses a threat to fresh produce farming						p-value	Corr coef
	Categories	No (%)	Yes (%)	Not sure	Total			
Frequency of agrochemical usage	Never	1 (100)	0 (0)	0 (0)	1 (100)	<0.001	0.028	
	Daily	1 (12.5)	6 (75)	1 (12.5)	8 (100)			
	Weekly	3 (1.2)	224 (94.1)	9 (3.8)	238 (100)			
	Monthly	1 (0.8)	128 (97)	3 (2.2)	132 (100)			
	Occasionally	0 (0)	11 (100)	0 (0)	11 (100)			

Source: Researcher (2024)

Regression analysis confirmed a significant association ($p < 0.05$), indicating that belief in climate change as a threat predicted differences in agrochemical use behavior.

A statistically significant association was found between farmers' belief that climate change influences agrochemical use and three variables: type of agrochemicals used ($p < 0.001$), method of application ($p < 0.001$), and decision-making on agrochemical use ($p = 0.048$).

53.4% of farmers using four types of agrochemicals reported that climate change influenced their use "to a great extent."

Only 6.9% of those using one type reported the same.

Table 4. 16*Associations between beliefs about climate change influence and agrochemical use trend*

Variable	Adjusted OR	95% CI	p-value
Previous experience	Ref	-	-
Recommendation from other farmers	0.45	0.18- 1.10	0.081
Recommendation from experts	3.05	1.12 – 8.32	0.029

*Source: Researcher (2024)***4.6.5 Knowledge on Climate Change and Agrochemical Use**

Awareness of the potential environmental impacts of agrochemicals was significantly associated with decision-making on agrochemical use ($p < 0.001$).

87% of respondents using expert recommendations were aware of environmental impacts.

72.1% of those relying on previous experience, and 48.1% of those relying on farmer recommendations, were aware of environmental impacts.

Table 4. 17*Association between awareness of environmental impacts and agrochemical decision-making*

Variable	Awareness of the potential environmental impacts of agrochemicals				p-value
	Categories	No (%)	Yes (%)	Not sure	
How decisions are made on agrochemical usage	Previous experience	78 (23.6)	238 (72.1)	14 (4.2)	<0.001
	Recommendation from other farmers	8 (29.6)	13 (48.1)	6 (22.2)	
	Recommendation	2 (6.5)	27 (87.0)	2 (6.5)	

from an agriculture
expert

Source: Researcher (2024)

Table 4. 18

Association between awareness of climate change and agrochemical use trends

(Binary Logistic regression)

Variable	Adjusted OR	95% CI	p-value
Previous experience	Ref	-	-
Recommendation from other farmers	0.45	0.18- 1.10	0.081
Recommendation from experts	3.05	1.12 – 8.32	0.029

Source: Researcher (2024)

Regression results indicated that farmers relying on recommended from agricultural experts were three times more likely to be aware of climate change compared to those relying on experience (aOR = 3.05, 95% CI [1.12, 8.32], p = 0.029).

Farmers’ awareness levels varied across sub-counties. In Bahati, some training seminars had been held but reached few participants:

“...still not a lot, you know we call for seminars, but not everyone gets the information, they come like 20 people.”

In Kuresoi North, awareness was limited, often based only on television exposure:

“Not really, most people have just heard of climate change from different media platforms like television, but they don’t know what it is. People haven’t been educated yet...”

In Mau Narok, farmers reported attending meetings organized by field officers and agrochemical companies, but cited financial constraints limiting their ability to act on knowledge:

“People are aware because there are barazas, and these field officers do call us for meetings sometimes.”

4.7 Health and Safety Interventions Adopted by Fresh Produce Farmers

4.7.1 Strategies implemented to prevent potential health impacts

Most respondents (86.6%) reported that they did not implement any specific health and safety measures when using agrochemicals. A smaller proportion (12.6%) indicated that they practiced organic farming as an alternative approach, while only 0.8% reported wearing personal protective equipment (PPEs) as a preventive strategy. When asked about the role of training, 95.6% of the respondents believed that education would “somewhat” ensure safer use of agrochemicals, 3.1% indicated it would help, and 1.3% expressed the view that training would not contribute to improved safety.

Table 4. 19

Strategies implemented to prevent potential health impacts

Variable	Frequency	Percentage (%)
Strategies implemented to prevent health impacts		
None	336	86.6
Organic farming	49	12.6
Wearing PPEs	3	0.8
Strategies influenced agrochemical use		

No	338	87.1
Yes	50	12.9
Continuous education and training		
No	5	1.3
Yes	12	3.1
Somewhat	371	95.6

Source: Researcher (2024)

Note. Percentages are based on the total number of respondents (N = 388).

A binary logistic regression was conducted to examine associations between preventive strategies and health outcomes. Adoption of organic farming and the use of PPEs were both significantly associated with a lower likelihood of experiencing adverse health effects.

Table 4. 20

Association between preventive strategies and health effects (binary logistic regression)

Variable	Adjusted OR	95% CI	p-value
Strategies implemented to prevent health impacts			
None	Ref	–	–
Organic farming	0.55	0.32–0.94	0.028
Wearing PPEs	0.20	0.05–0.85	0.029
Strategies influenced agrochemical use			
No	Ref	–	–
Yes	1.80	1.05–3.10	0.032

Continuous education and training

No	Ref	–	–
Yes	0.70	0.30–1.60	0.400
Somewhat	0.95	0.60–1.52	0.820

Note. OR = odds ratio; CI = confidence interval; Ref = reference category. Source: *Researcher (2024)*

4.7.2 Willingness to enhance safety in fresh produce farming

Findings indicated that 61.1% of respondents were open to adopting new technologies or practices aimed at improving safety and quality in fresh produce farming, while 38.9% were not. Financial limitations were reported as the most significant barrier to safe agrochemical use (68.3%), followed by inadequate resources (21.4%). A smaller group (10.3%) reported no challenges.

Regarding the future of agrochemical use under changing climatic conditions, 80.2% of respondents anticipated increased reliance, while 16.5% expected a decrease, and 1.5% foresaw no change. When asked about adopting climate-resilient farming practices, 59% were unwilling, while 41% expressed willingness to do so.

Table 4. 21

Willingness to enhance safety in fresh produce farming

Variable	Frequency	Percentage (%)
Open to new technologies		
No	151	38.9
Yes	237	61.1

Main challenges related to agrochemical use

Financial constraints	265	68.3
Inadequate resources	83	21.4
None	40	10.3

Evolution of agrochemical use with climatic changes

Decrease	64	16.5
Don't know	6	1.5
Increase	311	80.2
Remain the same	6	1.5

Considering adoption of climate-resilient practices

No	229	59.0
Yes	159	41.0

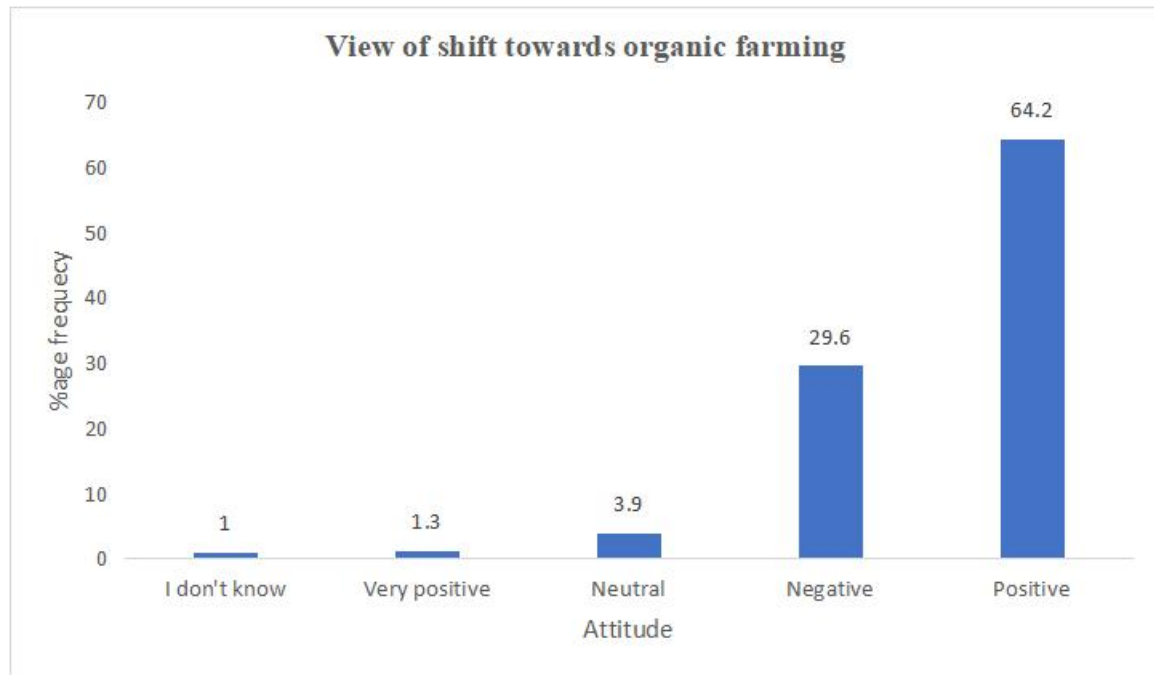
Source: Researcher (2024)

4.7.3 Exploration of sustainable farming practices as alternatives to agrochemicals

A majority of respondents (58%) indicated openness to adopting sustainable farming practices as alternatives to agrochemical use, while 42% reported they were not open. When asked about attitudes toward transitioning to organic farming and reducing reliance on conventional inputs, 64% expressed a positive outlook, 30% reported a negative view, and 1% indicated uncertainty.

Figure 4. 8

View of shift towards organic farming



Source: Researcher (2024)

CHAPTER FIVE: DISCUSSION

5.0 Introduction

This chapter presents the discussion of the study. It presents a discussion of the demographic characteristics of the Fresh Produce Farmers, distribution of Fresh Produce Farmers by type of farming, the socio-economic status of Fresh Produce Farmers using agrochemicals and their associated health effects, Agrochemical use practices among Fresh Produce Farmers, the Occupational Health and Safety measures adopted by Fresh Produce Farmers using agrochemicals, the association between climate change and agrochemical use trends among Fresh Produce Farmers and health and safety interventions that can be adopted by Fresh Produce Farmers using agrochemicals. The overarching goal of the study was to investigate the effects of climate change on agrochemical use and the health of fresh produce farmers in Nakuru County in Kenya.

5.1 Demographic and Socio-Economic Status of Fresh Produce Farmers using Agrochemicals and their associated health effects in Nakuru County, Kenya

In considering the Socio-Economic Status of Fresh Produce Farmers using Agrochemicals and their associated health effects, the descriptive statistics showed that majority of fresh produce farmers are older, aged between 51- 60 years old, with the least dominant age group being 20 - 30 years old. The results are consistent with similar studies that reported the average age of Kenyan farmers is 60 years old (Jayne et al., 2017). This poses a threat to the future of fresh produce farming in Kenya, if the younger generation is not mentored into engaging in the sector. The findings of the study showed that a majority of the Fresh Produce Farmers (51.8%) had completed secondary school, which aligns with a study in Cameroon by Tambe et al. (2023). The study revealed that more females than males are

fresh produce farmers in Nakuru county, which is congruent with several studies in Africa showing that more women than men are fresh produce farmers. This is despite women having limited capacity and knowledge, and because of laws and customs that limit them from accessing and controlling productive resources (Nortje et al., 2023).

From the study findings majority of the respondents, 66%, experienced financial constraints. Most African farmers have limited financial and economic resources to implement safe farming (FAO, 2024b). Warsaw et al. (2021) posits that socio-economic status of farmers can be influenced by various factors such as access to resources. Further, most of the fresh produce farmers did not have cooperative groups. A study by Candemir et al. (2021) shows that financial constraints that farmers face are increased by a lack of membership in cooperative groups that could assist them in investing in safer alternatives to agrochemicals and sustainable farming.

The findings revealed that 32% of the fresh farm produce farmers have experienced some health issues related to agrochemical use. According to Devi et al. (2022), approximately 30% of agrochemicals used in developing countries, especially in Africa, pose a serious threat to human health and the environment since they do not meet internationally accepted quality standards. Lack of knowledge about the harmful effects of pesticide exposure has been reported to have an impact on low rates of adoption of preventive measures when using pesticides (Ziso et al., 2022). There was also an association between experiencing health effects due to Agrochemical use with the type of farming, financial constraints, membership in any farmers' group, and years of experience.

The study showed that financial constraints have a statistically significant association with the development of health effects because of agrochemical use, with fresh farm produce

farmers being approximately 5 times more likely to develop health effects if they have financial constraints compared to those without financial constraints. The findings align with Demi and Sicchia (2021), who in their study posit that the use of agrochemicals has been associated with negative health effects, which are accounted for by financial constraints and limited economic resources. Ziso et al. (2022) in their mixed-method study on Increasing Access to Healthy Foods through Improving Food Environment and (Glasgow, 2019) agree with the findings of the study, arguing that lack of membership in a farmer's organization would result in a risk of developing adverse health effects.

From the study findings, there was a statistically significant association between the development of adverse health effects and years of experience with the use of agrochemicals. The more experienced fresh produce farmers were in the use of agrochemicals; they were found to be 1.3 times more likely to develop adverse health effects. This was in agreement with a study on the Health Risks of Farmers Exposed to Agrochemicals in Bangladesh, which found that Farmers with more experience are more likely to use agrochemicals, which pose a threat to their health (Mahjabeen, 2024). Fresh produce farmers with more experience have had more exposure to toxicity symptoms during pesticide application (De-Assis et al., 2021). It is worth noting that the study findings showed no association between the level of education and the development of health effects. The findings differ of Shahidullah et al. (2023), who argue that low education levels may influence the ability of fresh produce farmers to adapt to modern farming practices and to correctly use agrochemicals.

The study found that 30.4% of the respondents developed health effects because of agrochemical exposure, and 15.7% were not sure. Exposure to agrochemicals is usually underestimated, yet can occur during loading, mixing, and spraying, of which pesticide

residues can be harmful (Sunanda & Ghosh Sachan, 2023). Similar sentiments were shared by Violet et al. (2022) that inappropriate use of agrochemicals poses serious acute and chronic health effects to farmers and consumers of the fresh produce. From the study findings, agrochemical exposure had an association with the socio-economic characteristics of the fresh produce farmers. Specifically, the type of farming, household income, financial constraints, membership in any farmers' group, and years of experience. According to Glasgow (2019), there exists a heightened risk for the development of health effects in fresh produce farmers due to high exposure to agrochemicals driven by socio-economic vulnerabilities.

The study findings further revealed a statistically significant association between the development of health effects because of agrochemical exposure and financial constraints, with an odds ratio of 0.23 for fresh produce farmers who did not have financial constraints. Therefore, fresh produce farmers with no financial constraints were 0.2 times less likely to develop health effects because of agrochemical exposure. Most farmers in the global south cannot afford sophisticated machinery to apply agrochemicals because of financial constraints, accounting for health effects due to agrochemical exposure as a result of using manual farm tools and appliances for agrochemical application (Demi & Sicchia, 2021; Issahaku & Abdulai, 2020).

5.2 The Agrochemical Use Practices in Nakuru County, Kenya

On agrochemical use practices the study showed that 98.5% of the respondents' decision on use of agrochemicals on their farms is influenced by pest infestation, 85.3% because of climate change, 71.6% because of disease management, 52.1% because of weed control, 3.9% because of cost, and government regulations that was selected by 0.5% of the

respondents. This is in agreement with a study by Anaduaka et al. (2023), which found that in Africa, use of agrochemicals continues to dominate fresh produce farms, which farmers consider the best insurance for protecting their crops from pest infestation. Globally, it is estimated that 35% of crop yield is lost because of preharvest pest attack, supporting extensive use of agrochemicals, as stated by Pathak et al. (2022). The findings also revealed that economic pressure played a critical role in the use of agrochemicals for fast results or growth and maturity acceleration of fresh produce. The study findings also agree with a study by Duchenne-Moutien and Neetoo, which posits that climate change is characterized by extreme increases in temperature and alterations in weather patterns that affect food security, which makes most farmers use agrochemicals as a fast alternative for securing their produce (Duchenne-Moutien & Neetoo, 2021).

The study revealed that there is widespread high use of agrochemicals among fresh produce farmers. The findings showed that 96.4% of the respondents used pesticides on their fresh produce farms, 63.1% used fungicides, 59.5% used insecticides, and 41.5% used herbicides. This is congruent with the findings of other studies that have shown a drastic increase in the use of agrochemicals over time, with a growth of 261% in recent years in Africa (Gnanaprakasam & Vanisree, 2022; Sharma et al., 2019). Pesticides are the most commonly used agrochemicals, whose tremendous benefits are when different types are used (Tudi et al., 2022). Herbicides, fungicides, and insecticides are commonly used globally, with insecticides majorly in low- and middle-income countries (LMICs) (Ssemugabo et al., 2022). In modern agriculture, farmers continue to use herbicides, insecticides, and fungicides because they have become effective agrochemicals for increasing agricultural productivity, controlling weeds, diseases, and extending the shelf life of farm produce (Akpan et al., 2023;

Maino et al., 2023; Mukah et al., 2023). The study findings differed from a study by Owemigisha and others done in Uganda, where the researchers found that insecticides were the most commonly used, closely followed by pesticides, while herbicides were the least used (Owemigisha et al., 2024).

The study revealed that 60.8% of the respondents used agrochemicals every week on their farms, with the least, 0.3% never having used agrochemicals. Another study done in Nigeria showed that all its farmers applied agrochemicals every week, confirming the commonness of weekly application as seen in Nakuru county (Ademola et al., 2024). Overuse of agrochemicals is considered to be a contributor to the loss of soil fertility and a major cause of health effects to human beings and disruption of environmental conditions (Anjaria & Vaghela, 2024; Ahmad et al., 2024). Inaccurate application schedule of agrochemicals may lead to adverse effects because of residue leakage, deposit of toxic chemicals, and air pollution (Koka et al., 2022).

The study showed that all the respondents (100%) used spraying as a method for application of agrochemicals, followed by 27.1% that used foliar application, and the least used methods were fertigation and drenching, used by 1% and 0.8% of the respondents, respectively. Foliar application of agrochemicals can improve growth and seed yield, especially by mitigating nutrient stress at reproductive stages (Haakenstad et al., 2022). Fertigation is a modern agro-technique capable of minimizing environmental pollution while maximizing yield (Pibars et al., 2022). Application of agrochemicals through drenching is an effective and economically acceptable method for management of pests (Mao et al., 2022). However, from the study findings, fertigation and drenching were the least used methods of application of agrochemicals in Nakuru County.

The study revealed that the majority (85%) of the respondents considered their previous experience when deciding the method of application of agrochemicals, 8% used recommendations from agricultural extension services, and 7% considered recommendations from other farmers. The findings align with one done in Ghana by Demi and Sicchia, where they found out that most farmers use personal experience to influence their agrochemical use practices (Demi & Sicchia, 2021). The findings also showed that it matters from whom the farmers receive recommendations on the use of agrochemicals, since this influences their knowledge and social learning. Receiving recommendations from extension services is especially critical when farmers' choices not only affect themselves but have a direct impact on their neighbors and the public (Wuepper et al., 2023). Farmers who specifically get advice from public extension services are more likely to engage in protective use of agrochemicals.

From the study, 67% of respondents did not have any future plans of eliminating the use of agrochemicals in their fresh produce farms, with only 8.8% having such plans. However, 24.2% would consider eliminating agrochemical usage. The findings concur with the argument that agrochemical use may increase over the years, especially for crop protection, because of pest abundance and behavior caused by climate change (Punniyakotti et al., 2024). However, farmers are prioritizing sustainability in their markets as well as their environment (AGRA, 2022), which explains the motivation of 24.2% of the respondents who considered the elimination of agrochemical use.

5.3 The Occupational Health and Safety measures adopted in Nakuru County, Kenya

The findings of the study showed that 97% of the respondents practice hand washing after applying agrochemicals, 2% use it sometimes, and 1% do not wash or change clothes after

applying agrochemicals. According to Tudi and others, an important source of exposure to pesticides is through dermal contact with contaminated clothing (Tudi et al., 2022). This makes it a priority for fresh produce farmers to wash their clothing and hands after application of agrochemicals (Aksüt & Eren, 2023).

In the study findings, there was acceptable use of PPEs seen; 69.1% of the respondents always use PPEs when handling agrochemicals, 16% of them use PPEs sometimes while 9.8% rarely use, and 5.2% of them never use any PPEs. Inadequate use of PPEs among fresh produce farmers is an issue in Kenya, which has also been identified in other studies, including (Marete et al., 2021b). In the qualitative data collected in the FGDs, the majority of the respondents reported that they did not use PPEs, which aligns with another study in Kenya by Kinyua and others showing that few applicants of agrochemicals used PPEs when applying agrochemicals (Kinyua et al., 2023).

According to the study, fresh produce farmers did not immediately notice health impacts, and the most frequent ones were headaches, dizziness, rashes, skin irritation, and respiratory issues. This was in agreement with a study by Marete et al. (2021b) on Pesticide usage practices as sources of occupational exposure and health impacts on horticultural farmers in Meru County, Kenya.

The study revealed that 68% of the respondents have not been trained on safe handling and use of agrochemicals, while 22% have been trained, and 10% partially trained. Lack of training is a notable challenge in the implementation of occupational health and safety precautions that play a role in the use of PPEs and adherence to instructions on agrochemical use (Kinyua et al., 2023). More so, the availability of training courses is a significant factor influencing the use of agrochemicals (Owemigisha et al., 2024). From the study, 93.3% of

the respondents always read and followed instructions on agrochemical product labels regarding proper use, handling, and storage, 3.9% followed sometimes, and 2.8% did not adhere to instructions. The findings are contrary to Rother 2018, who argues that most agrochemical end-users in LMICs are unable to comprehend and follow instructions on the agrochemicals (Rother, 2018; Utyasheva et al., 2024).

The study showed that 57% of the respondents conducted safety inspections on an irregular basis, while 42% did weekly inspections. Only 1% of the respondents conducted monthly inspections as part of compliance with OHS standards. The study revealed that 98% of the respondents did not monitor their health regularly because of exposure to agrochemicals, while only 2% did monitor their health. Fresh produce farmers' perception about climate change plays a role in determining their adaptation strategies (Balasha et al., 2023). Farmers' knowledge about extreme weather patterns, including floods, drought, and rising temperatures, will affect the methods of application they use to manage risks by implementing appropriate strategies (Amani et al., 2022).

5.4 Association between Climate Change and Agrochemical Usage Trends

The study revealed that 98.7% of the respondents were aware of climate change and its potential impacts and they believed that climate change posed a significant threat to fresh farm produce. According to Islam et al. (2021), awareness of climate change and its impact on agricultural practices are influenced by indigenous knowledge and traditional farming practices, which (Islam et al., 2021). The study also showed that only 33.8% had noticed changes in local weather patterns in the past decade. The findings align with a study implemented in Nigeria, where the authors noted that while farmers will identify long-term changes in temperature and rainfall, only some can identify them as climate change

(Oluwatimilehin & Ayanlade, 2021). A study in Kenya explains that some of the local weather patterns identified by farmers include droughts, floods, thunderstorms, hailstorms, winds, and temperature changes (Chepkoech et al., 2018).

The study revealed that 98.7% of respondents believed that climate change affected farming practices through its influencing on pest pressure, and precipitation affecting the frequency and volume of agrochemical use to achieve the desired outcome. According to Kalele et al. (2021), climate change events affect agricultural productivity, socioeconomic status of households, and food security, which directly influences the farming practices to mitigate the negative impacts (Kalele et al., 2021). In Kenya, where 98% of agriculture is rain fed and depends on a bimodal rainfall pattern, abnormal changes in rainfall and temperature have threatened agricultural activities, calling for adaptive methods against climate change (Kalele et al., 2021).

The study found that a significant majority of respondents—96.4%—reported noticeable changes in pest pressure, weed growth, and disease incidence in their fresh produce farms, which they attributed directly to climate change. Farmers across all regions of Nakuru County, including Bahati, Njoro, and Mau Narok, described observable increases in both the diversity and aggressiveness of pests and diseases, as well as shifts in weed behavior, which they linked to changing rainfall patterns, rising temperatures, and prolonged dry or wet spells.

These findings corroborate existing literature, particularly the work of Tudi et al. (2021), who assert that climate change intensifies biotic stressors such as insect pest infestations, fungal and bacterial diseases, and weed resistance, all of which compel farmers to adjust their pest management strategies. According to Tudi et al., environmental changes

significantly affect pesticide dynamics, as pest populations tend to flourish in warmer and more humid conditions, prompting increased reliance on chemical controls.

From the qualitative and quantitative data collected in this study, it became evident that climate-related stressors had a direct impact on both the frequency and quantity of agrochemical usage. A considerable number of farmers reported having to spray more frequently—sometimes up to twice as often compared to previous seasons—for the same crop cycle. Others indicated an increase in the volume or concentration of pesticides applied per spraying session due to what they described as "stronger pests" or "weeds that don't die easily anymore."

A farmer from Njoro explained:

"We used to spray once or twice in a season. Now we do it almost every week, especially when the weather changes suddenly. If we don't spray more, we lose everything to pests."

Similarly, another respondent from Mau Narok stated:

"There are new diseases we never used to see. Even the pesticides we trusted before don't work as well. We mix more or try different ones, sometimes stronger ones."

These accounts suggest a trend toward increased pesticide use, both in terms of application frequency and chemical volume, in response to evolving pest behavior and ecological conditions. This intensification not only raises production costs but also increases the risk of environmental contamination, pesticide resistance, and adverse health effects for farmers and consumers.

Furthermore, the need to manage new or re-emerging pests has led some farmers to combine multiple agrochemicals in one spraying round often without professional guidance raising concerns about chemical interactions and the compounding of toxic effects. Others reported shortening spray intervals, sometimes applying pesticides within just a few days of a previous treatment, particularly when wet conditions favored fungal outbreaks.

The findings from this study are consistent with global observations. According to the Food and Agriculture Organization (FAO) and related scientific literature, climate change has led to expanded geographical ranges of pests, faster pest life cycles, and reduced efficacy of certain agrochemicals, necessitating a more intensive pesticide regime (FAO, 2023; Tudi et al., 2021).

The study clearly demonstrates that climate change is a key driver of increased agrochemical use among fresh produce farmers in Nakuru County. Farmers are responding to heightened biotic stress with more frequent and heavier applications of pesticides and herbicides. This trend underscores the urgent need for climate-smart pest management strategies, including integrated pest management (IPM), enhanced extension services, and farmer education to promote safe and sustainable agrochemical use in the face of evolving climatic conditions. The study revealed a weak negative association between climate change and the methods used to apply agrochemicals. Therefore, if fresh produce farmers realized extreme changes in weather patterns, they would use fewer methods they used for applying agrochemicals. The results are consistent with previous studies that argued that fresh produce farmers seek the best methods of application or technologies that will maximize their gross profit and be as efficient as possible in mitigating negative consequences of extreme weather patterns (Ahumada et al., 2023; Reddy et al., 2022). There was a statistically significant association

between changes in climate change (odds of 0.87 and p-value 0.01) and application of agrochemicals, implying that fresh produce farmers in Nakuru who noticed changes in weather patterns over the past few years were 0.89 times less likely to use numerous methods of applying agrochemicals. Lack of information is a significant factor that undermines farmers' ability for good application of agrochemicals and timing (Iyiola et al., 2023). Lack of knowledge and ignorance were considered the primary reasons for unnecessary, excessive, and indiscriminate application of agrochemicals (Khatun et al., 2023).

The study revealed that there was a significant positive association between extreme weather changes and decisions on the use of agrochemicals, which implies that respondents who saw changes in weather patterns over the past years were 1.2 times more likely to make better decisions by using recommendations from experts. The findings are similar to a previous study on farmers' advisory systems, where the authors found a positive and significant relationship between private advisory systems and agrochemical use (Tabe-Ojong et al., 2023). Private and public advisory systems matter in agrochemical usage by farmers, since they are the source of education and training of smallholder farmers (Tabe-Ojong et al., 2023). Recommendations from public extension systems are particularly important in informing environmentally friendly measures (Wuepper et al., 2021).

5.5 Health and safety interventions by Fresh produce farmers using agrochemicals in Nakuru County

In the study, 86.6% of the respondents did not implement any strategies to prevent potential health impacts of agrochemical use on their fresh produce farms; 12.6% of them used organic farming, and 0.85% wore PPEs as a preventive strategy. Africa, despite using the

lowest quantity of agrochemicals compared to other regions, engages in high agrochemical usage patterns that undermine the safety and health of farmers (Demi & Sicchia, 2021b), explaining why a majority of farmers do not implement preventive strategies. Worth acknowledging, organic farming is a beneficial method that takes into consideration key principles including health, fairness to producers and consumers, and the ecology (Gnanaprakasam & Vanisree, 2022).

The study further revealed that 95.6% of the respondents believed that continuous education and training would be essential for ensuring safety in agrochemical usage; 3.1% were somewhat sure, with 1.3% not believing in education and training. According to Humphrey et al. (2023), education and training are useful for the reduction of risks associated with agrochemical use, which is especially important for adequate and comprehensive training on safe farm practices to farmers (Humphrey et al., 2023).

The study showed that 61.1% of the respondents were open to adopting new technologies or practices that would enhance safety and quality in fresh produce farming, and 38.9% were not open to the idea. A study in Tanzania concurs with the findings, explaining that adoption and speed of new technologies by farmers vary since different technologies will have different peak levels of adoption at different time intervals (Ochieng et al., 2022). The most important measure for health and safety interventions is the application of good agricultural practices (Aworh, 2021).

The study revealed that there were challenges respondents faced in the implementation of health and safety interventions related to agrochemical usage, 68.3% mentioned financial constraints, 21.4% mentioned inadequate resources, and 10.3% did not have any challenges.

A lack of resources is a major reason for deficits in the implementation of health and safety interventions, with financial constraint as a leading cause in Africa (Röösli et al., 2022).

In the study, 80.4% of the respondents foresaw an increase in agrochemical usage in response to changing climatic conditions, 16.5% foresaw a decrease, 1.5% were not sure, and 1.5% foresaw no change (remain the same) in agrochemical usage. The findings corroborate with a previous study in Ghana, where the researchers argued that environmental challenges, specifically climate change, are a key factor that causes fresh produce farmers to increase agrochemical usage (Demi & Sicchia, 2021b).

The study revealed that 59% of respondents were not considering the adoption of climate-resilient and regenerative farming practices to mitigate the impact of climate change on fresh farming. According to 2025, climate-resilient agriculture is a significant problem, especially in growing populations, which also faces societal, economic, and technological challenges (Roohi et al., 2025). The study also revealed that 64.2% of the respondents were positive about their shift towards organic farming and reduction of reliance on traditional agrochemicals. Organic farming in Sub-Saharan Africa is increasing with better performance economically than the use of agrochemicals, which is, however, largely heterogeneous (Schader et al., 2021).

5.6 Implications of the Study Findings: Policy, Theory, Practice, and Climate Change Interventions

This study explored the intersection of agrochemical use, health, climate change, and farming practices among fresh produce farmers in Nakuru County. Based on the findings and conclusions, the implications span across policy development, theoretical enrichment, practical applications, and climate change mitigation strategies. This section outlines these

implications in detail, offering a roadmap for stakeholders aiming to enhance sustainability, health, and productivity in smallholder agriculture.

5.6.1 Policy Implications

The findings of this study underscore critical gaps in the regulatory and institutional frameworks guiding agrochemical usage and climate adaptation in Kenya's agricultural sector, particularly among smallholder fresh produce farmers in Nakuru County. These gaps reflect both structural deficiencies such as weak enforcement of existing pesticide regulations and systemic challenges such as inadequate farmer training, low adoption of climate-smart agricultural practices, and limited integration of climate change considerations into agricultural policies. The implications are profound: without targeted public policies, unsafe agrochemical practices will continue to threaten farmer health, consumer safety, and environmental sustainability, while climate variability will exacerbate existing vulnerabilities.

This section expands on the policy implications of the study's findings. It highlights the need for reforms in occupational health and safety (OHS), financial support mechanisms, and integrated climate-agriculture frameworks. It also emphasizes the importance of aligning local agricultural policy with global climate and trade regimes to ensure that farmers not only protect their health and environment but also remain competitive in international markets.

Strengthening Occupational Health and Safety (OHS) Regulations, a striking outcome of the study is the limited adherence to safety standards among farmers handling agrochemicals. Many farmers in Nakuru County apply pesticides without personal protective equipment (PPE), engage in risky behaviors such as eating or drinking during spraying, and lack

awareness of pre-harvest intervals (PHIs). These practices directly contribute to both acute and chronic health risks.

To address this, policies must prioritize the institutionalization of OHS in agriculture. First, there should be mandatory and continuous training programs for farmers and farm workers. Training should not be treated as a one-time activity but rather as an ongoing requirement embedded in county extension services. Farmers should be trained not only in the technical aspects of pesticide application but also in health risk recognition, first-aid responses to exposure, and safer alternatives to chemical use.

Second, policy must ensure stronger enforcement mechanisms. Currently, OHS enforcement in agriculture is weak compared to other sectors such as mining or construction. County governments, through agricultural and health departments, should establish joint enforcement units to monitor compliance with pesticide regulations and OHS standards. This includes conducting farm audits, licensing pesticide retailers, and penalizing unsafe practices.

Finally, there is a need for better coordination between national and county governments. While national policies often establish broad pesticide regulations, their enforcement at the county level remains inconsistent. A coordinated framework that empowers counties to enforce OHS regulations, while ensuring national oversight, would help close this gap.

Subsidies and Incentives for Safer Alternatives

The study highlighted economic constraints as a major determinant of unsafe agrochemical practices. Farmers often cited the high costs of PPE, safer pesticides, or bio-based alternatives as reasons for continued reliance on hazardous chemicals. This finding aligns

with global evidence that financial barriers hinder the adoption of safer practices (Raihan, 2024).

Policy interventions must therefore address affordability. One avenue is targeted subsidies. Governments can provide financial support for protective equipment, either directly through voucher schemes or indirectly by reducing import tariffs on PPE. This would lower the financial burden on farmers and encourage safer practices.

Beyond subsidies, incentive structures are also critical. For example, governments could establish certification schemes for farmers adopting Integrated Pest Management (IPM) or bio-based alternatives. Certified farmers could benefit from preferential access to export markets or premium pricing, creating economic motivation for safer practices. In addition, cooperative-based models could be strengthened, allowing farmers to pool resources for bulk procurement of safer inputs.

Importantly, subsidies and incentives should not only reduce costs but also shift farmer perceptions. By coupling financial incentives with awareness campaigns, policymakers can create a culture where safe and sustainable practices are seen not just as regulatory requirements but as economic opportunities.

Integrated Climate Agriculture Policy Frameworks, one of the most significant findings of this study is the close association between extreme weather variability and farmers' agrochemical use decisions. During periods of erratic rainfall or temperature fluctuations, farmers reported increasing pesticide use to protect crops against climate-induced pest outbreaks. This underscores the fact that pesticide dependency cannot be fully understood without reference to climate stressors.

Current agricultural policy frameworks in Kenya often treat climate change and agrochemical regulation as separate domains. Yet the evidence calls for their integration. Policymakers should develop climate-smart agricultural policies that explicitly address the nexus of pest management, agrochemical use, and climate adaptation.

This integration could take multiple forms, localized climate information services. Farmers require timely and region-specific forecasts to anticipate pest outbreaks linked to weather variations. County extension services should embed climate projections into pest management advisories, ensuring that agrochemical application decisions are weather-smart rather than reactive.

Pest surveillance and predictive modeling, national agricultural research institutions should invest in predictive pest models that use climate data to forecast outbreaks. This would allow proactive interventions, reducing the need for blanket chemical applications.

Weather-smart application guidelines, policies should mandate that extension officers provide farmers with location-specific recommendations on pesticide application, taking into account rainfall patterns, temperature fluctuations, and crop growth cycles. By embedding climate data into agricultural decision-making, policymakers can help farmers reduce unnecessary chemical use while also building resilience against climate-induced shocks.

Aligning Policies with International Trade and Food Safety Standards, fresh produce farmers in Nakuru County, like many in Kenya, participate in both domestic and export markets. Export markets, particularly the European Union, impose stringent maximum residue limits (MRLs) on pesticides. Failure to comply can result in shipment rejections, loss of market access, and reputational damage for the entire sector (Radeny, 2023). Policy must

therefore address both domestic safety and international competitiveness. Strengthening local residue monitoring systems is crucial. This requires investments in laboratories capable of testing pesticide residues in fresh produce before export. Moreover, policies should harmonize Kenya's pesticide regulations with international standards to reduce the risk of non-compliance.

Equally important is farmer capacity building. Many farmers are unaware of MRLs or lack knowledge of safe pre-harvest intervals. Extension services should therefore incorporate training on global trade requirements, linking safe practices with market opportunities. By aligning agrochemical use policies with international trade standards, Kenya can not only protect farmer livelihoods but also enhance its competitiveness in global food systems.

Building Multi-Sectoral and Participatory Policy Frameworks

Finally, the findings highlight the importance of multi-sectoral collaboration in addressing agrochemical risks. Agrochemical use sits at the intersection of health, environment, agriculture, and trade. Yet, too often, policies are developed in silos, with limited coordination across ministries and agencies. A participatory approach to policy formulation is needed, involving farmers, cooperatives, extension officers, health practitioners, and civil society organizations. This would ensure that policies are not only technically sound but also socially grounded and contextually relevant. Moreover, engaging farmers in policy design could enhance compliance and ownership, as farmers would see regulations not as external impositions but as collective solutions to shared challenges.

The policy implications of this study point to the urgent need for comprehensive reforms. Strengthening OHS regulations would address immediate health risks, while subsidies and incentives could remove financial barriers to safer practices. Integrated climate-agriculture

frameworks would bridge the gap between climate adaptation and pest management, while alignment with international trade standards would secure Kenya's position in global markets. Finally, multi-sectoral and participatory policy approaches would ensure that reforms are inclusive, sustainable, and farmer centered.

Together, these policy implications highlight a pathway toward a safer, more resilient, and climate-smart agricultural system in Nakuru County and beyond.

5.6.2 Theoretical implications

The results of this study carry important theoretical implications for the fields of agricultural decision-making, environmental health, and climate change adaptation. By situating the experiences of fresh produce farmers in Nakuru County within broader conceptual frameworks, the findings not only reinforce existing theories but also extend their applicability to new contexts. In particular, the study contributes to three interrelated theoretical domains: risk perception and behavior, the Theory of Planned Behavior (TPB), and climate change adaptation theory.

Risk Perception and Behavior Theory, the risk perception and behavior theory suggests that individual actions in the face of uncertainty are guided not only by objective risks but also by how those risks are subjectively understood. In the agricultural sector, this translates to how farmers perceive threats such as pest infestations, volatile markets, or long-term health consequences of pesticide exposure.

This study affirms the central claim of the theory that behavior is shaped by perceived rather than strictly measured risks. Farmers often prioritized short-term threats, such as crop damage from pests, over long-term health risks associated with pesticide exposure. For many, the immediate fear of losing harvest income outweighed the more abstract concern of

chronic illnesses. This behavioral orientation aligns with other research indicating that smallholder farmers frequently discount future risks when faced with urgent livelihood pressures (Agila, 2025).

Moreover, the study demonstrates how socioeconomic vulnerability magnifies these risk perceptions. Farmers with limited financial resources were significantly more likely to use agrochemicals unsafely, despite awareness of potential health hazards. This suggests that resource constraints narrow the “choice architecture” available to farmers, forcing them into risk-laden practices. Risk Perception and Behavior Theory is therefore extended here to emphasize how structural inequalities particularly income insecurity and lack of access to affordable protective equipment shape not just perceptions of risk but also the capacity to act upon them.

The Theory of Planned Behavior (TPB), the theory of planned behavior (Ajzen, 1991) posits that behavior is driven by attitudes, subjective norms, and perceived behavioral control. The study’s findings align closely with TPB’s propositions while also offering new dimensions to its application in agricultural contexts.

Attitudes, Farmer attitudes toward agrochemicals were ambivalent. While many acknowledged their harmful effects, pesticides were still widely perceived as indispensable for protecting crops. This echoes findings by farmer behavior studies (ResearchGate, 2025) which show that positive yield-related attitudes often override health and environmental concerns.

Subjective norms, Social networks and farmer groups emerged as important influencers of pesticide practices. Farmers often mirrored the behaviors of peers within cooperatives or

local associations, validating TPB's emphasis on the power of norms. Notably, some farmers reported adopting safer practices only after observing others benefit from them.

Perceived behavioral control, Perhaps most significant were the constraints farmers perceived regarding their ability to change practices. High input costs, limited extension support, and inadequate market incentives reduced farmers' sense of control, reinforcing unsafe or excessive pesticide use.

By highlighting these dynamics, the study extends TPB in two ways. First, it underscores the importance of collective-level influences (cooperatives, peer groups) in shaping norms, suggesting that TPB may need to more explicitly account for community structures in agrarian settings. Second, it shows how structural barriers can undermine perceived behavioral control even when attitudes are favorable, thereby limiting the efficacy of individual-level interventions.

Climate Change Adaptation Theory, climate change adaptation theory posits that farmer capacity to respond to climate variability depends on both individual adaptive strategies and institutional support systems. This study provides empirical support for the claim that climate variability directly influences agrochemical use patterns. For example, farmers reported reducing the diversity of application methods during extreme weather conditions, which reflects constrained adaptive capacity under stress.

The findings further show that adaptation is not merely a technical process of adjusting farming practices but a socio-institutional one. Farmer ability to adapt was mediated by access to localized climate information, extension services, and knowledge about Integrated Pest Management (IPM). Without these institutional supports, farmers often defaulted to chemical-intensive practices, even when aware of their long-term risks. This suggests that

Climate Change Adaptation Theory should integrate a stronger behavioral dimension. Adaptation is not only about the availability of technological options but also about how farmers perceive risks, interpret information, and act within their socio-economic constraints. This study therefore extends the theory by emphasizing that adaptation must be conceptualized as both a behavioral and structural process.

Intersections and Theoretical Integration, taken together the findings illustrate the interconnectedness of the three frameworks. Risk Perception Theory explains why farmers may prioritize short-term threats; TPB clarifies how attitudes, norms, and perceived control shape pesticide practices; and Climate Change Adaptation Theory situates these behaviors within broader climatic and institutional contexts. This integration points toward a more holistic conceptual model of farmer decision-making under climate stress. Farmers' agrochemical practices in Nakuru County cannot be fully explained by individual psychology alone, nor by structural climate impacts in isolation. Instead, they emerge at the intersection of perception, behavior, and systemic constraint. Theoretically, this calls for a cross-framework synthesis that bridges behavioral science with adaptation studies.

This study makes three key theoretical contributions. First, it extends Risk Perception Theory by showing how socioeconomic vulnerability shapes both perception and behavior in pesticide use. Second, it enriches the Theory of Planned Behavior by emphasizing collective norms and structural constraints as central to farmer decision-making. Third, it advances Climate Change Adaptation Theory by framing adaptation as a behavioral as well as structural process. Together, these contributions highlight the need for integrated theoretical models that capture the complexity of agricultural decision-making in the era of climate change.

5.6.3 Practical implications

The practical implications of this research are wide-ranging, spanning farm-level decision-making, institutional support mechanisms, and public health interventions. The findings underscore the urgent need for actionable strategies that translate research evidence into real-world practices. These implications are particularly relevant to fresh produce farmers in Nakuru County but also carry lessons for other smallholder agricultural contexts across Sub-Saharan Africa.

Extension Services Enhancement, one of the clearest outcomes of the study is the pivotal role of extension officers in shaping farmer behavior regarding agrochemical use. Extension services function as the primary bridge between scientific knowledge and practical on-farm practices. However, this study reveals that extension officers are often under-resourced, leading to inconsistent farmer training and poor dissemination of climate-smart knowledge. Strengthening extension services must therefore become a cornerstone of agricultural practice. The following practical measures are critical:

Culturally adapted training programs, training should be conducted in local languages and aligned with farmers' cultural contexts to maximize comprehension and adoption. For instance, using local metaphors and analogies can make abstract risks more relatable.

Use of visual and participatory methods, since literacy levels vary widely among farmers, visual aids such as posters, pictograms, and field demonstrations can significantly enhance learning. These approaches have proven effective in narrowing literacy-related knowledge gaps (FAO, 2024).

Regular and accessible sessions, instead of one-off trainings, extension officers should conduct periodic refreshers, ideally aligned with agricultural calendars. This ensures that

knowledge is retained and updated in response to evolving climate conditions. Research emphasizes that effective agricultural extension directly enhances sustainable farming practices, boosts technology adoption, and improves resilience against climate-related shocks (ResearchGate, 2024). Thus, investing in extension services has multiplier effects across productivity, environmental sustainability, and public health.

Promotion of Cooperative Membership, another practical implication concerns the importance of farmer cooperatives and organized groups. Farmers who were members of cooperatives demonstrated greater access to protective equipment, safer handling practices, and timely information about climate-resilient methods.

Strengthening cooperatives carries several practical benefits. Peer-to-peer learning, farmers often learn best from peers, particularly when trust in external institutions is limited. Cooperatives provide platforms for peer exchange, mentoring, and demonstration of best practices.

Collective bargaining power, cooperatives can negotiate lower prices for safer agrochemicals, protective equipment, and even climate advisory technologies. This reduces the financial barriers that frequently prevent farmers from adopting safe practices.

Institutional legitimacy, legally recognized cooperatives are better positioned to access government subsidies, donor programs, and financial services. This institutional support can further strengthen farmers' resilience to climate and market shocks. By reinforcing cooperative structures, governments and NGOs can leverage existing social capital to promote safe, sustainable, and climate-smart farming practices.

Tailored Climate Information Services, the study also highlights the importance of real-time, localized climate information in shaping safe agrochemical practices. Farmers frequently

reported that extreme weather events forced them to adjust pesticide use, often in unsafe ways due to lack of timely information.

The following practical interventions are recommended: Mobile-based advisories, SMS alerts and mobile applications can deliver timely weather forecasts, pest outbreak warnings, and safe application windows. These services should be simplified and available in local languages to ensure accessibility.

Radio and community platforms, since mobile penetration is uneven, community radio programs and local information boards should complement digital platforms. In regions with low literacy, radio remains one of the most trusted and accessible communication channels.

Integration with extension services: Climate information should not operate in isolation but be embedded into broader extension programs. This integration allows farmers to contextualize weather advisories within their broader decision-making frameworks.

As the FAO (2025) notes, extension services that integrate climate advisories not only enhance knowledge dissemination but also build farmers' resilience against climate variability. Tailored information services, therefore, have the potential to reduce unsafe agrochemical practices while simultaneously strengthening climate adaptation.

Public Health and Agro-Dealer Engagement, although not initially emphasized, this study also suggests practical implications for public health authorities and agro-dealers. Public health systems must adopt more proactive roles in monitoring pesticide-related illnesses, while agro-dealers should be engaged as critical intermediaries in promoting safer alternatives. For example, health surveillance systems could integrate agrochemical exposure indicators to track emerging risks among farming communities.

Agro-dealer training programs should emphasize ethical sales practices, ensuring that dealers not only sell but also educate farmers about safe handling and alternatives. This dual approach would complement extension efforts and strengthen the institutional ecosystem surrounding agrochemical use. In practical terms, this study underscores that achieving safe and climate-smart agrochemical practices requires a multi-pronged strategy. Strengthened extension services, empowered cooperatives, and tailored climate information platforms stand out as immediate pathways for improvement. Furthermore, engaging public health systems and agro-dealers adds complementary support structures that enhance farmer resilience and community well-being.

Ultimately, the translation of research findings into practice demands coordinated action from farmers, government agencies, NGOs, and private sector stakeholders. Only through such holistic engagement can the gap between knowledge and practice be bridged, ensuring agricultural sustainability in the face of climate change.

5.6.4 Interventions to mitigate the adverse effects of climate change

The findings of this study highlight that climate change is not only altering the agricultural production environment but also shaping the frequency, timing, and intensity of agrochemical use among fresh produce farmers. Unpredictable weather patterns, new pest dynamics, and heightened crop vulnerabilities have collectively led to increased dependence on agrochemicals, often with unsafe consequences. To mitigate these adverse effects while safeguarding farmer health, food security, and environmental integrity, a set of strategic interventions is proposed.

Climate-Smart Agriculture Training, capacity building is central to reducing agrochemical dependency under changing climatic conditions. Farmers require systematic training in climate-resilient agronomic practices, including:

Integrated Pest Management (IPM): Emphasizing biological controls, such as natural predators and pheromone traps, reduces the need for repeated chemical spraying.

Crop rotation and intercropping: These practices enhance soil fertility and disrupt pest life cycles, thereby minimizing reliance on chemical pesticides.

Adoption of drought- and pest-tolerant varieties: Locally adapted varieties can withstand climatic stressors, lowering susceptibility to pests and reducing the perceived need for heavy agrochemical application.

Such training should be designed to be participatory and context-specific, with field demonstrations that allow farmers to visualize the benefits of alternative practices. The study findings highlighted the need to strengthen agricultural advisory systems through farmer centered approaches significantly enhances adoption of safer agrochemical practices.

Weather-Sensitive Agrochemical Guidelines, climate variability makes traditional agrochemical application schedules increasingly ineffective and unsafe. The development of weather-sensitive guidelines is therefore crucial.

Dynamic Pre-Harvest Intervals (PHIs), adjustments should be made to account for rainfall, humidity, and temperature forecasts that influence chemical persistence and residue breakdown. **Localized advisories:** Mobile-based systems and community radio platforms can deliver region-specific recommendations on safe spraying windows.

Pest and disease early warning systems: Linking weather forecasts with pest surveillance can allow farmers to anticipate outbreaks and plan interventions in advance, reducing the

need for excessive spraying. Such measures ensure that agrochemical use is not only safer but also more efficient, minimizing waste while protecting consumer health.

Research and Development Support, technological innovation is a critical driver of sustainable adaptation to climate-agrochemical interactions. Investment in locally relevant research and development (R&D) can generate safer and more effective alternatives. Promising areas include precision spraying technologies, tools such as drone-assisted application and solar-powered sprayers ensure that chemicals are applied accurately and in optimal quantities, reducing exposure and environmental contamination.

Biodegradable and bio-based pesticides, innovations in plant-based formulations can reduce toxic residues and mitigate long-term ecological harm. Soil health research, advancing knowledge of regenerative soil management can help farmers build resilience naturally, reducing reliance on external inputs.

The findings underscore the need for locally adapted innovations, as imported technologies often fail to address the unique socio-economic and agro-ecological conditions of Kenyan smallholder farmers.

Public-Private Partnerships addressing climate-agrochemical challenges requires collective action that transcends individual farmers. Public-private partnerships (PPPs) present an opportunity to mobilize resources, knowledge, and distribution networks. Possible initiatives include: Safe-use kits, partnerships with agrochemical companies can ensure that every chemical purchase includes protective gear and user-friendly application guides. Mobile residue-testing units, Collaborative efforts with NGOs and universities could provide affordable testing services, empowering farmers and consumers with knowledge of food safety. Awareness campaigns, jointly funded campaigns can disseminate information on the

climate-health nexus of agrochemical misuse, reaching both rural farmers and urban consumers. Such collaborations align incentives across stakeholders, fostering a shared responsibility for sustainable agriculture and public health.

5.6.5 Broader societal and health implications

Beyond direct impacts on farmers, the findings of this study point to far-reaching societal and health consequences of climate-driven agrochemical use. These implications extend from individual well-being to public health systems and consumer safety, necessitating a multi-sectoral response.

Farmer Health and Occupational Safety, farmers remain the most vulnerable group due to direct exposure during mixing, spraying, and post-application handling. Climate variability exacerbates this exposure by increasing spraying frequency, often under unsafe weather conditions such as high winds or extreme heat. The result is heightened risks of acute poisoning, respiratory illnesses, and long-term conditions including cancers and neurological disorders. Integrating agrochemical exposure monitoring into rural health services can help identify emerging health patterns. Routine screening, coupled with medical record tracking, would provide critical data for policy and intervention design.

Public Health and Food Safety, agrochemical residues in food systems pose significant risks to consumers. Fresh produce, consumed raw or with minimal processing, is especially vulnerable. As weather fluctuations disrupt PHIs, residues may persist beyond safe levels. This has implications for both local consumption and international trade, where stringent residue limits often determine market access.

Consumer protection agencies should prioritize awareness campaigns on safe food handling, including washing, peeling, and storage techniques to reduce residue exposure. Community-

based surveillance systems could also be mobilized to monitor misuse and report adverse health events.

Food Security and Climate Resilience, over-reliance on agrochemicals as a response to climate stress undermines long-term food security. While chemical inputs may deliver short-term yield gains, they degrade soil health, reduce biodiversity, and exacerbate climate vulnerabilities through greenhouse gas emissions and ecosystem disruption.

This study reinforces that sustainable food security requires diversified adaptation pathways, combining improved agrochemical regulation with ecosystem-based approaches such as conservation agriculture and agroforestry. Without such balance, the cycle of chemical dependency will perpetuate both health and climate risks.

Multi-Sectoral Response, the complexity of the agrochemical-climate-health nexus demands coordinated action across agriculture, health, environment, and education sectors. Key elements of a multi-sectoral response include: Education, Integrating climate-smart agrochemical management into school curricula and farmer training programs. Regulation, strengthening cross-sectoral enforcement mechanisms to monitor residues, protect farmers, and guide agro-dealers. Research and innovation, supporting interdisciplinary studies on the linkages between climate change, chemical use, and health outcomes. Community engagement, empowering farmers and consumers as active participants in monitoring and decision-making processes.

Failure to address the intersection of climate change and agrochemical use carries profound risks for human health, food security, and environmental sustainability. However, with targeted interventions spanning farmer training, technology innovation, tailored weather-sensitive guidelines, and multi-sectoral engagement these risks can be significantly

mitigated. Building such resilience is not only vital for Nakuru County but also provides lessons for broader agricultural systems across the Global South.

CHAPTER SIX: CONCLUSION, RECOMMENDATIONS, AND PUBLICATIONS

6.1 Introduction

This chapter summarizes findings, highlights contributions to knowledge, and provides recommendations for policy, practice and further research. It further outlines the practical and policy implications of the findings and provides targeted recommendations for practice, policy, and further research. The chapter closes the thesis by situating the study within the broader discourse on climate change, agrochemical use, and occupational health, particularly in the Kenyan smallholder fresh produce farming context.

6.2 Summary of Major Findings

The study examined the intersection of climate change perceptions, agrochemical use practices, and health effects among fresh produce farmers in Nakuru County, Kenya. Several key findings emerged: Agrochemical use and health effects, a high proportion of farmers reported exposure to agrochemicals, with significant associations between financial constraints and likelihood of reporting health symptoms related to exposure.

Farmers facing financial limitations were nearly five times more likely to experience adverse health outcomes compared to those without financial barriers.

Experienced farmers with more than 15 years of agrochemical use in fresh produce farming were at a higher risk of developing adverse health effects due to agrochemical use with 1.3 times higher likelihood of developing adverse health effects compared to those with fewer years of experience.

Climate change perceptions and agrochemical practices, farmers widely perceived climate variability, especially erratic rainfall and temperature extremes, as affecting their farming.

Perceptions of changing weather patterns significantly influenced both the frequency and decision-making processes around agrochemical use. For instance, those perceiving extreme weather changes were more likely to rely on experts rather than past experience for decision-making. Farmers noticing extreme weather were 1.2 times more likely to rely on expert advice as opposed to previous experience when making agrochemical use decisions.

Agrochemical application practices, spraying remained the predominant method of application, with most farmers relying on previous experience rather than technical guidelines.

Regression analysis indicated a negative association between perceived climate change and the number of application methods used, but a positive association with decisions to increase chemical inputs such as herbicides and fungicides. Knowledge, training, and safety practices, while many farmers practiced basic hygiene such as handwashing after application, fewer consistently used PPE. A majority reported never receiving formal training on safe agrochemical handling, and safety inspections were irregular.

Preventive strategies and willingness to adapt, few farmers had adopted structured preventive strategies; most cited cost as a major barrier. Willingness to adopt climate-smart and alternative sustainable farming practices was high, but constrained by limited financial resources, inconsistent extension services, and lack of affordable inputs.

6.3 Scientific Contribution

This study makes several contributions to knowledge. Empirical linkage, it provides one of the first epidemiological analyses in Kenya explicitly linking climate change perceptions, agrochemical use patterns, and health outcomes in fresh produce farming. Context specific

evidence, the findings move beyond generic global claims by providing locally grounded, quantitative evidence from Nakuru County.

Policy-relevant insights, the study demonstrates how financial constraints and weak extension services interact with climate change to perpetuate hazardous agrochemical practices negatively affecting the health of fresh produce farmers. This fills a documented gap in the literature, where occupational health has rarely been examined alongside climate change in smallholder agricultural contexts.

Methodological innovation, by using mixed methods integrating household surveys with regression modelling and qualitative farmer narratives, the study presents a multidimensional understanding of agrochemical use in the face of climate variability.

6.4 Conclusion

In addressing the research objectives, several conclusions are drawn including agrochemical exposure and health, farmer health risks are not merely a function of exposure but are compounded by socioeconomic status, particularly financial constraints. This highlights the social gradient in occupational health within smallholder farming.

Climate change and agrochemical use, climate change perceptions directly shape agrochemical practices. Farmers who recognize climatic changes adjust application frequency, adopt additional chemical types, or alter their decision-making sources. This establishes a novel link between climate variability and occupational exposures.

Training and safety, while awareness of risks exists, the absence of structured, continuous training and affordable protective gear undermines safe handling. Reliance on irregular safety checks and informal learning perpetuates unsafe practices. Adaptation pathways, although farmers are open to adopting climate-smart and sustainable practices, structural

barriers, notably financial limitations and weak institutional support hinder effective transitions.

Knowledge gaps and limitations, the study relied partly on self-reported symptoms and practices, which may under or over-estimate prevalence. However, triangulation with qualitative narratives and regression modelling strengthened validity.

6.5 Recommendations

Based on the findings, the following recommendations are advanced. They are organized by policy, practice, and research, and prioritized by feasibility and potential impact.

6.5.1 Policy recommendations

Integrate climate change and occupational health into agricultural policy: National and county-level policies should explicitly address the health risks of agrochemical exposure in the context of climate variability.

Subsidize and regulate PPE: Government and county programs should subsidize protective gear, ensuring affordability and compliance, while establishing stricter enforcement of occupational health standards.

Strengthen extension services: Recruit and train more agricultural officers to provide continuous, localized support on climate-smart agrochemical use and sustainable alternatives.

Target experienced farmers with more than 15 years of agrochemical use with accessible routine health screenings and refresher trainings on safe agrochemical use.

6.5.2 Practice Recommendations

Promote climate-smart pest management: Encourage adoption of Integrated Pest Management (IPM) and agroecological practices that reduce reliance on synthetic chemicals.

Enhance cooperative structures: Support farmer cooperatives to pool resources, reduce financial vulnerability, and access safer technologies and alternatives.

Embed continuous training: Establish farmer training programs that are iterative and community-based, ensuring knowledge transfer across generations.

6.5.3 Research Recommendations

Longitudinal health studies: Future research should track long-term health outcomes of agrochemical exposure in relation to climate change to establish causal pathways.

Intervention trials: Test the effectiveness of providing subsidized PPE, climate-smart alternatives, or extension packages on reducing exposure and improving health.

Economic feasibility studies: Assess cost-benefit trade-offs of shifting from high-chemical input systems to climate-resilient, low-input farming models.

6.6 Publications

Kirongo, D., Kubai, P., & Rutto, J. (2025). Climate change effects on agrochemical use trends and health of fresh produce farmers in Nakuru County, Kenya: Exploring emerging associations. *Stratford Journal of Medicine and Nursing Practice*, 6(2), 44–59. <https://stratfordjournalpublishers.org/journals/index.php/Journal-of-Medicine-Nursing-P/article/view/2555>

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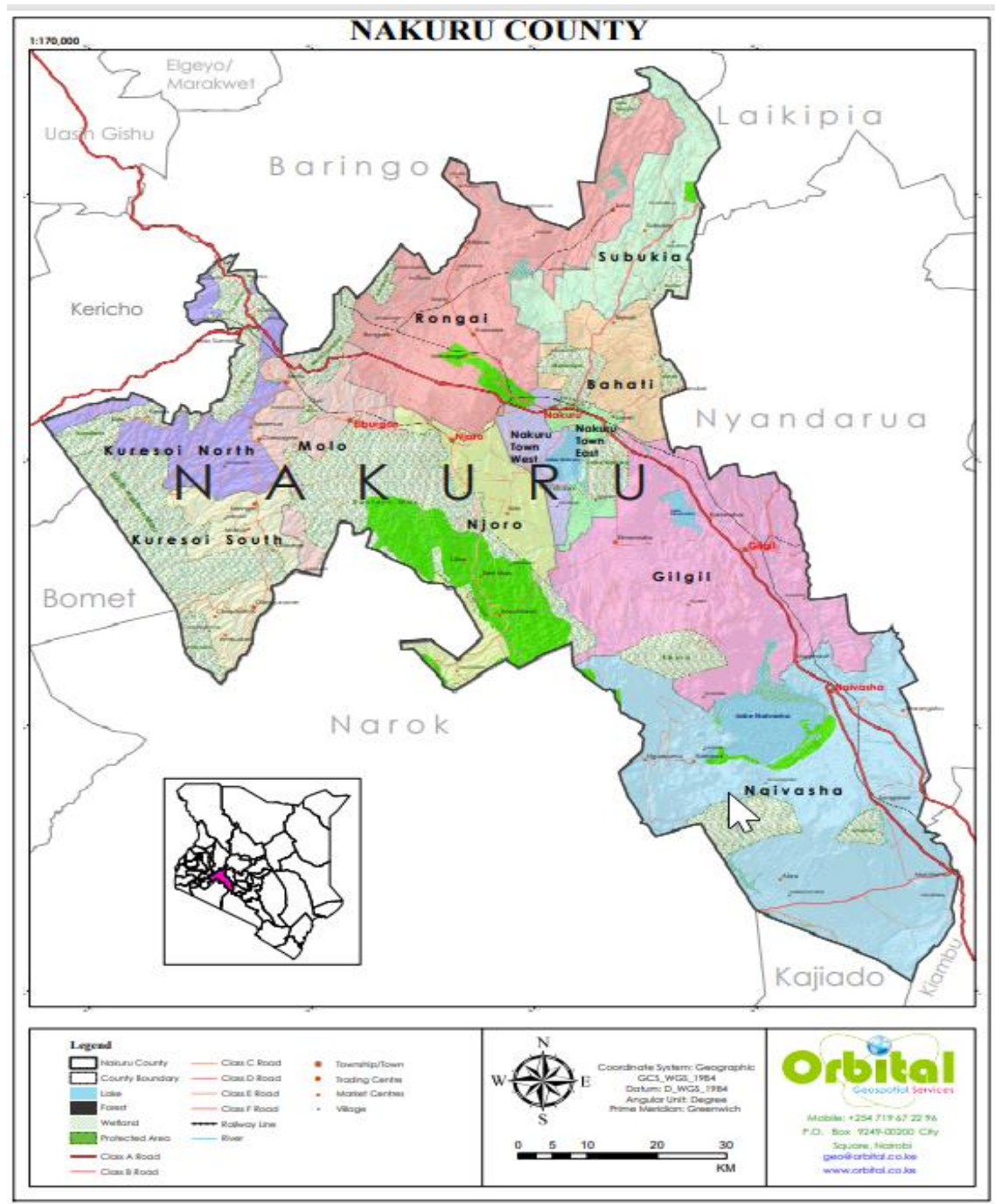
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APPENDICES

Appendix A: Nakuru County and 11 Sub-Counties



Appendix B : Informed Consent Document (ICD)

Study Title: Effects of climate change on agrochemical use and health of fresh produce farmers in Nakuru County, Kenya.

Respondents (Farmer's) Name: -----

Principal Investigator: Kirongo David Kihara

This informed consent Form has two parts

- Information sheet (to share information about the study with participants)
- Certificate of consent (for signatures if you choose to participate)

Part I: Information Sheet (to share information about the study with participants)

Introduction

We are/I am conducting a study to evaluate the Effects of climate change on agrochemical use and health of fresh produce farmers in Nakuru County to ascertain the practices and health effects among fresh produce farmers and come up with interventions to mitigate the negative impacts. To be sure that your/institution is/are informed about being in this research, you are being asked to read (or will read to you) this consent form. The purpose of this consent form is to give you/institution the information you/it will need to help you/it decide whether to participate in the study. Please read the form carefully. You may ask questions about the purpose of the research, what I/we would ask you to do, the possible risks and benefits, your rights as a participant, and anything else about this research or this form that is not clear.

Before you decide if you wish to be in this study, you need to know about any good or bad things that may affect you if you decide to join. This form tells you about the study. This consent form may contain some words that are unfamiliar to you. Please ask us to

explain anything you may not understand.

Being in the Study is Your Choice

When we have answered all your questions, you can decide if you want to participate in the study or not. This process is called ‘informed consent. This consent form gives you information about the study, and the risks involved will be explained to you.

Once you understand the study, and if you agree to take part, you will be asked to sign your name or make your mark on this form in the presence of a witness. We will give you a copy of this form for your records.

Before you learn about the study, you must know the following:

- Your participation in this study is entirely out of your choice (voluntary).
- You may decide not to answer questions, give any specimens, or even withdraw from the study at any time.

Purpose of the Study: Research

The purpose of the study is to evaluate the Effects of climate change on agrochemical use and the health of fresh produce farmers in Nakuru County. The study shall examine the demography, distribution, and the relationships between the farmers’ socioeconomic status, education level, risk perception, personal protection, and precautions taken in the use of agrochemicals, volume and frequency of use of agrochemicals in relation to the climate change and health challenges they suffer.

Study Participants

The study participants will include Fresh produce farmers in Nakuru County who have lived in the research region for at least two years, and those who will willingly sign the consent form to show their willingness to be part of the study. The study will also

include key stakeholders in the fresh produce farming sector, such as agriculture extension workers, local administrators, farm workers, and their family members.

Length of study and Procedures

If you agree to participate in this study by signing at the end of this form (ICD), you will participate in the following activities: You will be questioned about agrochemical use practices related to this study such as; socio economic status, education level, risk perception, personal protection and precautions taken in the use of agrochemicals, volume and frequency of use of agrochemicals in relation to the climate change and health challenges.

We shall also request you to provide us with any known or perceived health effects or illnesses that have resulted from due or exposure to agrochemicals, frequency and duration of exposure to agrochemicals in your daily work, quantity and method used to apply the agrochemicals to the crops.

We will observe you during your normal working/application of agrochemicals in the farm and document the process, We will also hold group discussions called Focus Group Discussions with other farmers to discuss the challenges and opportunities of agrochemical use in fresh produce farming, market dynamics, and common challenges you face.

Precautions

There will be no direct contact with any hazardous materials, and therefore, no risk will be associated with the study. The team of well-trained and experienced research staff will guide you through this exercise and will take all necessary precautions to ensure ultimate safety and confidentiality of information accessed and documents reviewed.

Possible Risks/Discomfort

There will be no disturbing encounters during the interviews and observations. You may feel uncomfortable during the interview due to the explicit nature of some questions, including loss of privacy, but safeguards will be implemented to minimize this risk. We will minimize risk and discomfort from the interview by using a trained staff to place you at ease during the interview. You may skip any questions that you do not want to answer and may terminate the interview at any time without consequence. You will also be free to withdraw from the study at any time you feel like.

Data Security and Confidentiality

All the information gathered by the research team will be used in confidence for the sole purpose of this research. Any records relating to your identity and shared information will remain confidential. The names, results, and findings will not be put (divulged in any report of the results, and you will receive a copy of this consent form. No one will be allowed access to the interviews except the researchers and supervisors. The study team will give results and feedback immediately for the analysis and investigations done. Strict data management procedures are in place to ensure the confidentiality of the study subjects.

New Findings

Results will be distributed/ disseminated to the relevant specific institutions, departments, and health ministries in Kenya, Nakuru County Government, and other stakeholders in the country.

The findings will be used to provide information necessary for the design of interventions to ensure safe use of agrochemicals, design interventions to reduce risk of environmental

degradation and adverse health effects resulting from agrochemical use and propose approaches to dealing with the climate change that negatively affect the use of agrochemicals in fresh produce farming in Nakuru County.

Benefits of taking part in this study

Results obtained will aid in providing information necessary for the design of interventions to ensure safe use of agrochemicals, design interventions to reduce risk of environmental degradation and adverse health effects resulting from agrochemical use and propose approaches to dealing with the climate change that negatively affect the use of agrochemicals in fresh produce farming thereby help in improving your farming methods, crop yields, environmental safety your health and the health of consumers of your fresh produce.

Costs to you

There will be no cost for participating in the study.

Reimbursement

As a participant in this study, you will not be reimbursed for out-of-pocket expenses incurred to visit the study site.

If You Decide Not to Be in the Research

You are free to decide if you want to be in this research. Your decision will not affect you in any way.

Leaving the Research

If you choose to be in the study, you can still decide not to complete the interview. If you leave the study, please tell the interviewer why you are leaving so that this information can be used to improve our work and provide more support if possible.

Problems and Questions about the study

If you ever have questions about this study, you should contact: Kirono David Kihara, Study Principal Investigator, (Mobile: +254 722 922 733) or the Institutional Review Ethics Committee (IREC) on 05333471 ext. 3008

Your Rights as a Participant

This research will be reviewed and approved by the School of Health Sciences ethics review committee and obtain clearance from the Ethical Review Committee of the Meru University of Science and Technology (MIRERC). If you have any questions about your rights as a research participant, you may contact +254 722 922 733.

Part II: Certificate of consent (for signatures if you choose to participate)

Your Statement of Consent and Signature

If your institution has read the informed consent, or had it read and explained to you, and you understand the information and provision of the evaluation of Effects of climate change on agrochemical use and health of fresh produce farmers hereby agree to join this study, please carefully read the statements below and think about your choice before signing your name or making your mark below. No matter what you decide, it will not affect your rights in any way:

- The risks and benefits involved in this study have been read and explained to me.
- I/We will be given the chance to ask any questions I may have, and I am content with the answers to all of my questions.
- I/We know that my/our records will be kept confidential and that I may leave this study at any time
- I/We will be given the name, phone number, and address of whom to contact in case of

an emergency, which has been handed over to me and given to me in writing.

- I/We agree to freely take part in this study as a volunteer, and will be given a copy of this informed consent form to keep

Participant's Name/Designation. Signature/Participant thumb print (can't sign)

Date/Time

Name of Representative/witness. Relationship to Participant

Name of Person obtaining consent. Signature of Person taking
consent Date/Time

Name of Investigator. Signature of

Investigator Date/Time

NOTE: You are not giving up any of your legal rights by signing this informed consent document.

Appendix C: Questionnaire

Title: Questionnaire on Effects of climate change on agrochemical use and health of fresh produce farmers.

Introduction:

Thank you for participating in this study. The purpose of this questionnaire is to gather information about the impact of climate change on agrochemical use and its associated health effects among fresh produce farmers. Your responses will contribute to understanding the challenges faced by farmers and inform strategies for sustainable agriculture. Please answer each question to the best of your knowledge and experience.

Section 1: Demographic Information

1. Gender:
 - Male
 - Female
 - Other (please specify)

2. Age:
 - Under 20
 - 20-30
 - 31-40
 - 41-50
 - 51-60
 - Over 60

3. Educational Background:
 - Primary School

Secondary School

Vocational/Technical School

Bachelor's Degree

Master's Degree

Ph.D. or Equivalent

4. Marital Status:

Single

Married

Divorced

Widowed

Section 2: Socio-Economic Status and associated health effects

1. Type of Farming:

Subsistence farming

Commercial farming

Mixed farming

Size of Farm (in acres/hectares): _____

2. Types of Fresh Produce Cultivated (select all that apply):

Fruits

Vegetables

Herbs

Other (please specify)

3. Household Income Level:

Below the poverty line

Lower middle class

Middle class

Upper middle class

Upper class

4. How do you perceive the economic viability of your farming activities?

- Very viable

- Viable

- Somewhat viable

- Not viable

5. Are there any financial constraints that limit your ability to invest in safer alternatives to agrochemicals?

- Yes

- No

6. Have you or any of your workers experienced any adverse health effects due to agrochemical exposure?

Yes

No

Not sure

7. Have you experienced any health issues that you believe are related to agrochemical usage?

- Yes

- No

If yes, please specify the health issues you have experienced (e.g., skin irritation, respiratory problems, etc.):

Are you aware of any long-term health effects associated with the agrochemicals you use?

- Yes

- No

If yes, please specify the long-term health effects you are aware of:

9. What is your primary source of income?

Are you a member of any farmer groups or cooperatives?

10. Have you received any training related to farming practices or agrochemical use?

What types of crops do you primarily grow?

How many years have you been involved in fresh produce farming?

Section 3: Agrochemical Use Practices among Fresh produce farmers

11. What factors influence your decision to use agrochemicals on your farm?

(Check all that apply.)

Pest infestation

Weed control

Disease management

Cost-effectiveness

Government regulations

Climate conditions

Other (please specify)

12. Types of Agrochemicals Used (select all that apply):
- Pesticides
 - Herbicides
 - Fungicides
 - Insecticides
 - Other (please specify)
13. Frequency of Agrochemical Usage:
- Daily
 - Weekly
 - Monthly
 - Occasionally
 - Never
14. What methods do you use to apply agrochemicals? (Check all that apply.)
- Spraying
 - Drenching
 - Fertigation
 - Foliar Application
 - Other (please specify)
15. How do you decide which agrochemicals to use on your crops?
- Recommendations from agricultural extension services
 - Previous experience
 - Recommendations from other farmers
 - Consultation with agronomists

Other (please specify)

16. Do you have any plans to reduce or eliminate the use of agrochemicals on your farm in the future?

- Yes

- No

- Considering

17. If yes, what alternative methods or practices are you considering?

Additional Comments:

How do you dispose of empty agrochemical containers and leftover spray solutions?

18. Do you observe the recommended pre-harvest interval (PHI) before harvesting crops after applying agrochemicals?

Do you wash your hands and change clothes after applying agrochemicals?

Section 4: Occupational Health and Safety Measures Adopted by Fresh produce farmers

19. Do you and your workers use personal protective equipment (PPE) when handling agrochemicals?

- Always

- Sometimes

- Rarely

- Never

20. Are you and your workers trained in the safe handling and application of agrochemicals?

Yes

No

Partially

21. Have you or any of your workers experienced any adverse health effects due to agrochemical exposure?

Yes

No

Not sure

22. Do you use any protective measures (e.g., gloves, masks) while handling agrochemicals?

- Always

- Sometimes

- Rarely

- Never

23. Do you always read and follow the instructions on agrochemical product labels regarding proper use, handling, and storage?

24. How often do you conduct safety inspections on your farm to ensure compliance with Occupational Health and Safety standards?

Weekly

Monthly

Quarterly

Annually

Irregularly

1. Do you monitor your health regularly due to exposure to agrochemicals?

Yes

No

If yes, please specify the type of health monitoring conducted:

Section 5: Association between climate change and agrochemical use among Fresh produce farmers

2. How would you rate your awareness of climate change and its potential impacts on agriculture?

Very Aware

Moderately Aware

Slightly Aware

Not Aware

3. Have you noticed any changes in local weather patterns or climate conditions in the past decade that you believe are linked to climate change?

Yes

No

If yes, please describe.

4. Do you believe that climate change poses a significant threat to fresh produce farming in your region?

Yes

No

Somewhat

5. Have you noticed any changes in local weather patterns over the past few years? If yes, please describe these changes.

6. How has climate change affected your farming practices, if at all? (e.g., changes in planting seasons, pest/disease outbreaks)

7. To what extent do you believe climate change has influenced the need for agrochemical use in fresh produce farming? (scale: 1 - Not at all, 5 - To a great extent)

8. Are you aware of the potential environmental impacts of agrochemical use?

Yes

No

Somewhat

1. Do you take any measures to mitigate the environmental impact of agrochemicals?

Yes

No

If yes, please specify.

2. Have you observed any changes in pest pressure, weed growth, or disease incidence on your farm that you attribute to climate change?

Yes

No

If yes, please specify.

Section 6: Health and safety interventions that can be adopted by Fresh produce farmers

3. What strategies, if any, have you implemented to prevent the potential health impacts of agrochemical use on your fresh produce farm?

4. Have these adaptation strategies influenced your agrochemical use in any way?

Yes

No

If yes, please explain

1. Do you believe that continuous education and training are essential for ensuring safety in agrochemical usage?

Yes

No

Somewhat

2. Are you open to adopting new technologies or practices that enhance safety and quality in fresh produce farming?

3. What are the main challenges you face in implementing health and safety interventions related to agrochemical use?

Challenge: _____

1. Do you have any suggestions for improving health and safety practices in fresh produce farming using agrochemicals?

2. How do you foresee your agrochemical use evolving in response to changing climate conditions?

3. Are you considering adopting climate-resilient and regenerative farming practices to mitigate the impact of climate change on your fresh produce farming?

4. Are you open to exploring sustainable farming practices as an alternative to heavy agrochemical use?

Yes

No

If yes, please explain

1. How do you view the shift towards organic farming and the reduction of reliance on traditional agrochemicals?

15. Do you have any additional comments or insights you would like to share regarding the relationship between climate change, agrochemical use, and health effects in fresh produce farming? Thank you for participating in this study. Your input is valuable in addressing the challenges posed by climate change in agriculture and health.

Appendix D: Key Informant Interview Guide

Key Informant Interview Guide: Effects of climate change on agrochemical use and health of fresh produce farmers

Introduction:

Thank you for agreeing to participate in this key informant interview. The purpose of this interview is to gain insights into the impact of climate change on agrochemical use and its associated health effects among fresh produce farmers. Your expertise and experiences are crucial in understanding the complexities of this issue. The information gathered will contribute to informing strategies for sustainable agriculture. Your responses will be kept confidential and used solely for research purposes.

Background Information:

- a. Could you please provide a brief overview of your experience and expertise in fresh produce farming?
- b. How long have you been involved in fresh produce farming?
- c. Have you noticed any significant changes in local weather patterns and climate conditions over the years?

Socio-Economic Status and associated health effects

2. What are the demographic and socioeconomic characteristics of farmers who use agrochemicals in their farming practices, and how do these characteristics influence their adoption of sustainable agricultural practices?
3. How do the socioeconomic benefits of adopting Good Agriculture Practices (GAP) in Fresh Produce production, such as improved health outcomes and reduced agrochemical use, vary across different farming sectors and regions?

4. How do the attitudes of Fresh produce farmers towards organic farming, and their perceptions of pesticide safety behavior, influence their adoption of sustainable agricultural practices and the health effects associated with agrochemical use?
5. Have you or any of your workers experienced any adverse health effects due to agrochemical exposure?
6. Have you experienced any acute health effects that you believe are related to agrochemical usage?
7. Are you aware of any long-term health effects associated with the agrochemicals you use?
8. Based on your experience, what are the primary health risks associated with agrochemical exposure among fresh produce farmers?
9. Have you encountered any instances where farmers or farmworkers have suffered health issues related to agrochemical use? If so, could you provide some examples?
10. How do farmers in your community typically address or mitigate the health risks associated with agrochemical exposure?

Agrochemical Use Practices among Fresh produce farmers

1. What factors influence your decision to use agrochemicals on your farm?
2. What types of Agrochemicals do you use on your farm?
3. How often do you use Agrochemicals on your farm?
4. What methods do you use to apply agrochemicals?
5. How do you decide which agrochemicals to use on your produce?
6. Do you have any plans to reduce or eliminate the use of agrochemicals on your farm in the future?

7. Do you observe the recommended pre-harvest interval (PHI) before harvesting crops after applying agrochemicals?

Occupational Health and Safety Measures Adopted by Fresh produce farmers

1. What types of agrochemicals do you use in your farming practices?

2. How often do you use agrochemicals on your farm?

3. Do you follow any specific practices to minimize agrochemical use, such as integrated pest management or organic farming methods?

4. What types of equipment do you use to apply agrochemicals (e.g., knapsack sprayers, motorized sprayers)?

5. How do you dispose of empty agrochemical containers and leftover spray solutions?

6. Do you wash your hands and change clothes after applying agrochemicals?

Association between climate change and agrochemical use trends among Fresh produce farmers

1. What is the size of your fresh produce farm (in acres/hectares)?

2. How would you rate your awareness of climate change and its potential impacts on Fresh Produce Farming?

3. Have you noticed any changes in local weather patterns or climate conditions in the past decade that you believe are linked to climate change? If yes, please describe.

4. Do you believe that climate change poses a significant threat to fresh produce farming in your region?

5. What strategies, if any, have you implemented to adapt to the potential impacts of climate change on your fresh produce farm?

6. Have these adaptation strategies influenced your agrochemical use in any way? If yes, please explain.

Health and safety interventions that can be adopted by Fresh produce farmers

1. Do you believe that continuous education and training are essential for ensuring safety in agrochemical usage?

2. Do you always read and follow the instructions on agrochemical product labels regarding proper use, handling, and storage?

3. Are you familiar with the regulations and guidelines set by authorities regarding the safe use of agrochemicals in fresh produce farming?

4. Do you believe that certification systems for safe produce production can benefit both farmers and consumers?

5. Do you have any plans to reduce or eliminate the use of agrochemicals on your farm in the future?

6. Are you open to adopting new technologies or practices that enhance safety and quality in fresh produce farming?

Additional Insights:

a. Is there any additional information or insights you would like to share regarding the relationship between climate change, agrochemical use, and health effects in fresh produce farming?

Conclusion:

Thank you once again for your valuable input and expertise. Your insights will contribute significantly to advancing our understanding of the complexities surrounding climate change impacts on agriculture. If you have any further comments or would like to elaborate on any

point discussed, please feel free to do so. Your participation in this interview is greatly appreciated.

Appendix E: Observation Guide

Observation Guide: Effects of climate change on agrochemical use and health of fresh produce farmers

Introduction:

This observation guide is designed to facilitate the systematic observation of climate change-related factors, agrochemical use practices, and potential health effects among fresh produce farmers. The observations gathered using this guide will complement other data collection methods in the study, providing valuable insights into real-time farming activities and their implications. Please adhere to ethical guidelines and seek consent from farmers before conducting observations.

Setting and Environmental Conditions:

Note the geographic location and environmental characteristics of the farm (e.g., climate zone, soil type).

Record current weather conditions, including temperature, humidity, and precipitation, if applicable.

Observe any visible signs of climate change impacts, such as changes in vegetation, water availability, or soil quality.

Farming Practices and Agrochemical Use:

Document the types of crops being cultivated and their growth stages.

Observe farmers' activities related to agrochemical use, including:

Preparation and application of pesticides, herbicides, fungicides, and fertilizers.

Equipment and protective gear used during agrochemical application.

Note the frequency and timing of agrochemical applications throughout the observation period.

Record any observed deviations from recommended agrochemical use practices, such as overuse or improper application techniques.

Pest and Disease Management:

Identify any signs of pest infestation or disease outbreaks in the crops.

Document farmers' responses to pest and disease pressures, including:

Use of chemical and non-chemical control methods (e.g., biological control, crop rotation).

Effectiveness of pest management strategies in mitigating crop damage.

Note any observable changes in pest and disease patterns compared to historical data or farmer perceptions.

Health and Safety Practices:

Observe farmers' adherence to health and safety protocols during agrochemical handling and application.

Document the use of personal protective equipment (PPE), such as gloves, masks, and goggles.

Assess the presence of warning signs or labels on agrochemical containers and storage areas.

Note any instances of accidental spills or exposure to agrochemicals and farmers' responses to such incidents.

Farmer-Environment Interactions:

Document farmers' awareness and perceptions of climate change impacts on their farming practices.

Observe any adaptive strategies or innovations implemented by farmers in response to climate variability.

Note interactions between farmers and their natural environment, including water management practices, soil conservation efforts, and biodiversity conservation measures.

Health Effects and Well-being:

Monitor farmers' physical well-being during the observation period, noting any signs of acute or chronic health effects.

Document any self-reported symptoms or complaints related to agrochemical exposure, such as skin irritation, respiratory issues, or neurological symptoms.

Assess farmers' access to healthcare services and support systems for managing health-related concerns.

Conclusion:

Thank you for using this observation guide to collect data on climate change impacts, agrochemical use practices, and health effects among fresh produce farmers. Your detailed observations will contribute to a comprehensive understanding of the multifaceted interactions between environmental changes, agricultural practices, and human health in farming communities.

Appendix F: Focus Group Discussion (FGD) Guide

Focus Group Discussion Guide: Effects of climate change on agrochemical use and health of fresh produce farmers

Introduction:

Welcome to the focus group discussion on the impact of climate change on agrochemical use and health effects among fresh produce farmers. The purpose of this discussion is to gather diverse perspectives and insights from farmers regarding the challenges and opportunities related to climate change adaptation, agrochemical use, and health risks. Your participation is invaluable in shaping our understanding of these complex issues. Please feel free to express your opinions and share your experiences openly. The discussion will be moderated to ensure everyone has the opportunity to contribute.

Introduction and Icebreaker:

1. Introduce yourself and explain the purpose of the discussion.
2. Ask participants to briefly introduce themselves, including their background in farming and any experiences related to climate change and agrochemical use.
3. Icebreaker question: How has climate change impacted your farming practices in recent years?

Socio-Economic Status and associated health effects

1. What are the demographic and socioeconomic characteristics of farmers who use agrochemicals in their farming practices, and how do these characteristics influence their adoption of sustainable agricultural practices?

2. How do the attitudes of Fresh produce farmers towards organic farming, and their perceptions of pesticide safety behavior, influence their adoption of sustainable agricultural practices and the health effects associated with agrochemical use?
3. Have you or any of your workers experienced any adverse health effects due to agrochemical exposure?
4. Based on your experience, what are the primary health risks associated with agrochemical exposure among fresh produce farmers?
5. Have you encountered any instances where farmers or farmworkers have suffered health issues related to agrochemical use? If so, could you provide some examples?
6. How do farmers in your community typically address or mitigate the health risks associated with agrochemical exposure?

Agrochemical Use Practices among Fresh produce farmers

1. What types of Agrochemicals do you use on your farm?
2. How often do you use Agrochemicals on your farm?
3. What methods do you use to apply agrochemicals?
4. How do you decide which agrochemicals to use on your produce?
5. Do you have any plans to reduce or eliminate the use of agrochemicals on your farm in the future?
6. Do you observe the recommended pre-harvest interval (PHI) before harvesting crops after applying agrochemicals?

Occupational Health and Safety Measures Adopted by Fresh produce farmers

1. What types of agrochemicals do you use in your farming practices?

2. Do you follow any specific practices to minimize agrochemical use, such as integrated pest management or organic farming methods?
3. What types of equipment do you use to apply agrochemicals (e.g., knapsack sprayers, motorized sprayers)?
4. Do you observe the recommended pre-harvest interval (PHI) before harvesting crops after applying agrochemicals?
5. Do you wash your hands and change clothes after applying agrochemicals?

Association between climate change and agrochemical use trends among Fresh produce farmers

1. How would you rate your awareness of climate change and its potential impacts on Fresh Produce Farming?
2. Have you noticed any changes in local weather patterns or climate conditions in the past decade that you believe are linked to climate change? If yes, please describe.
3. Do you believe that climate change poses a significant threat to fresh produce farming in your region?
4. What strategies, if any, have you implemented to adapt to the potential impacts of climate change on your fresh produce farm?
5. Have these adaptation strategies influenced your agrochemical use in any way? If yes, please explain.

Health and safety interventions that can be adopted by Fresh produce farmers

1. Do you believe that continuous education and training are essential for ensuring safety in agrochemical usage?

2. Do you always read and follow the instructions on agrochemical product labels regarding proper use, handling, and storage?

3. Are you familiar with the regulations and guidelines set by authorities regarding the safe use of agrochemicals in fresh produce farming?

4. Do you believe that certification systems for safe produce production can benefit both farmers and consumers?

5. Do you have any plans to reduce or eliminate the use of agrochemicals on your farm in the future?

6. Are you open to adopting new technologies or practices that enhance safety and quality in fresh produce farming?

Is there anything else you would like to add or emphasize before we conclude the discussion?

Thank participants for their contributions and insights.

Conclusion:

Thank you for your participation in this focus group discussion. Your perspectives and experiences are essential for informing strategies to address the impacts of climate change on agriculture and promote sustainable farming practices. If you have any further thoughts or would like to follow up on any topic discussed, please don't hesitate to reach out.

Appendix H: MIRERC Approval Letter



MERU UNIVERSITY INSTITUTIONAL RESEARCH & ETHICS REVIEW COMMITTEE
(MIRERC)

Email: mirerc@must.ac.ke Website: <https://research.must.ac.ke/research-ethics/>

REF: MU/1/39/28 Vol.3 (099)

Date: 1st October, 2024

Kirongo David Kihara (PhD Epidemiology- MUST)
Dr. Patrick Kubai, PhD, Dr. Jane Rutto, PhD

Dear Sir/madam

RE: Effects of Climate Change On Agrochemical Use and Health of Fresh Produce Farmers in Nakuru County, Kenya.

This is to inform you that *MIRERC* has reviewed and approved your above research proposal. Your application approval number is *MIRERC 039/2024*. The approval period is *1st October, 2024– 30th September, 2025*.

This approval is subject to compliance with the following requirements;

- i. Only approved documents including (informed consents, study instruments, MTA) will be used
- ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by *MIRERC*.
- iii. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to *MIRERC* within 72 hours of notification
- iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to *MIRERC* within 72 hours
- v. Clearance for export of biological specimens must be obtained from relevant institutions.
- vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
- vii. Submission of an executive summary report within 90 days upon completion of the study to *MIRERC*.

You may also be required to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI), visit: <https://research-portal.nacosti.go.ke> and also obtain other clearances that your study may require.

Yours sincerely

Prof. Peter Masinde, Ph.D.
Chairperson, MIRERC



MUST IS ISO 9001:2015 and ISO/IEC 27001:2013 CERTIFIED

Appendix I: Publications

Stratford Peer Reviewed Journals and Book Publishing
Journal of Medicine, Nursing and Public Health
Volume 8|Issue 2|Page 46-57| July|2025
Email: info@stratfordjournal.org ISSN: 2706-6606



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*

<https://doi.org/10.53819/81018102t7059>



Agrochemical use Patterns among Fresh Produce Farmers in Nakuru County, Kenya: Examining the Instigators

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ARTICLE INFO

Keywords

Agrochemical use Patterns

Fresh Produce Farmers

Nakuru County

ABSTRACT

Agriculture is the most important economic activity in Kenya, despite only 10.2% of the total land cover being arable. The agriculture sector contributes 51 percent of Kenya's GDP, 26 percent directly and 25 percent indirectly, accounting for 60 percent of employment and 65 percent of exports (KNBS, 2024). To achieve optimal production in the agricultural sector, agrochemicals play a significant role. On average 12,983 tons of agrochemicals are imported in to the country annually with a total value of KES 10.7 billion. More agrochemical volumes are required over time resulting in a vicious cycle

between agrochemical use dependency and worsening health and climatic conditions. This study sought to determine the agrochemical use practices among Fresh Produce Farmers in Nakuru County, Kenya and their drivers. The study design was a community based cross-sectional analytic and descriptive study. The target population included Fresh Produce Farmers residing in Nakuru County for at least two years routinely applying agrochemicals in their daily occupational activities. 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 388 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 analyzed using SPSS v28 for descriptive and inferential statistics, and NVivo for thematic analysis. The findings revealed a significant association between awareness of pest pressure and resistance of agrochemicals and decision-making on volume and frequency of agrochemical usage. 87% of respondents who used recommendations from experts were aware of the potential environmental impacts of agrochemicals. 72% and 48% of those who used previous experience and those using recommendations from other farmers were also aware of the potential environmental impacts of agrochemicals, respectively. Fresh produce farmers who have realized extreme weather patterns use fewer methods of applying agrochemicals. The Ministry of Agriculture and the Ministry of Environment, Climate Change, and Forestry need to work collaboratively to support fresh produce farmers in Nakuru County in public extension services, which will play a critical role in increasing the protective use of agrochemicals. Public extension services will shift the decision-making habits of the farmers to ensure that they use recommendations from the extension services in all their farming practices.

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**OCCUPATIONAL HEALTH AND SAFETY MEASURES
ADOPTED BY FRESH PRODUCE FARMERS USING
AGROCHEMICALS IN NAKURU COUNTY, KENYA**

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ABSTRACT

Purpose: The study sought to identify the occupational health and safety (OHS) measures adopted by fresh produce farmers using agrochemicals in Nakuru County, Kenya.

Methodology: The study used a cross-sectional analytic and descriptive design targeting 388 farmers, with data collected through surveys, interviews, observations, and FGDs. Quantitative data were analyzed descriptively, while qualitative data underwent thematic analysis.

Results: The study revealed that while 97% of farmers reported practicing handwashing after agrochemical application, only 69.1% consistently used personal protective equipment (PPE), with focus group discussions indicating actual usage was as low as 2% in some areas due to cost and limited awareness. Additionally, 68% of respondents had not received formal training on agrochemical safety, 57% conducted safety inspections irregularly, and 98% did not monitor their health after exposure. Although 93.3% claimed to follow product label instructions, qualitative findings showed that most farmers selectively read only dosage guidelines and often increased concentrations beyond recommended levels.

Unique contribution to theory, policy and practice: The study recommends structured capacity building, subsidized access to PPEs, regular health monitoring, and stronger institutional support to enhance compliance with OHS standards.

Keywords: *Occupational Health and Safety measures, Agrochemicals, Fresh Produce Farmers, Nakuru County*